Sneh Punia Bangar
Sanju Bala Dhull *Editors*

Faba Bean: Chemistry, Properties and Functionality

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Preface

Faba bean (*Vicia faba* L.) is one of the oldest and most diversified legumes with high nutritional value. Globally, it is the third most important food grain legume after soybean (*Glycine max* L.) and pea (*Pisum sativum* L.), currently grown in 58 countries. Faba beans demonstrate global acceptability due to adaptability, genotypic and phenotypic diversity, and several means of preparations and culinary uses. It is a good source of lysine-rich proteins, minerals, vitamins, and many bioactive compounds, especially Levodopa (L-dopa), a dopamine precursor. It is also used as medicine for the treatment of Parkinson's disease and a nutraceutical agent, which might help in controlling hypertension. Despite the nutritional and biological importance of the faba bean, it has not gained due importance in the past like other crops such as soybean and staple grains (wheat, rice, corn, etc.). However, faba bean is gaining importance nowadays due to the increasing demand for plant-based proteins and meat alternatives. Moreover, pulse flours and ingredients are finding new uses in diverse food applications with enhanced nutritional and sensory properties. Additionally, the contribution of faba bean in maintaining the sustainability of the agricultural system is equally important, as it can efficiently fix the atmospheric nitrogen symbiotically. Therefore, it can play an important role in the rotation and mixed crops for improving soil fertility and intercropped with vegetables, sugarcane, etc.

A number of factors affect the nutrient content and their bioavailability in faba bean, including type and cultivar, growing environment and systems, and handling and storage conditions, hence, determining it's final utilization in different products. In recent years, faba bean has been cited for imparting health-promoting effects, such as hypocholesterolemic response, diabetes and colorectal cancer prevention, and weight control. The increasing use of faba bean focusing on improved dietary health is an opportunity within both subsistent and developed populations.

As a result of current studies and processing practices, the knowledge generated about faba bean utilization is huge and relevant to different research areas such as food, nutrition, pharma, nutraceuticals, agriculture, and environmental studies. Therefore, the massive food-processing and scientific community will have rapid access to the related advances in faba bean to their field with this book. The book

Faba Bean: Chemistry, Properties, and Functionality serves as a current resource of information for teachers, scientists, researchers, students, and industry managers, as well as all those who have a stake in faba bean production, processing, and utilization. It covers a wide range of subjects, including production, postharvest technologies, composition and processing technologies, quality and nutritional profile, importance to human health, biofortification, and disease management practices. The content has been described in 14 chapters written by an experienced team of scientists from diverse disciplines, including crop sciences, horticulture, food science and technology, food biochemistry, food engineering, nutritional sciences, and environmental sciences and agricultural extension.

We hope that this book will satisfy the needs of most researchers who are working or have a great interest in the concerned field. Undoubtedly, it will be helpful for the general use of students, research scholars, teaching professionals, traditional practitioners, ethnobotanists, and pharmacologists, who may have an extraordinary interest in this crop of paramount importance. This book will also prove fruitful in the field of agriculture, agronomy, botany, plant biology, food science, biotechnology, medicinal chemistry, medical sciences, pharmacognosy, pharmacology, and pharmaceutical and environmental sciences.

We are greatly thankful to Springer Nature Singapore Pte. Ltd. for the prompt acceptance and compilation of this scientific task. We also sincerely extend our gratitude to the staff at Springer for their dedication, sincerity, support, and friendly cooperation in producing this book. With great pleasure we express our sincere thanks to all the contributors for their timely response, outstanding and up-to-date research contribution, support, and consistent patience, which will give way to future directions for research students who believe that laboratory research should be aligned with field applications. Lastly, thanks are also due to well-wishers, research students, and family members for their moral support, blessings, and inspiration in the compilation of this book.

Clemson, SC, USA — Sneh Punia Bangar
Sirsa, India — Sanju Bala Dhull

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Sneh Punia Bangar PhD, is a researcher at Clemson University, USA. Earlier, she worked as an assistant professor (C) in the Department of Food Science and Technology, Chaudhary Devi Lal University, Sirsa. Her research interests include extraction and functional characterization of bioactive compounds, starches, functional foods, and nanocomposites films and coatings. She has presented her research at various national and international conferences and has published more than 100 research papers/book chapters in national and international journals/books. To date, she has authored or co-authored more than 80 (published/accepted), 1 book series, 2 authored books (CRC, Taylor and Francis), 5 edited books (CRC, Taylor and Francis, Springer, Elsevier), a reference book (CRC, Taylor and Francis), 35 book chapters, 20 conference proceedings/seminars, and 3 journals special issues as guest editor (*Food Research International*, *International Journal of Food Science and Technology*, *Journal of Food Processing and Preservation*, *Foods and Polymers*).

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Chapter 1
Introduction: Global Status and Production of Faba-Bean

Sneh Punia Bangar and Priyanka Kajla

1.1 Introduction

Kingdom	Plantae
Family	Fabaceae
Subfamily	Faboideae
Tribe	Fabeae
Genus:	*Vicia*
Species:	*V. faba*

The faba bean (*Vicia faba L.*), also known as the fava bean, is an annual herbaceous plant and ancient legume belonging to the family Fabaceae. Faba beans have a vast number of species distributed around the globe ranging from around 16,000–19,000 species in 750 genera in Fabaceae family (Chakraverty et al., 2013). It is a cool-season leguminous crop that dates back to prehistoric times in the Middle East and is traditionally utilized as a major source of protein for both humans and animals (Multari et al., 2015). Regarding economic importance, the Fabaceae family is second only to the Poaceae. Fabaceae species have been reported to be cultivated in varied temperature zones, viz., temperate zones, humid tropics, tropical areas, altitudes, grasslands, & plains; furthermore, even a few aquatic species of these legumes have also been reported (Wrigley et al., 2015). The faba bean is a rich source of fiber, and quality protein, having balanced essential amino acids with high digestibility and low amounts of anti-nutritional factors (Iannotti, 2020). They are reported

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to have high-quality protein content owing to the presence of all required essential amino acids (Vogelsang-O'Dwyer et al., 2020). Faba beans are a rotational crop grown in the Mediterranean region and able to fix nitrogen that serves more than 80% of the nitrogen requirements of plants (Denton et al., 2017) therby reducing fertilizer use in agricultural production systems. However, as compared to other field crops, it is extremely sensitive to water scarcity/ drought conditions (Parvin et al., 2019; Desoky et al., 2021). The faba bean ranks third and seventh in area and production among major grain legume crops grown in Europe (Sellami et al., 2021). In 2019, France was the leading producer in Europe, accounting for 34% of total output, followed by Italy, Spain, and Belgium (Table 1.1). The cultivation of this legume has expanded steadily in Italy during the previous 10 years, from over 46,130 hectares to over 60,000 hectares (Sellami et al., 2021). Its global acreage declined from 5.4 to 2.4 million ha between 1980 and 2017, and productivity among countries is very heterogeneous due to varied agronomic conditions and other stresses (FAO, 2017). Heat sensitivity, soil acidity, salinity and other abiotics stress limit the productivity of legumes in different geographical regions as these stress affects its potential of nitrogen fixation.

In this chapter, the worldwide production status of the beans is discussed. Agronomic conditions suitable for the growth and yield of beans as per region specificity are also augmented here.

Table 1.1 Leading faba bean producers, exporters, and importers in 2019

Countries	Quantity (metric tons)
Producers	
China	1,740,945
Ethiopia	1,006,752
United Kingdom	547,800
Australia	327,000
France	177,380
Exporters	
Australia	265,543
United Kingdom	119,071
Lithuania	92,445
Egypt	71,022
Latvia	66,860
Importers	
Egypt	309,355
Norway	6437
Germany	46,707
Saudi Arabia	43,397
France	30,396

Source: FAO (2020) adapted from Dhull et al. (2021)

1.2 Production Status of Faba Beans

The faba bean ranks fifth among pulse crops in terms of annual global production over the last decade. The faba bean is grown in over 66 countries throughout the world. In 2017, the overall area farmed for faba bean production was 2,463,966 hectares, and the total volume produced was 4,840,090 tonnes from year 2008 to 2017 (Merga et al., 2019). As mentioned above, the cropped area for faba bean production has been constantly reducing. The yearly production of this crop is over 4.5 million tonnes on average, according to global pulse crops data from Faba bean production improved from 4,05, 000 tonnes in 1961–65–6,05, 000 tonnes in 2011–14 in North Africa, despite the fact that the area under cultivation has remained constant during the last five decades. Egypt, Morocco, and Sudan are the biggest faba bean-producing countries in North Africa, importing 0.34 MT worth 320 million USD in 2013, while West Asia imported 93,589 tonnes worth 65 million USD in 2011–14 (FAOSTAT, 2016),

Further, the trajectory of legume production in the European Union's main agricultural countries shows significant disparities. As evident from data that France, Germany, the United Kingdom, and Poland have consistently increased (by 29–420%), whilst Italy, Spain, Greece, and Romania have decreased (ranging from 29 to 79 percent) (Confagricoltura, 2019). It should be noted that there has been a surge in global interest in legumes in recent years.

Fava bean production increased from 2.60 million hectares in 1999 to 3.90 million tonnes in 2003 worldwide. China was the leading producer (1.9 million tonnes per year from 1.2 million hectares) (FAO, 2009). From 1999 to 2003, annual production in Sub-Saharan Africa was estimated to be 510,000 tonnes, with almost all of it coming from Ethiopia (405,000 tonnes) and Sudan (100,000 tonnes). It is worth noting that annual productivity in Sub-Saharan African region in the year 2000 increased from 230,000 tonnes (250,000 ha) to 540,000 tonnes (450,000 ha) (Mihailovic et al., 2005). The world production of faba bean crop output was estimated at 5669185 t/year from 2.67 million hectares area, as depicted from Fig. 1.1 with the top faba beans producing country China (1,723,588 t/year), second is Ethopia (1,070,637 t/year) followed by United Kingdom, Australia, Germany producing most of the world faba beans as evident from Fig. 1.1 (FAO, 2020). Green faba bean seed output is extremely low in tropical regions of Africa and Asia (Mihailovic et al., 2005). Egypt is the world's leading consumer of faba beans, with around 75% of daily per capita protein intake coming from plants, primarily cereals, and beans. Much of the protein in the Mediterranean and Chinese diets comes from faba beans (Rahate et al., 2021). The world average faba bean productivity is currently 2.1 kg/ha, with Egypt leading the way with 2.96 t/ha (FAO, 2020).

The area under faba bean cultivation was reported to be increased alongwith significant increase in productivity from 1 t/ha to 1.9 t/ha. Advanced and improved cultivars are reported to produce more (3.5 t/ha) than the average yield (1.8 t/ha).

Over 5 years, from 2013 to 2017, Asia led the world in average productivity (2836.13 kg/ ha), and total production quantity (8,276,692 tonnes) on an average

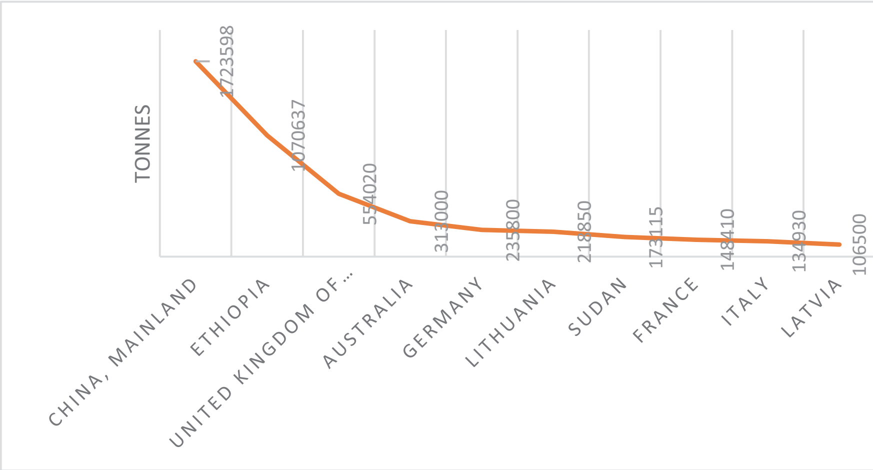

Fig. 1.1 Top ten faba bean producing countries of the world (FAO, 2020)

Table 1.2 Production area and yield status of top five faba bean countries (FAO, 2020)

Country	Area harvested (ha)	Yield (kg/ha)
China	826,597	20,852
Ethiopia	297,600	10,969
UK	181,340	30,551
Australia	36,537	7059
Germany	58,700	40,170

total land area of 4,088,758 ha, followed by Africa with an average total land area cultivated (4,097,769 ha), the average production of 6,873,438 tonnes, and average productivity of 1527.18 kg ha. In terms of faba bean production, China leads the world with 40%, while Ethiopia comes in second with 24% (Table 1.2).

According to FAOSTAT, the world's Faba bean growing area is located in nine different agro-ecological areas, including Ethiopia, Central Asia, and FAO (2016). Northern Europe, Ethiopia, the Mediterranean, Central Asia, Latin America, and East Asia, are other notable producers. Faba beans are virtually primarily utilized for cattle pasturage, hay, and silage in Northern Europe and the United States where they are not widely farmed (Singh & Bhatt, 2012; Oplinger, 1982). Despite the dwindling land size, yield per area has increased due to reduced exposure to varied abiotic and biotic stresses (Singh & Bhatt, 2012). Over the last three decades, fava bean production increased by 2% per year, while the global area has remained unchanged (Abou-Khater et al., 2022). Asia leads the world in overall faba bean output, with 33.55%, followed by Europe and Africa, with 29.36% and 27.04%, respectively.

1.2.1 Global Trade of Faba Bean

The worldwide export of faba beans was about 475,000 tonnes from 1998 to 2002. Global faba bean exports increased modestly between 1994 and 2016, according to FAO data. Ethiopia ranks second only to China in faba bean production, with 930,633 tonnes produced in 2017 and a total value of $315.97 million dollars. Exports of faba beans averaged 41,473.4 tonnes from 2012 to 2016, with a productivity potential of 1995.52 kg ha[1] from 2013 to 2017. In Ethiopia, the faba bean occupies the most land (466,698 hectares) and yields the most pulses (1006751.828 tonnes) (Mekonnen & Mnalku, 2021).

From $3.06 billion in 2020 to $3.18 billion in 2021, the global faba bean market is expected to develop at a compound annual growth rate (CAGR) of 3.77%. The desire for natural and plant-based proteins is driving the increase. At a CAGR of 2.19%, the faba bean market will reach $3.47 billion in 2025. Faba bean production globally reaches 4 million tonnes per year, although only around 2% of that is traded worldwide. Australia, France, and the United Kingdom are the top exporting countries. China used to be a big supplier of faba beans, but it is now a major importer. All of the faba beans grown in Australia are destined for human consumption. The Middle East, particularly Saudi Arabia, Egypt, and the United Arab Emirates, are the biggest purchasers of faba beans. Whole, canned, split, or processed into flour faba beans are commonly consumed. Egypt is the largest importer of food-grade faba beans on the international market, with numerous other nations buying lesser but still important quantities. In addition, several countries are significant importers of faba beans for livestock feed (GRDC, 2017).

Australia is one of the top five exporters of faba beans (308,257.2) followed by Ethiopia (51,456.6), France (157,090.8), and the United Kingdom (152,779.4), and Lithuania (51,090.8) as evident from Fig. 1.2. Egypt is the world's largest faba bean importer, accounting for around 74% of global annual import amounts. Sudan, Saudi Arabia, Norway, and Italy are the following countries on the list (FAO, 2019; Merga et al., 2019).

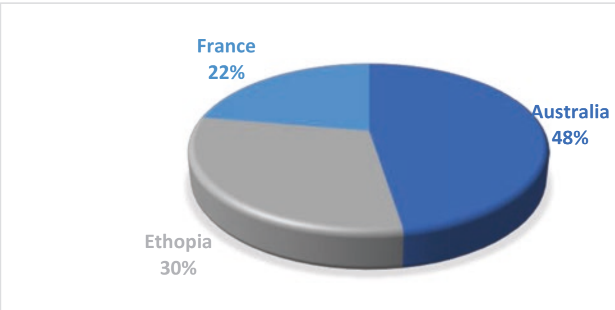

Fig. 1.2 Top three exporters of faba beans

1.3 Agronomic Conditions

1.3.1 Climatic and Geographical Conditions

Faba bean productivity is declining due to different biotic and abiotic stressors. Examples of abiotic issues include waterlogging, moisture stress, soil acidity, and inadequate cultural practices (Keneni et al., 2016). The reproductive phase of the faba bean is very sensitive to these abiotic stresses; especially drought causes yield reductions of up to 79% (Migdadi et al., 2016). The presence of acidic soil, combined with low nutrient availability, is currently the primary constraint to faba bean production (Tadele et al., 2019). Because almost all of the biological and chemical functions of a crop are affected by soil acidity (Jensen et al., 2010). Furthermore, the symbiotic relationship between rhizobia and their host beans can also be destroyed by soil acidity and their survival, growth, and nitrogen fixation efficiency (Chen et al., 1991; Graham, 1992; Zahran, 1999). In many Mediterranean, cultivating beans mostly depends on rainfall for growth and development instead of irrigation practices. The main cause of inconsistency and variations in faba bean production is widely assumed to be disparities in rainfall amount and distribution (Bond et al., 1994). In addition to that, heat stress has also emerged as an impediment to broad bean productivity in some regions consequently shifting from cooler, long-season habitats to warmer, short-season habitats (Gaur et al., 2015). Faba bean cultivation area in Egypt decreased from 113, 000 ha to 46, 000 ha in the period from 2001-2014, while the growing acreage of Sudan climbed from 50, 000 ha to 76, 000 ha in the above said period of 14 years (FAOSTAT, 2016). This is majorly attributed to climate change which is making arid areas get hotter. As depicted from the data as well, heat sensitivity in grain legumes resulted in reduced production and quality while also restricting geographic adaptation. Extreme heat threatens faba bean output in Sudan, southern Egypt, and the lowlands of Ethiopia. Studies also reported that artificially induced terminal heat stress also significantly reduced fava bean genotype yield and yield components (Abdelmula & Abuanja, 2007). The genotype C.52/1/1/1 of faba beans resulted in excellent tolerance to heat stress. They facilitated the cultivation of these beans even in non-traditional sites in Sudan, according to Abdelmula and Abuanja (2007). Drought is frequently regarded as the most critical environmental impediment to crop production, defined as a period of water scarcity that results in a significant decline in crop output (Borlaug & Dowswell, 2005). Despite the fact that genotypic variation in faba bean drought/heat stress response has been well explored (Abdelmula et al., 1999), the tailoring of drought-tolerant genotypes is crucial to boost production sustainability, which NARS partners have assessed at diverse locations (Malouf et al., 2011). In contrast, different research investigations have discovered a variety of frost-tolerant genotypes that could be used in breeding programs). It is reported that fava beans are sensitive to frost throughout the reproductive phases (Maqbool et al., 2010; Sallam et al., 2015). Plant frost tolerance can be improved by hardening seedlings before the onset of winter by exposing them to low non-freezing temperatures (Arbaoui & Link, 2008).

Despite the faba bean's agronomic and economic value, its cultivation is currently limited due to a variety of issues (Torres & Avila, 2011) Several investigations of genotype-environment interactions in faba bean populations have revealed that yield instability is an unfavourable characteristic in this crop (Annicchiarico & Iannucci, 2008; Skovbjerg et al., 2020). The production of faba beans is typically seen as perilous by European farmers, who prefer producing non-legume crops such as cereals, oilseeds, and tubers due to high interannual output fluctuation. (Pahl et al., 2006). The crop sensitivity to weather conditions (particularly cold and drought) as well as its high susceptibility to diseases and pests hinder yield performance (Torres & Avila, 2011). Faba beans are resistant to cold but not to extreme heat or drought. After blossoming, late frosts and cold temperatures can produce a substantial decline in flowers and pods. Faba beans, on the other hand, thrive in sunny locations with cool, deep, well-structured soils rich in lime and clay .Faba beans appear to be shabby and resilient to a variety of conditions in particular. The water availability during the development phases, however, is inherently related to the production output (Flores et al., 2013; Karkanis et al., 2018). Cold tolerance, planting time, geographical regions (Mediterranean, temperate, or arid), and harvesting seasons are all essential characteristics that influence adaptability, selection conditions, production stability, and base material for breeding (Sellami et al., 2021). Seeds of fava bean germinate within a period of 10–14 days under ideal growth conditions (Etemadi et al., 2018a). But dry conditions or if soil temperature is very low, then germination might take significantly longer. On average, the fava bean plant grows by one node per week. As the faba bean stems are rather robust and grow erect, therefore plant grows tall by achieving the height of almost 90–130 cm depending on the genotype. Faba bean produces its first flowers when around 8–10 node has appeared, and the plant is almost around 30 cm tall, this development phase is normally observed in June in the Northeastern United States. Around 20 cm above the ground, flowers and pods appear. Approximately 25% of the flowers develop pods, which typically contain three to six seeds (Etemadi et al., 2019). As a result, good management methods such as soil fertility, irrigation practices, and planting time can greatly minimize the number of aborted blooms, resulting in increased seed/pod production. Generally, low soil temperature affects the germination of most legume seeds as these are frost-sensitive. The fava bean, on the other hand, is a cool-season legume whose germination is more resistant to low/cold soil temperatures in comparison to most grain legumes. Some studies reported similar results that have been obtained by selecting the seeds that have good germination capability at low soil temperatures (below 15 °C). At 12.5 °C, large-seeded cultivars had a higher germination rate than small-seeded cultivars . The faba bean is one of the most significant legume crops around the globe due to its exceptional nutritional properties, which include quality protein, carbs, B-complex vitamins, and minerals (Dhull et al., 2021). In the past few years, faba bean agriculture has received a lot of interest in the United States, Europe and Canada (Etemadi et al., 2018a). In places with a shorter growing season, such as the Northeastern United States, faba bean can be utilised as a cool-season legume in a variety of cropping systems. Only two types of faba bean are now available to gardeners in the Northeastern United States. The existing cultivars have a number of drawbacks, including a high seed price due to the large seed size and poor yield of pod. Along with utilization of faba beans as staple food as well as feed for animals it is also used in crop rotation systems to reduce the incidence of cereal cyst nematode (*Heterdera avenae*) and other soil-related disorders (Landry et al., 2016). Faba bean blooms attract a variety of pollinators, including honey bees, despite the fact that it is partially self-pollinating. Honey bees and other natural pollinators, according to new research, can increase faba bean pollination and, as a result, grain yield. (Marzinzig et al., 2018). It has been discovered that faba beans have the most efficient nitrogen fixation ability among all the short and temperate region legumes (Mekkei, 2014). According to reports, faba beans have the capability to fix approximately 50–330 kg Nhm^{-2} to fix atmospheric nitrogen depending on cultivation practices and other agronomic conditions (Etemadi et al., 2018a).

The faba bean is usually regarded to be a large-seed crop, however seed size varies greatly between species and cultivars. Seed size varies greatly based on pod position among cultivars. Faba bean seeds are broadly categorized into three: large, medium, and small which might show variations within each cultivar, and generally seed size varies widely depending on the position of pods.

1.3.2 Soil Type

The faba bean thrives naturally in fine-textured soils, but it can flourish in almost any type of soil (Jensen et al., 2010). The best soil pH for growing faba bean is 7. The soils in locations with considerable precipitation, such as the Northeastern United States, are acidic. When the pH of the soil falls below 6, liming is essential for faba bean growth and development. While sandy loams are also acceptable for growing faba beans, therefore adequate irrigation is required for the proper development of plants. As faba beans have shallow root system, therefore plants are susceptible to drought stress in rapidly drying soils. The faba bean appears to be resistant to waterlogging for a short duration (Etemadi et al., 2019; Tekalign et al., 2016).

1.3.3 Seed Germination

At optimum conditions coditions of growing, brad beans start sprouting or germinating within 10–15 days of sowing. Germination may also be prolonged if conditions are adverse like if temperature of soil is too low or dry soil conditions are there. Oftenly the seeds of faba beans are sensitive to low temperature but it is comparatively more tolerant than other legumes. (Etemadi et al., 2019). Varieties with large sized seeds tend to show better germination capacity in comparison to small seeded varieties. (Kang et al., 2008). When bfaba bean is grown as cash or cover crop it is recommended to use small seed varieties as it considerably reduces productions as less number of seeds are required per unit of area.

1.3.4 Plantation

The faba bean is planted as a winter or spring crop in cold climates when the temperature and day duration varies significantly from those seen in Mediterranean climates (Luna-Orea et al., 1996). During long growth seasons, plants generally adjust for low plant density of population by producing additional lateral branches. (Etemadi et al., 2015). As a consequence, the cropping cycle (winter season vs. spring season) significantly influences the duration of the vegetative growth stage and thus the final dry matter. Early planted legumes have been shown to increase biomass and grain yield (Etemadi et al., 2018b). López-Bellido et al. (2005) found that delaying faba bean sowing reduced seed yields. In New England, delaying faba bean planting in the spring causes flowering to coincide with high summer temperatures, resulting in more aborted flowers and pods as well as an increase in the prevalence of chocolate spot bacterium illness (Etemadi et al., 2015).

Faba beans are traditionally sown directly into the soil. However, faba bean transplanting may be preferable to direct seeding in shorter-season areas to ensure early sowing (Etemadi et al., 2015). Faba bean transplantation permits for double cropping and eliminates diseases like chocolate spot *(Botrytis fabae)* in places with a short planting season, especially in Northeastern United States (Etemadi et al., 2018b). Furthermore, meteorological variables such as moist soil in early spring may preclude early planting in such locations, therefore transplanting faba beans as a potential substitute to direct sowing should be investigated. Other potential advantages of transplanting seedlings include increased output, enhanced rate of survival, flowering in the early phase of development, and betimely harvest (Lee et al., 2018). Indoor seeding in late March is required for faba bean transplantation, and seedlings must be 15 cm tall before being transplanted into the main field. According to studies, the ideal temperature for producing faba bean in the greenhouses is around 15 °C, and seedlings are ready for transplanting in 12–15 days. (Etemadi et al., 2015). Pro-mix media in a 3.2 cm cell size tray is sufficient for this short greenhouse growing period. Plant faba bean seeds 2.5 cm deep in the field, with 15 or 23 cm spacing between plants on planting rows, depending on plant spacing. This planting design provides approximately 48,000–60,000 plants hm^2 and is provided by approximately this (Etemadi et al., 2015).

1.3.5 Mineral Requirements

Different minerals -nitrogen, phosphorus, potassium, magnesium are required for growth and development of faba beans plants. Alongwith these minerals also plays an important role in improving soil fertility by providing the deficit minerals and hence increase in yield of crop. Major functions of all these required minerals are presented in Fig. 1.3.

1.4 Diseases in Faba Beans

Parasitic weeds (*Orobanche and Phelipanche* spp.), foliar diseases primarily chocolate spot (*Botrytis fabae),* rust (*Uromyces viciae fabae*), Ascochyta blight (*Ascochyta fabae*), powdery mildew (*Microsphaera penicillata var. ludens*), are common diseases of faba beans (Sahar et al., 2011; Maalouf et al., 2016; Hailu et al., 2014). The faba bean necrotic yellow virus decimated the crop in Middle Egypt in 1992, wiping out all beans landraces and cultivars. (Katul et al., 1993). Most of the breeding projects focus on producing resistance genotypes for a single economically relevant disease (Maalouf et al., 2013; Temesgen et al., 2015). Villegas-Fernández et al. (2012) report that efforts are increasingly being devoted toward developing disease-resistant fava bean lines. Due to low resistance, the intricate structure of the resistance mechanism, and poor heredity, breeding for Orobanche resistance in faba bean is difficult. (Rubiales et al., 2012). Despite all the challenges of breeding, Egypt, Spain, Italy, Morocco, and ICARDA (Khalil et al., 2004) have made great progress in continuing to develop tolerant/resistant varieties and breeding materials based on the main source of Orobanche resistance line F402 identified by Egyptian researchers in the early 1970s (Nassib et al., 1982) as well as some minor sources available in different countries.

For the parasite population in Syria, ICARDA has created fava bean lines with varying levels of tolerance and susceptibility to *Orobanche* (Khalil et al., 2004).

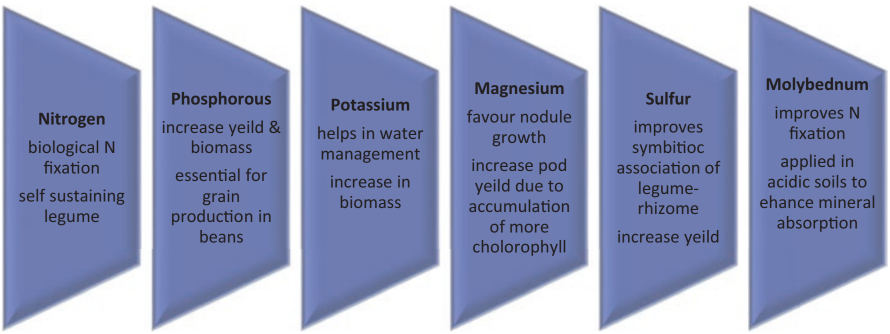

Fig. 1.3 Role of different minerals for growth & development of fab beans

ICARDA revealed the most potential ascochyta blight and chocolate spot resistance sources. (Hanounik & Robertson, 1988, 1989). ICARDA and the National Agricultural Research Systems (NARS) employed these lines to develop breeding lines with great yield potential and resistance. As a result, new varieties have developed in Australia, Ethiopia, China, Canada, Egypt, and Spain (Tivoli et al., 2006; Redden et al., 2008; Villegas-Fernández et al., 2009).

1.5 Conclusion

It is necessary to develop high-yielding, nutritious, and disease-resistant varieties appropriate for various cropping systems found in diverse agro-ecological zones to increase farm profitability through the implementation of enhanced faba bean technology. Climate-smart cultivars must be developed that are heat and drought-tolerant, as well as ideal for waterlogged and acidic soils. Herbicide-tolerant fava bean germplasm is also needed to combat weeds, as well as water and nutrient-efficient cultivars for arid environments. Acidic soils and salinity are becoming an issue for faba bean cultivation and necessitate specific attention. Finally, there is extra value for animal nutrition that should be investigated. Breeding efforts are sluggish because of the nature of the mechanisms of resistance for numerous foliar diseases, Orobanche resistance, main abiotic stresses (heat and drought), and herbicide resistance. New biotechnological approaches are needed to reduce breeding cycles, such as marker-assisted selection, which has not been widely adopted despite significant advancements in quantitative trait loci investigations.

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Chapter 2
Agrarian Conditions and Post-harvest Practices of Faba Bean

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2.1 General Overview: Composition Production and Marketing

Faba beans (*Vicia faba* L.) are pulses often known as horse beans, broad beans, tick beans, or fava beans when green (Robinson et al., 2019) and is one of the world's oldest crop (Mínguez & Rubiales, 2021). It is a Fabaceae legume with large, leathery pods and green fruits that grow to a blackish-brown color (Layla, 2012). Although the *V. faba* plant originated in the prehistoric period in the Middle East (Multari et al., 2015), it is now cultivated extensively worldwide (Prabhu & Rajeswari, 2018). It is the world's third-largest grain legume (Gu et al., 2020). China is the largest faba bean producer, accounting for 36.7% of worldwide output, followed by Ethiopia (20.1%), the United Kingdom (8.2%), and Australia (8.2%) (FAO, 2018). The faba bean is indeed a versatile cool-season grain legume that may be grown in various regions for human and animal consumption (Crépon et al., 2010). It is cultivated for food and feed and consumed by both humans and animals (Singh et al., 2013; Duc et al., 2015; Multari et al., 2015; Crépon et al., 2010). Var. minor (40 g per 100 seed), var. equina (40–80 g per 100 seed), and var. major (>80 g per 100 seed) are the three major botanical varieties of faba bean (Duc, 1997). Minor and equina varieties are mainly used as ripe, dry seeds, while var. major immature seed is most frequently eaten as a fresh vegetable (Hawtin & Hebblethwaite, 1983; Baginsky et al., 2013a). Humans consume both fresh and dried faba bean seeds, which are high in lysine-rich protein, complex carbohydrates,

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dietary fibre, non-nutrient secondary metabolites, and active components (antioxidants, phenols, and aminobutyric acid), all of which have been linked to a variety of health rewards (Khazaei et al., 2019; Liu et al., 2022). Starch (40% DW) and protein (30% DW) are the main energy components and thus the value of mature faba bean seed (Pritchard et al., 1973; Guillon & Champ, 2002). The protein concentration was comparable to that seen in meat and fish. As a result, it is frequently known as "poor man's meat" (Frühbeck et al., 1997; Macarulla et al., 2001). *faba* is one of Egypt's most important crops, and it is eaten in the form of cakes, pasties, and soup (Hendawey & Younes, 2013). It also contains numerous macro- and microelements and minerals (Hacseferogullar et al., 2003; Rahate et al., 2020). It's high in potassium, calcium, magnesium, iron, and zinc (Lizarazo et al., 2015; Longobardi et al., 2015; Neme et al., 2015). Antinutritional elements found in faba beans include lectins, saponins, trypsin inhibitors, phytic acids, condensed tannins, and favism producing substances, all of which reduce the biological value of the bean (Revilla, 2015). Through its ability to fix nitrogen faba bean production has been proven to contribute towards reducing the carbon footprint of cereal-based agriculture production (Jensen et al., 2010).

The chemical makeup of faba bean seeds is largely dependent on genotypes/cultivars, ambient circumstances, and crop management approaches, among other factors (Ivarsson & Neil, 2018; Micek et al., 2015; Pelagalli et al., 2020; Skylas et al., 2019). Faba bean seeds also have more carbohydrate, protein, dietary fibre, potassium, iron, and folic acid content than common grains like rice, corn, and wheat (Howard et al., 2018; Gu et al., 2020).

2.1.1 Nutritional, Bio-active and Antinutritional Components

Carbohydrates

Carbohydrate content in faba bean seeds ranges from 51% to 68%, with starch accounting for the majority (41–58%) (USDA, 2021; Vidal-Valverde et al., 1998). In faba bean carbohydrates, dietary fibre, starch quantity, and sugar type are the most important nutritional factors. The principal soluble sugars are oligosaccharides from the raffinose family: raffinose, stachyose, and verbascose, which are thought to cause flatulence and limit faba bean consumption from a digestive standpoint. Faba beans are high in starch (22–45%), which is mostly made up of two constituents: amylose and amylopectin (Punia et al., 2019). As seen under a scanning electron microscope, faba bean starch granules feature round, oval, elliptical, irregular forms, and cavities on their surfaces (Sofi et al., 2013). Poor solubility (9.92 g/100 g) and swelling index (12.67 g/g) of faba bean starch can be attributed to starch granule integration due to massive binding forces (Zhang et al., 2019). Faba bean starch resists enzymatic hydrolysis, as evidenced by its high resistant starch (RS) content (46.7%) but low instantly digested starch (15.3%) and slowly digestible starch (34.5%) levels (Bello-Pérez et al., 2007). Suarez-Dieguez et al. (2021) devised and improved a lab-scale technique for extracting RS from faba beans. The RS content of faba beans was elevated using an improved retrogradation process. Because of its reduced and delayed digestion, this study showed that faba bean RS might be employed as a functional component. The faba bean, according to Singh et al. (2014), is a very rich source of dietary fibre, containing both soluble and insoluble fibre. In comparison to lima, pinto, and red kidney bean flours, faba bean flour has the highest nutritional fibre level (Gu et al., 2020). Dietary fibre content in whole faba beans ranged from 15% to 30%, with hemicellulose, cellulose, and lignin being the primary components (Dhull et al., 2021). The seed coat of the faba bean contains a substantially larger amount of dietary fibre (82.3%) (Karatas et al., 2017; Vidal-Valverde et al., 1998). It is recommended that you eat the seed coat of the faba bean since it is a good source of dietary fibre, phenolic compounds, and minerals (Karatas et al., 2017).

Protein

In most underdeveloped nations, such as Africa, Latin America, and Asia, *V. faba* L. is one of the inexpensive dietary protein source (Ali et al., 2014; Duc, 1997). Except for a low quantity of methionine and cystine, faba bean proteins are highly digestable and, like other legumes, contain a well-balanced amino acid makeup (Waring & Shannon, 1969). The protein of faba beans ranges from 24% to 35% of seed dry matter DM (Crépon et al., 2010; Feedipidia, 2018), making it a far more protein-rich main pulse crop (Robinson et al., 2019). The faba bean is also a good source of amino acids, with up to 67 g kg^{-1} dry matter of the important amino acid's arginine, lysine, and leucine (Koivunen et al., 2016). Protein level in faba beans is about twice as high as protein content in cereal grains. Globulins account for 60%, Albumins for 20%, Glutelins for 15%, and Prolamins for 8% of the total protein content (Rahate et al., 2020). Prolamins are a major component of cereal storage proteins, whereas globulins are the storage proteins in legumes, and both have a considerable impact on protein rheological and textural qualities. The high protein content of faba beans is related to cultivar variances and the source type, such as flour, fraction, or isolation (Yang et al., 2018), and also fertilisation method, growing season, and planting site (Yang et al., 2018; Multari et al., 2015). Faba bean flour (FF) has the greatest protein level of 29.76%when compared to other beans including lima, pinto, and red kidney beans (Gu et al., 2020). According to Alonso et al. (2000), dehulling increased the protein level of the faba bean, which is used to fortify protein content in a variety of foods like bread, biscuits, and oil-in-water emulsions (Liu et al., 2022; Osman et al., 2014; Rosa-Sibakov et al., 2016). Essential amino acids such as isoleucine, leucine, lysine, methionine, tyrosine, phenylalanine, valine, histidine, tryptophan, and threonine, as well as nonessential amino acids such as aspartic acid, glutamic acid, alanine, arginine, glycine, proline, and serine, are found in faba bean (Khalil & Mansour, 1995). The amino acid composition of faba beans varies greatly depending on the cultivar (Nosworthy et al., 2018). Faba bean seeds have a total amino acid (TAA) content ranging from 217.4 to 322.7 g/kg DM. Essential amino acids (EAAs) account for 132.5 g/kg DM (arginine 25.3 g/kg DM, leucine 20.4 g/kg DM, and lysine 17.9 g/kg DM), with a greater EAA/TAA ratio than soybean meal (SBM) (mean EAA/TAA = 52.0% and 46.0%, respectively) (Angell et al., 2016). Faba bean seeds contain 125.4 g/kg DM of non-essential amino acids (NEAA) (glutamic acid 47.9 g/kg DM). and 30.7 g/kg DM aspartic acid). However, some variations in amino acid sequences and structure of faba bean seeds may exist (El-Fiel et al., 2002). With their higher quantities of lysine and arginine, faba bean seeds could be combined with cereals to supply some of the EAA components that faba bean lacks, resulting in a more balanced and desirable amino acid profile (Kumar et al., 2015; Skylas et al., 2019).

Minerals and Vitamins

Faba bean is said to include a variety of minerals (sodium, potassium, calcium, copper, zinc, iron, manganese, magnesium, phosphorus, and sulphur) (Khalil & Mansour, 1995; Luo et al., 2008; Nosworthy et al., 2018; USDA, 2021). The high potassium level (1062 mg/100 g) and low sodium content (13 mg/100 g) of ripe faba bean seed make it ideal for those with hypertension and those on a low-sodium diet. Immature faba bean seeds, on the other hand, have a higher sodium and potassium content, with 50 and 250 mg/100 g, respectively (USDA, 2021). The majority of the phosphorus in faba beans is unavailable because it exists as phytates, which are harmful to human health (Luo et al., 2012). In faba bean hulls, fibres, tannins, and phytate are more vital in complexing a high percentage of iron and zinc. The faba bean is high in folate, a necessary cofactor for the production of pyrimidines, purines, and amino acids (Hefni et al., 2015). They have 423 g folate, which is higher than soybeans (250 g) and peas (400 g) (274 mg). In addition, faba beans provide 0.37 mg of pyridoxine (vitamin B6), whereas soybeans have 1.1 mg. Thiamine (0.55 mg) and riboflavin (0.29 mg) are also present in higher concentrations, but not as much as in soybeans (Erbersdobler et al., 2017). In comparison to soybeans (6.5 mg), lupins (1.1 mg), and peas (0.11 mg), they have a very low level of tocopherols (0.08 mg) (Erbersdobler et al., 2017). Vitamin C level is lower in faba beans, and it declines as seed maturity increases by 25–40% (Turco et al., 2016).

Fats

Total lipids in faba bean seeds are 38.70 g/kg (Akpinar et al., 2001). The oleic (56.5 g/kg), palmitoleic (37.3 g/kg), and linoleic (36.4 g/kg) acids are the most abundant unsaturated fatty acids in faba bean seeds, whereas palmitic (67.3 g/kg) and stearic (34.9 g/kg) acids are the most abundant saturated fatty acids (Angell et al., 2016). These findings suggest that the unsaturated fatty acid content of faba bean seeds, when paired with their high crude protein (CP) content, makes them a low-cost vegetable protein source for both people and livestock. Linolenic acid (58.6–63.7%), linoleic acid (46.9–58.9%), and linoleic acid (45.7–63.6%) were the most abundant fatty acids in the leaves, immature pods, and seeds, respectively

Components with Bioactive Properties

Faba bean could be used as a functional food as it is loaded with various macro-, micro-, and non-nutrient phytochemicals. Brauckmann and Latté (2010), for example, found that faba bean seeds contain L-3,4 dihydroxyphenylalanine (L-DOPA), a precursor to the neurotransmitter catecholamine and a Parkinson's disease medication. Patients with Parkinson's disease may benefit from consuming *V. faba* because it is high in L-dopa (Natelson, 1969). L-dopa was abundant in all parts of the plant, notably the pods and young beans (50–100 mg), and eating these components increased L-dopa levels in the blood (Vered et al., 1994; Mohseni & Golshani, 2013). As a result, *Vicia faba* can be prescribed as a primary dietary supplement for Parkinson's disease sufferers (Ray & Georges, 2010).

Faba bean contains a variety of bioactive phytochemicals, including phenolic compounds, flavonoids, lignans, and terpenoids. Protocatechuic acid, ferulic acid, vanillic acid, caffeic acid, sinapic acid, salvianolic acid, cis- and trans-p-coumaric acid, hydroxyeucomic acid, eucomic acid, caffeoylquinic acid, and dicaffeoylquinic acid are among the free and esterified phenolic chemicals found in faba beans (Dhull et al., 2021). The total phenolic content of several kinds of faba bean pod extract ranged from 4.8 to 13 mg gallic acid equivalent (GAE)/g (Valente et al., 2018). The presence of phenolic chemicals in faba bean sections varies. The overall phenolic content of the whole faba bean is 2.9 mg GAE/g, compared to 22.5 mg GAE/g in the seed coat (Dhull et al., 2021). Faba beans contain flavonoids, which are bioactive chemicals with anti-inflammatory and anti-diabetic activities (Zhang et al., 2019). The antioxidant activity of whole faba bean seeds was just 1.8 mg Trolox equivalent (TE)/g, according to Karatas et al. (2017), however the seed coat had a substantially greater antioxidant activity (22.9 mgTE/g). Johnson et al. (2020) investigated 10 different Australian faba bean cultivars and found that their phenolic and anthocyanin content, as well as their antioxidant potential, varied significantly.

Antinutrients

The antinutrients found in faba beans are numerous (Hendawey & Younes, 2013;Multari et al., 2015) and their levels differ depending on the cultivar, maturity stage, cultivation environment, soil qualities, and other factors (Kumar et al., 2015). Phytates, vicine, convicine, saponins, lectins, oligosaccharides (raffinose, stachyose), condensed tannins, and trypsin and protease inhibitors are few examples (Labba et al., 2021; Nosworthy et al., 2018; Sharma & Sehgal, 1992). Faba beans also contain vicine and convicine, which can cause acute hemolysis in people who have an x-chromosome-inherited glucose-6-phosphate dehydrogenase (G-6-PD) impairment, a condition known as favism (Arese & Flora, 1990). Anti nutritional factors ANFs in raw fababean seeds range from 8.50–28.48 g/kg total phenolics, 3.80–14.50 g/kg tannins, 1.61–10.11 g/kg phytic acid, 16.90–24.02 g/kg verbascose, 7.60–18.70 g/kg stachyose, 2.00–4.50 g/kg raffinose, and 0.60–1.50 g/kg trypsin inhibitors (TI) based on the genotype/cultivar, growing season, seed maturity stage, and agronomic practises used (Cucci et al., 2019; Ivarsson & Neil, 2018; Kowalczyk et al., 2020; Oomah et al., 2011). The presence of protease inhibitors, which also are known to impair protein digestibility and promote pancreatic hypertrophy, is linked to the digestibility of legume-based proteins (Sharma & Sehgal, 1992). Faba bean trypsin inhibitors are lower than those found in other legume crops such as soybean, chickpea, and lentil (Sharma & Sehgal, 1992). Plant breeding interventions, such as gene finding, have lately made significant success in lowering vicine/convicine and seed coat tannins in faba bean (Khazaei et al., 2021). Due to phytate–mineral–protein complexes, phytic acid found in faba beans has been shown to reduce mineral bioavailability and change protein absorption. Phytate is a chelating substance that is thought to lower divalent cation bioavailability (Luo et al., 2008). These ANFs reduce feed palatability and protein and energy bioavailability, potentially affecting animal performance indices like as growth and egg production (Barłóg et al., 2019; Kowalczyk et al., 2020; Multari et al., 2015). The variability in ANFs in faba bean seeds may limit their usage in animal diet feed compositions. Relative to other legumes, such as soybeans and peas (*Pisum sativum* L.), Fababean seeds contain similar amounts of tannins and polyphenols, but relatively less trypsin inhibitor activity (TIA), genistein, and daidzein content (Berger et al., 1999), which indicates that seeds may less impair the nonruminant nutrition status. Fababean seeds have similar quantities of tannins and polyphenols to other legumes like soybeans and peas (Pisum sativum L.), but less TIA, genistein, and daidzein (Berger et al., 1999), indicating that faba bean seeds may have a lower impact on nonruminant nutrition. In fact, high tannin levels in the diet can create stable complexes that protect proteins from rumen microbial breakdown, making tannins in the ANFs potentially advantageous for protein absorption in the small intestine (Mohamaden et al., 2020). According to the literature, high raw faba bean seed inclusion rates in diets had no negative impact on male lamb development performance (Bonanno et al., 2012; Lanza et al., 1999). Phytic acid concentration in faba beans was 6.9 mg/g (Vasić et al., 2012). Phytic acid accumulates in the seeds throughout the ripening period. The availability and content of nutrients varies depending on the vegetative stage of faba beans; nonetheless, it has been discovered that faba bean sprouts contain higher polyphenols and L-3,4-dihy-droxyphenylalanine (L-Dopa) following germination (Randhir & Shetty, 2004).

2.1.2 Market

The size of a faba bean seed is a significant factor in influencing its marketability and consumption form (Karkanis et al., 2018). Broad bean types with large seeds are extensively consumed as a fresh green vegetable or as (dehulled) dry seeds (Karkanis et al., 2018). Animal feed is usually made from varieties with small to medium-sized seeds (Crépon et al., 2010). The faba bean can also be used in the bakery business (Belghith-Fendri et al., 2016); for example, combining faba bean and wheat flour improves bread's nutritional characteristics (Coda et al., 2017). Small faba bean seeds (less than 12 mm) are currently quite popular in Spain (Cubero, 2017). The frozen faba bean (Baginsky et al., 2013b) and canning businesses both prefer small seed genotypes. As an appropriate rotation crop, it contributes to soil fertility restoration by fixing atmospheric nitrogen, resulting in cost reductions for smallholder farmers due to reduced fertiliser use (IFPRI, 2010). As a result, it is a very beneficial legume crop that improves soil health, reduces disease, insect pest, and weed development, and hence benefits to the sustainability and versatility of cropping systems (Jensen et al., 2010). It's also planted as a green manure crop or as a cereal rotation crop (McVicar et al., 2013). Improvement of soil physical qualities, preservation of soil fertility, and interruption of pest and disease cycles are some of the other benefits provided by faba bean in rotation systems (Chalk, 1998; Mandal et al., 2003; Stoddard et al., 2010; Adekiya et al., 2017). Ethiopian farmers are well aware of the importance of the faba bean, which is commonly used in crop rotation (Gemechu et al., 2016). It is a source of revenue for farmers and foreign money for the country from an economic standpoint (Tewodros et al., 2015; Asnakech et al., 2016; Gemechu et al., 2016). Traditional diets, particularly in the Middle East, the Maghreb, South America, and Asia, rely heavily on the faba bean (Lacampagne, 2007). China is the world's top consumer of faba beans, followed by Egypt. In China, over 30% of faba bean production is consumed as a green vegetable (Schneider & Muel, 2007). The faba bean is the major protein source for Ethiopians living in the highlands who cannot afford to buy animal goods (Mesfin, 2019). However, in the United States and northern Europe, the beans are nearly entirely utilised for livestock feed and silage (Askar, 1986). The UK and France, which are among Europe's top producers, sell combine-harvested beans at a premium price to Nile Valley food markets (Lammerts van Bueren & Myers, 2011).

2.2 Insects and Diseases in Faba Beans

Grasshoppers are a common faba bean pest, while the pea leaf weevil is a new and serious threat to both faba and pea. Lygus can cause quality losses because they move into faba bean after other crops have matured and, if present in sufficient numbers, can cause grade loss (pin holes in the seed coat).

Other insects considered to be faba bean pests include aphids, blister beetles, and leafhoppers, which can be found in faba beans on occasion but rarely at economically damaging levels. Aphids and leafhoppers can spread viruses while feeding on faba bean.The leafhopper can cause harm by spreading aster yellows. Blister beetles and grasshoppers feed on faba bean shoots and buds, causing damage to the area that is being fed on.

2.2.1 Grasshoppers

Damage

Grasshoppers can be a serious pest in faba bean fields. On the prairies, there are over 80 species of grasshoppers, yet only three of them are harmful to faba beans. These three pest grasshoppers prefer the foliage of faba beans and will feed on them even when other food sources are available.

Melanoplus sanguinipes, Melanoplus packardii (Packard grasshopper) and Melanoplus bivittatus (Two-striped grasshopper) are the three grasshopper species that threaten faba beans (Migratory grasshopper).They all have a spine below the head and a spur-throated throat. Adult grasshoppers that develop in late May on the grasslands are usually not pests. Grasshopper defoliation is a concern during the vegetative stage of the crop.

Grasshoppers are the most damaging from the bud stage to early pod development because they eat flower buds, open flowers and developing pods. In this instance, yields can be lowered by up to 90%. Grasshopper infestations can influence plant buds and pods as they evolve into reproductive stages, affecting pod formation, seed development and ultimately yield. As the plant tries to compensate for the lost biomass, feeding on early developing pods can diminish production and cause maturity to be delayed.

Life Cycle

Eggs overwinter in soil-deposited pods (8–150 eggs per pod), hatching in the spring when the temperature reaches 4.5 °C. Every year one generation of cycle occurs.

Control Measures

Begin by sampling at least twenty places in a straight line from a field corner to the field centre, then to one side. As you approach each location, count how many nymphs jump in a 1 ft^2 area (e.g., every 100 steps). To calculate number/m^2, divide the total number of grasshoppers calculated by two.

Check the field borders for grasshoppers that have migrated in from the roadside and the headland. Field margins will have more insects, and a dense lentil crop will keep them from going farther into the field, as they favour more open and exposed regions. During drought seasons, keep an eye out for damp locations.

If grasshopper populations are only above the economic threshold on the field's edges, an edge treatment with a suitable pesticide can save time and money while still ensuring effective control.

If you need to control grasshoppers in large enough numbers to cause economic damage, When the nymphs are in their third instar stage, which is usually around mid-week of June, is the optimal time to use an insecticide. Only insecticides allowed for use in faba beans should be used, and the pesticide's pre-harvest interval must be followed to maintain crop marketability.

Pyrethroids, some organophosphate pesticides and carbamate insecticides are all toxic to grasshoppers.Birds, coyotes, parasitic, small rodents and predatory insects, microsporidian parasite Nosema locustae Canning and the pathogenic fungus Entomophthoragrylli Fresenius are all-natural predators.

2.2.2 Lygus Bug

Damage

Lygus insect outbreaks have posed a significant threat to viable faba bean production in Alberta due to the large amount of canola planted.

Lygus bugs can degrade faba bean quality by entering the crop after other crops have matured and feeding through pin holes in the seed coat with their sucking mouth parts.

Lygus bugs pierce tissue to extract contents from new growth and plant reproductive parts (flower buds, seeds, and pods); buds turn white and fail to mature; flowers fail to develop pods or pods fail to mature.

Feeding causes seeds to collapse or shrink and discolour, jeopardising their quality and viability. Additional losses may occur if flowering is delayed due to severe feeding pressure or dryness. Lygus bugs infest still-green faba bean fields because canola is harvested first, causing seed damage and emerging pod damage.

Human consumption faba beans have a low tolerance for lygus bug damage (less than 1% for Grade No. 1).

Life Cycle

As adults, they spend the winter under plant detritus near fields. In the spring and summer, adults travel into crops to lay eggs on stems. Adults are excellent fliers.

In the southern grasslands, there are two generations per year, but only one in the northern prairies.

Control Measures

To establish the requirement for control operations, sample crops with a typical 40 cm (15 in.) diameter sweep net is needed.

During flowering to pod development, keep an eye on pulse crops for lygus bugs until the seeds in the pod become hard. During the warm, sunny portion of the day when lygus are most active (temperatures more than 15 °C), make 10–25, 180° sweeps at five to ten representative places in the field.

At each point, walk an arch with four to five sweep locations around 25 metres apart, sampling a minimum of two field margins. Due of the minimal number of lygus required to cause harm in the crop, 25 sweeps are recommended for faba beans.

Count both adults and nymphs of later instars. Include the nymphs with the five black dots on their backs in the count. Small nymphs without wing pads are not expected to harm the crop and are not counted when estimating thresholds for faba beans if the crop is monitored at the early pod stage.

If crop growth is too dense, samples can be taken near the field edges or at right angles from the edges, as long as the crop is at the same stage as the rest of the field. Samples should not be collected from poor areas with thin stands because lygus is far more abundant there than in thick stands, and field populations will be overestimated.

2.2.3 Pea Leaf Weevil

Damage

The pea leaf weevil is a small insect that packs a powerful punch in terms of crop yield impact. This non-native invasive insect, the size of a rice grain, has appeared in recent years as a threat to Alberta's field pea, faba bean, and chickpea pulse crops.

The pea leaf weevil is a slender greyish-brown insect that measures about 5 mm in length and has a short snout. Three pale-colored stripes run lengthwise down the thorax and onto the elytra. Mature larvae measure 3.5–5.5 mm in length, are c-shaped, without legs and have a brown head.

The fact that this insect appears intermittently complicates growers' pea leaf weevil defence and in some years it's a major issue, whereas in others it's just a slight inconvenience.

The grey adult weevil feeds on the leaf margins (notching) and increasing points of host seedlings, but the harm is not economically significant.

Unless there is a lot of feeding pressure, pea and faba bean seedlings can withstand leaf notching and generally improve.

Adult females will lay a large number of eggs at the base of pea plants, but Faba plants will usually survive this defoliation.

When the larvae hatch and reach the soil, they cause more serious harm by devouring nitrogen-fixing nodules on the plant's roots, limiting nitrogen available to the crop, resulting in reduced plant growth and poorer seed yield.

Life Cycle

The adult spends the winter in soil near or within alfalfa, other perennial legume crops or tree shelters. Eggs are placed on or near developing chickpea plants from May to June.

Adults disperse up to a few kilometres in the spring, primarily by flying once temperatures exceed 17 °C or walking short distances. Throughout the summer, each female lays up to 300 eggs in the soil near or on evolving plants.

The larvae hatch in one to three weeks and travel to Rhizobium nodules on the root, where they feed.When the larval stage is finished, the insect pupates and re-emerges as an adult in late July to September.

Adults that have just emerged look for any pulse crops to feed on.

Prior to overwintering life cycle starts.

Control Measures

In early spring, it's a good idea to keep an eye out for the distinctive U-shaped notches on seedlings.

Inspect the clam leaf of 10 plants for notches at each of five points along the field perimeter and another five sites within the field when the pea crop is at the second or third node stage, up to the fifth node stage. The weevil has most definitely placed its eggs if notches happen on lower leaves but not on clam leaves, and spraying is no longer a possibility.

The percentage of seedlings with terminal leaf damage (for example, leaf notches) accurately predicts overall plant damage and to a lesser amount, possible yield losses.

Where pea leaf weevils are a continuous risk, use seed treatments. Otherwise use the suggested foliar sprays on adults as needed. Weevils may re-invade fields, so keep an eye on them.

2.2.4 Blister Beetle

Damage
Faba beans canbe attacked by three species of caragana, or blister beetle. Blister beetles attack faba beans in swarms, though they usually attack in small patches scattered throughout the field. They usually only feed for a short period of time before moving on.

Adult blister beetles have flexible elytra and a thorax that is narrower than the spherical head and elytra.

Adult Nuttall blister beetles are 16–28 mm long and metallic green or purplish in colour.

Crops are not consumed by the larvae.

Life Cycle
Over winter in the soils as larvae. Adults who have just emerged assemble on food plants to feed and mate.

Females lay four to five batches of 200–400 eggs in the soil, and the eggs hatch in two to three weeks.

Most adults are present from early June to mid-August, depending on the species.

One generation is born each year.

Control Measures
Scouting has not yet been settled. Collect adults congregating on plants with a sweep net.

2.2.5 Pea Aphid

Damage
The adult pea aphid is small, measuring around 4 mm (0.15 inches) in length, pale green in colour and long-legged.

By draining the plant's sap, the pea aphid weakens it, and it can also disseminate viruses from sick plants to healthy ones. They are also responsible for the transmission of viral illnesses in warmer countries.

It's possible that the bug is wingless or has noticeable, translucent wings.

Early in the spring, the eggs hatch, and the juvenile aphids feed on newly emerged alfalfa or clover plants.

Because aphids deprive plants of resources through penetrating and sucking rather than chewing and defoliating, the damage they inflict can be difficult to assess.

Because they may give birth to live young without mating and since they can easily travel into places carried by air currents, populations can grow quickly.

To cause damage, the population must reach critical levels before the plant reaches maturity.

Life Cycle
Pea aphids overwinter as eggs on the leaves and stems of perennial legumes like clover crowns or alfalfa, although they're more likely to arrive in June and early July on warm southerly winds from the United States.

In May and June, a new generation develops wings and flies to faba bean fields, aided by wind currents.

Multiple generations of the pea aphid may finally result in numbers high enough to inflict economic loss if the insect arrives early enough and the atmosphere is suitable to fast reproduction.

Before winged females go to summer crop hosts, where some generations are developed over the summer, up to 23 generations are produced asexually.

Colonies are less thick than those of other species that attack agricultural crops.

Late in the summer, winged sexual forms develop, and females return to their winter hosts to deposit eggs.

Control Measures
At each blossom, look for pea aphids. Check five plant tips (top 8 inches) at four spots each field, or sweep 10 times using a sweep net.

Insecticides are exclusively approved for the control of aphids on peas and lentils.

Winds and rain can help to mitigate the damage.

Due to crop dryness, parasitic wasps, illnesses, and other factors, pea aphid numbers often begin to drop around mid-to-late August.

2.3 Breeding and Genomics in Faba Beans

Plant breeding is the discipline of altering the characteristics of plants with the aim of production of desirable features. It has been widely adopted to enhance the nutritional quality of foods intended for humans and animals' consumption. The objective of plant breeding is to develop plant varieties that possess exceptional and superior characters for numerous applications in agriculture. The traits which are most commonly addressed are associated with biotic and abiotic stress factors, improved crop yield, final product quality characteristics related to taste or the biological composition (fibers, fat, protein, sugar, lipids, vitamin) and processing requirements (baking, harvesting, milling etc.).

2.3.1 Breeding Methods

Outcrossing frequencies range from 4% to 84% in *V. faba* L., a limited allogamous species (Suso et al., 1999). The amount of realised heterosis, which increases yield stability, yield and resilience to abiotic stressors, is possibly determined by the level of cross fertilization (Gasim & Link, 2007). In faba bean, a high level of cross fertilisation (>0.5) is required for the development of artificial varieties and enhanced exposed population (Metz et al., 1994). In the absence of insect pollinators, developing synthetic varieties employing auto fertile lines to assure minimum yield and taking advantage of their presence by studying heterosis to boost yield and yield stability is the best alternative (Cubero & Moreno, 1984).

Basically, breeding is divided into two classes, they are

1. Breeding for biotic stress
2. Breeding for abiotic stress

Breeding for Biotic Stress

Foliar diseases, parasitic weeds, insect pests and viruse are the most significant biotic limitations for faba bean. Rust (*Uromyces viciae-fabae*), Ascochyta blight (*Ascochyta fabae*), chocolate spot (B. fabae) and gall disease are the most common foliar diseases (OlpidiumviciaeGusano). Chocolate spot can reduce faba bean productivity by up to 61% (Sahile et al., 2008); rust disease by upto 30%; and gall disease by upto 100% (Sahile et al., 2008). (Abebe et al., 2014).

Faba bean necrotic yellow virus (FBNYV) is also regarded as the most serious virus disease affecting faba beans, causing up to 90% yield losses in Egypt (Kumari & Makkouk, 2007). Orobanche crenata Forsk is thought to be native to the Mediterranean basin. In Morocco, Orobanche infestation in faba bean increased from 12% in 1981 to 51% in 2003. Upper Egypt abandoned the faba bean primarily due to Orobanche infestation. Orobanche also has an impact on faba bean productivity in Ethiopia and northern Sudan.

The primary effective resistant sources for Chocolate spot and Ascochyta blight were discovered at ICARDA (Robertson, 1984; Hanounik & Robertson, 1989) andused by ICARDA and National Agricultural Research Systems (NARS) to grow breeding lines with high resistance and yield potential.

The Ethiopian Institute of Agricultural Research (EIAR) has released several varieties with high chocolate spot resistance. Several high yielding faba bean varieties were released by EIAR researchers through direct selection from ICARDA germplasm or by transferring good levels of resistance from ICARDA germplasm into locally adapted varieties'Moti' (ILB 4432 × Kuse-2-27-33), Obsie (ILB 4427 × CS20DK), 'Gebelcho' (ILB 4726 × 'Tesfa') and 'Walki' (ILB 4615 × Bulga 70) are among the faba bean varieties released (Temesgen et al., 2015) with limited resistance to chocolate spot. Another variety, 'Gora' (ILB2717-1 × R878-1) was recently released in Ethiopia with greater resistance to chocolate spot and larger seed size than traditional cultivars.The yearly rate of genetic gain in these released cultivars was 0.27% for chocolate spot severity and 8.07 g/1,000 seeds (Temesgen et al., 2015).

In Ethiopia, recent efforts have been made to recognize faba bean accessions for resistance to a new Gall disease. 'Nc 58' and 'Degaga' were recognized as moderately resistant to Gall disease among 14 cultivars tested in Ethiopia (Yitayih & Azmeraw, 2017). Although most breeding programmes focus on developing resistant genotypes for a single economically important disease, recent efforts have been directed to developing faba bean lines with multiple disease resistance lines (Maalouf et al., 2016), which are now used in the ICARDA breeding programme to develop multiple disease resistant cultivars for target environments.

Efforts to breed Orobanche-resistant faba beans have led to in the release of cultivars with suitable levels of partial resistance. Resistance may be based on a combination of mechanisms (Pérez-De-Luque et al., 2006). For the parasite population that exists in Syria, ICARDA has developed faba bean lines with varying levels of tolerance and resistance to Orobanche, which have been tested in various locations.

In general, the resistant lines that are being developed in various countries appear to be broadly effective against Orobanche. For example, the Orobanche-resistant varieties ‘Hashbenge’ (ILB4358) and ‘Baraca’ (Rubiales et al., 2016) released in Ethiopia and Spain, respectively, were discovered in Tel Hadya Syria. Faba bean has regained some farming areas in Egypt as a result of the release and availability of Orobanche resistant cultivars (‘Misr3’, ‘Giza843’).

In addition to above biotic stresses, a number of insect pests such as Sitona weevil (*Sitonalineatus* L.), black bean aphid (A. fabae Scopoli) and cowpea aphid (Aphis craccivora Koch) cause harm by direct feeding as well as by transmission of viruses (Mwanauta et al., 2015). There are currently integrated pest management options to control these insect pests as described by Redden et al. (2018). In addition, borer weevil (*Lixusalgirus* L.) causes serious damage in faba bean in North Africa. Recently, new sources for resistance to this insect were identified and would be utilized to develop resistant cultivars (Ait taadaouit et al., 2018).

Aside from the biotic stresses mentioned above, a number of insect pests such as Sitona weevil (Sitonalineatus L.), black bean aphid (Aphis fabae Scopoli) and cowpea aphid (Aphis craccivora Koch) cause damage through direct feeding as well as virus transmission (Mwanauta et al., 2015). As described by Redden et al. (2018). There are currently integrated pest management options for controlling these insect pests Furthermore, in North Africa, the borer weevil (Lixusalgirus L.) causes significant damage to the faba bean. New sources of resistance to this insect have recently been identified and will be used to develop resistant cultivars (Ait taadaouit et al., 2018).

Breeding Techniques for Abiotic Factors

Abiotic factor is a term which indicates non-living components of environment. These include wind, temperature, rain, soil, nutrients, sunlight, pollution and altitude. The major abiotic factors which influence legume crops are waterlogging, heat, drought and frost (Anjum, 2016). The harmful impact of heat stress generally occurs during the reproductive stage. The Faba bean plants become highly sensitive due to damage to gametophyte and failure of fertilization (Bishop et al., 2016). Apart from this, yield of faba bean plants is reduced by terminal heat stress which significantly affects the yield components of genotypes. The adverse outcomes of these stresses lead to the development of short-stemmed crop with less branches and pods (Sita et al., 2017). Thus, the traits viz., count of seeds, pods that having strong relation with yield could be selected for improvement in sensitivity of beans to heat conditions. Another significant constraint to bean production is terminal which is common in semi-arid areas subjected to rainfed conditions. A possible solution would be to identify early maturing genotypes with adaptation to dryland conditions and additional irrigation to increase final yield. Breeding studies based on varied genotypic to tackle the drought stress in Faba bean has been reported by Abdelmula et al. (1999). Furthermore, other droughtrelated components such as stomatal conductance, carbon isotope discrimination, and leaf temperature (Khan et al., 2010), as well as spectral indices structureinsensitive pigment index and normalised pheophytinization index (Maalouf et al., 2015) could be chosen to improve yield. The abiotic stress which is fetching focus in breeding is frost tolerance which affects plant yield in North Europe and America. Substantial development is made in north Europe for breeding related to this aspect (Link et al., 2010; Arbaoui et al., 2008). In Ethiopia, the major constraints are soil acidity and waterlogging that impact the cultivation Faba beans (Keneni et al., 2010). To tackle this, a variety ‘Walki’ has been developed which is quite popular in the middle highlands of Ethiopia.

2.4 Harvesting of Faba beans

Harvesting of Faba beans is usually done when seeds attain full size but are green in colour. The optimum moisture content for harvesting is 14–15%. There are two methods of harvesting on the basis of their end use. For consumption of seeds in fresh form, beans may be harvested either manually or mechanically as soon as pods are filled with seeds. Harvesting with hand is generally done two to three times during the harvesting period. When Faba beans are to be used in dry seed form, the combine harvester can be used. The harvesting stage selection is a crucial to minimise the seed loss. The moisture content and maturity of Faba beans vary to large extent. The pods on the upper area contain seeds with high moisture and less maturity as compared to pods of lower side. Thus, drying and conditioning is crucial to attain uniformity in quality of beans. Faba beans must be dried at maximum temperature of 32 °C and drying process must be accomplished in two stages i.e., hot air drying-tempering if more than 5% moisture needs to be removed (Anonymous, 2022).

2.5 Storage of Faba Beans

The storage of seeds starts once the seeds attain physiological maturity and is maintained until the next sowing period. Hence, the various phases involved in storage are: (a) Physiological maturity to harvest, (b) Harvesting to packaging, (c) Packaging to storage (d) Storage to marketing and (e) Storage at farm. The storage life is dependent upon temperature, moisture, insects and diseases. The beans at the moisture content of 18–20% can be stored successfully as long as grains remain cooled. A rise in moisture content leads to hot spots within the bins. These factors need careful management to prevent deterioration during storage. Beans must be stored at 4–7 °C with 95% relative humidity. Beans possessing good germination potential and vigour can remain viable during storage for minimum three years, provided that the cool temperature is maintained along with moisture content of produce less than 11%. For long term storage, much attention is needed as they age continuously after harvest and exposure to sunlight further deteriorate the quality over time. After harvesting, the factors such as loss of sweetness, crispness, green colour and mealiness may deteriorate the keeping quality (Pariasca et al., 2000). The most common visual parameter to assess the quality of faba bean is the colour of seed coat (testa) which affects the consumer perception as well as marketing. The colour of testa of different varieties varies from white to purple. However, generally at the harvest stage, seed coat colour is beige/buff which converts to brown or black owing to duration and conditions of storage. Seeds with dark testa colour are unaccepted by consumers in markets as they perceive such produce have poor cooking and sensory attributes (Nasar-Abbas et al., 2008). Apart from this, seed coat darkening is also accelerated by environments with high temperature, relative humidity and exposure to light. These conditions lead to make beans hard to cook. Thus, consumers avoid purchase of beans which have dark seed coats as they believe such beans require long soaking as well as cooking times along with less palatability. To overcome this, beans with moisture content >12% must undergo aeration during storage to maintain lighter seed-coat colour. Apart from this, the seeds which suffer field weathering prior to harvesting are more susceptible to quick deterioration of the stored stock, even if the storage conditions are maintained at acceptable levels of temperature and relative humidity (GRDC, 2022).

During the initial periods of storage, insect infestation and thus the associated losses may appear low. However, these losses particularly due to insect infestatiom become higher during prolonged storage. Therefore, as the storage period ends, high losses occur in the quanity as well as quality of beans (Helmy et al., 2020). During storage, faba bean pods or seeds tend to lose moisture quickly if the produce is not packaged or relative humidity maintained is more than 95%. The relative humidity close to saturation point results in decay of product within a few days. Moreover, the stacking of containers should allow the circulation of abundant air. The deterioration starts rapidly due to accumulation of heat of respiration, if containers are stacked closely. The storage of faba beans in big bins or pallet boxes requires a provision for rapid cooling. The storage structure such as silos with conical bottom are the ideal option for storage of pulses. The conical bottom allows unloading of beans without any damage. The storage of produce for more than three months requires facilities for aeration and gas-tight seal to facilitate efficient fumigation. The silos must be filled or emptied using centre holes as it will prevent collapse of structure due to uneven weight on walls of silo.

2.6 Post-Harvest Treatments

To overcome the issues relevant to maintaining the quality of beans during storage, low temperature storage (4–10 °C) and modified or controlled atmosphere have been suggested as efficient techniques by several researchers to prolong the shelf-life of agricultural produce, especially for the foods which possess high respiration rates (Sánchez-Mata et al., 2003). The combination of these technologies facilitates less respiration and ethylene production, delayed softening, and other compositional changes attributed to senescence (Pariasca et al., 2000) as discussed below:

2.6.1 Packaging

Packaging is a vital technique to prolong the quality of agricultural produce by acting as a barrier against physical, chemical and microbial factors. Nasar-Abbas et al. (2009) analysed the effect of different moisture contents and storage temperatures for a period of one year on the color of faba beans packaged in polyethylene lined aluminium foil bags. Higher the temperature and moisture content, faster the rate of change in colour. Color of beans was darkened with the exposure to artificial light. The darkening of seeds led to loss of total phenolics, total tannins and proanthocyanins during storage. Logegaray et al. (2010) evaluated the quality of faba beans packaged in high density polyethylene (HDPE) boxes and boxes with stretch film (resinite) and stored at 1 and 4 °C. Weight loss, carbon dioxide percentage and firmness remained unaffected whereas visual quality declined with the storage duration. At 4 °C, increase in carbon dioxide was more as compared to decrease in oxygen concentration.

2.6.2 Modified Atmosphere Packaging (MAP)

MAP technique is effective in controlling the discolouration resulting from atmospheric oxidation. In this technique, the composition of gases surrounding the agricultural produce is altered. This composition differs from the composition of gas surrounding the package. This varied composition facilitates the long-term storability and prevention by discolouration by modifying the metabolic processes along with reduction of the respiration rate. The modified atmosphere constitutes the less concentration of oxygen and high concentration of carbon dioxide gas. Palma and D'Aquino (2018) studied the passive modified atmosphere packaging (MAP) of minimally processed faba bean seeds. The seeds were packaged in MAP within Bolphanefilm or Thermoplastfilm. During the storage for 4, 8 or 12 days at 5 °C, non-appreciable changes were perceived in flavour and odour, however a decrease was detected in crispness along with browning of seeds packaged in BHE film.

Although, slower degradation of total soluble solids and vitamin C was observed for bean seeds packaged in BHE film, high sensory scores were recorded for seeds stored in BHE films in contrast to those packaged in MY films. Collado et al. (2018) conducted a study on faba beans in which the impact of MAP and sanitation with chlorine, acidified sodium chlorite, chlorine plus citric acid and acidified sodium chlorite plus citric acid was evaluated on quality of immature seeds stored at 1 °C. Atmospheric composition remained nearly same for all the treatments after 9 days of storage. Colour of beans, firmness and sensory attributes were unaffected until day 6. In another study, Nasar-Abbas et al. (2008) used MAP technique in order to control darkening of faba bean during storage of 1 year at 30 °C. Seeds were flushed with CO_2, N_2, O_2 or ethylene, and vacuum packaging. Nitrogen efficiently reduced colour darkening, whereas storage in oxygen led to accelerate the darkening of beans. As flushing with N_2 minimized darkening and tannin losses, it would be helpful in preserving quality during long-term storage of faba beans.

2.6.3 Laser Treatment

The pests find their pathway from the crops standing in fields to stages of bean processing and storage. To overcome such issues, various techniques have been used at industrial levels. One of such methods is the application of laser light which has found various applications in agriculture sector. It is an effective technique however the narrow beams limit their application which require even exposure of seed to achieve full effect (Sharma et al., 2015). Mohammed et al. (2020a) conducted a study using a Helium-Neon gas laser (He-Ne) with an output power of 8 mW and 632.8 nm wavelength for 0, 15, 30 and 45 min on faba beans. During storage the observations for physical properties and proximate composition indicated a decline along with decrease in laser treatment time and an increase in the storage duration. Contrarily, bulk and true density, shear, penetration force, ash and carbohydrate increased as storage period increased and decreased laser exposure duration. More studies need to be conducted to provide the scientific basis for its potential to be utilized as disease control method.

2.6.4 Irradiation

Food irradiation is an efficient non-thermal technique to address food safety and quality. This technology has showed a great interest due to constant food losses caused by insects and micro-organisms and spoilage due to physical conditions. This technology is being used in more than 50 countries producing around 60 products worldwide (Maherani et al., 2016). Radiation treatment is proven to be an effective way of disinfestation and decontamination. Irradiated foods are safe and helpful to prolong the shelf-life of foods in areas deficient in cooling facilities. A joint expert committee (FAO/ IAEA/WHO) specified that irradiation dose up to 10 kGy safe for food products as it prevents any toxicological hazard.

In a study by Rady et al. (2020), packaged faba bean seeds were treated with gamma rays with doses varied in 0–10 kGy and assessed for antioxidant activity. Exposure to gamma irradiation encouraged steady inclination in the antioxidant activity with the maximum values detected in samples irradiated at 9 kGy. Sofi et al. (2013) irradiated the starch obtained from broad beans (*V faba* L.) using gamma rays at doses of 0, 5, 10 and 15 kGy. The results for physico-chemical properties indicated that solubility, carboxyl content, water absorption capacity and freeze thaw stability significantly increased as the irradiation dose was increased, contrarily, pasting properties, syneresis and pH declined significantly. Ali et al. (2014) investigated the effect of gamma radiation on phytochemical compounds in Faba bean using doses of 0–10 kGy. As the Faba bean seeds were exposed to ascending doses of gamma irradiation, a significant increase was observed in total phenolic and flavonoid contents. Mohammed et al. (2020a, b) conducted study on UV treatment on bean and seed quality of Faba beans for 0, 30, 60 and 90 min. The findings of this study suggested that the exposure to UV may favour preservation faba bean seeds quality.

There are few studies which utilized irradiation technique for other purposes. The presence of antinutritional compounds such as phytic acid and tannins have detrimental effect on the nutritional availability (such as protein and minerals) by various direct and indirect reactions (Bressani, 1993). Nutritional value of beans can be improved by removal of such antinutritional factors. Various processing methods have been proposed by researchers such as heating, roasting, boiling, soaking, germination, chemical treatment, fermentation and solvent extraction, germination. None of these approaches is efficient in complete removal of all the antinutrients. Single radiation treatment or combined with other processing techniques are vital to reduce or finish anti-nutrients in cereals and legumes (Sattar et al., 1990). Osman et al. (2014) investigated the nutrients and antinutritional factors of faba beans exposed to gamma irradiation dose of 0.5 and 1.0 kGy and cooking. These treatments had slight effect on chemical composition and mineral content, whereas tannin content was reduced significantly ($P \leq 0.05$). Irradiation and/or cooking of seeds resulted in improvement of vitro protein digestibility (IVPD). Apart from this Mejri (2012) reported that gamma irradiation treatment of Faba beans induced genetic diversity in germplasm, which is required for breeding of Faba beans to develop resistance again broomrape. The considered samples were prominent in the development of plant parasite tolerant synthetic varieties.

Irradiation treatment using gamma rays is a promising technique to enhance the plant productivity (Volkova et al., 2020). The exposure of gamma rays leads to root elongation (Melki & Marouani, 2010), increased shoot length, induction of nutrient carriers (Abbas et al., 2020), stimulation of plant growth and development (Galal et al., 2018), increased free radicals (Bhat et al., 2007), inactivation of plant pathogens (Rajkowski & Thayer, 2001) and enhancement of plant tolerance to biotic/ abiotic stresses (Macovei et al., 2014). Soliman and Abd-ElHamid (2003) investigated that the germination of kidney bean seeds and growth parameters improved significantly as a result of seed irradiation using gamma rays at low doses which might be due to increased symbiotic relationship between soil biota and the host plants (ChallouguiFatnassi et al., 2011). Apart from this, the translocation of fixed atmospheric nitrogen to the grown plants also increases. This might lead to increase the growth of plant roots, beside of improving the nutritional status of the grown plants.

2.7 Faba Beans as an Ingredient

The size of beans plays an important role in determining their final use. For food purpose, large seeds are used either in fresh green vegetable or dry seed form. The small-medium size seeds are commonly utilized as animal feed (Crépon et al., 2010). The addition of proteins derived from plants in human meals is fruitful for human well-being (Moorthi et al., 2015). Faba bean is an abundant source of amino acids, particularly contains essential amino acids (Koivunen et al., 2016). Faba beans are vital source of phytochemicals and have potential to act as a functional food. Brauckmann and Latté (2010) reported the presence of L-3,4-dihydroxyphenylalanine in faba beans which is used as a drug to cure Parkinson's disease. Fababean have potential to be used in the bakery industry (Belghith-Fendri et al., 2016); as a combination of faba bean and wheat flour enhances the nutritive value of bread (Coda et al., 2017). Thus, these can be incorporated into foods to develop nutrient-rich products. Moreover, high protein gluten-free legumes, which constitute more fibers, resistant starch and good amount of minerals are a great substitute for production of gluten-free pasta. There are several studies conducted to include faba beans in foods during the previous years as mentioned below:

Pasta and Spaghetti

Rosa-Sibakov et al. (2016) compared the structural, cooking, starch digestibility and rheological properties of pasta made from faba, lentil or black-gram flours and cereal based gluten free pasta. Legumes based pasta had high protein, resistant starch and fibre content and less anti-nutritional factors. The structure of legume-based pasta indicated less springiness and more cooking losses whereas black-gram pasta had high springiness and less loss during cooking. Pasta prepared from lentil and faba released starch gradually in contrast to commercial gluten-free pasta. In another study, Tazrart et al. (2016) developed pasta from semolina along with 10%, 30% and 50% faba bean flour. The fortified pasta indicated lower cooking time but higher dry matter loss. A significant increase in protein starch, ash and mineral and had low glycemic index in contrast to control pasta made of 100% semolina. Iron availability and in vitro protein digestibility improved as fortification level increased.

Bread

Sozer et al. (2019) evaluated the lactic acid fermentation to enhance the nutrients in Faba bean flour which was used to prepare gluten-free bread. The comparison of quality of prepared bread was done with the bread made from soy flour. The breads prepared from unfermented and fermented Faba bean flour breads exhibited softness and higher porosity compared with soy flour bread. Sensory evaluation presented that fermentation had negligible impact on the crumbliness, pore-size and springiness.

Emulsion Gel Product

Jiang et al. (2020) developed foods viz., yogurt, tofu analogue products from faba bean flour. The production process involved thermal pretreatments, dehulling, milling, addition of plant oil, homogenization, prevention of starch gelation by removal and hydrolysis, and inducing protein gelation. The starch hydrolysis resulted in better quality yogurt because the hydrolysates improved viscosity and strength of gel whereas, removal of starch was improved than hydrolysis in production of tofu as the hydrolysates resulted in less water-holding capacity and gel strength of tofu.

Protein Isolates and Other Products

do Carmo et al. (2021) reported the possibility of production of meat analogue product from faba bean concentrate. The developed product exhibited good sensory attributes. Vogelsang-O'Dwyer et al. (2020) prepared flour from Faba bean by milling and protein isolation by acid extraction and precipitation by isoelectric method. Felix et al. (2018) developed protein concentrates using densification, which were suitable for the formation of food emulsions possessing microstructure which depends upon microstructure. Hence, on the basis of pH, best results for droplet sizes and viscoelastic properties were attained at pH 2.5. Protein isolates with 94% protein content were prepared by Singhal et al. (2016) from Faba beans by utilizing alkaline extraction process along with isoelectric precipitation. Functional properties of FPI and oil holding capacity were equivalent with those of isolates from soybean, egg, whey and pea. In a study by Sulaiman et al. (2018), minced beef patties were prepared using 20% Faba bean protein, which led to high product yield and more dietary fibre.

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Chapter 3
Physical and Milling Characteristics of Faba-Bean

Nilgun Efe and Sezen Sevdin

3.1 Introduction

The Faba bean, which can be referred to as: fava bean, broad bean, or horse bean. Faba beans are originally from the Mediterranean region and there are many varieties and uses in different countries, such as: Turkey, India and China (Altuntaş & Yildiz, 2007). Faba beans are generally round in shape, and can differ in size/shape according to the differing varieties and origins, which can be seen in Fig. 3.1. Faba beans have a high production yield, high adaptation ability, and long storage times, which are advantageous for farmers and various industrial applications.

Moreover, faba beans are a vegan alternative to meat due to the high protein and low lipid content, and the dried faba bean has a 25% protein content. Thus, consuming faba bean in human diet is becoming more popular and important (Altuntaş & Yildiz, 2007; Paul & Gupta, 2021). Understanding the physical, milling, and chemical properties of faba beans are becoming more significant. In this chapter, physical and milling characteristics will be explained in detail. The chemical properties and nutrition facts will be explained in Chap. 4.

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Fig. 3.1 (**a**) fresh faba bean seeds, (**b**) dried faba bean seeds (Mavromichalis, 2017; Vicia faba, n.d.)

3.1.1 Size, Shape, Volume, Density, Porosity and Physical Attributes

The major physical properties of faba beans will be size, shape, and volume, since these characteristics are important for harvesting and separation. Grinding processes, density, and porosity are important for the storage and transportation processes (Altuntaş & Yildiz, 2007; Duc, 1997).

Size

The size of the faba beans can be determined by calculating projected area. The three characteristic dimensions in this method are mainly major, intermediate and minor diameters indicating length width and thickness, respectively (Sahin & Sumnu, 2006). A digital camera and software can be used to determine length, width, and thickness. In order to obtain more accurate results, this method is implemented in repeated trials with randomly selected faba beans (Haciseferoğullari et al., 2003).

Shape

Shape of a food material gives information about heat and mass transfer calculations, evaluating the quality of a material or separation of unwanted/unrelated foreign substances and "sphericity" is the term to define shape of a spherical substances (Sahin & Sumnu, 2006). This term is important for faba beans since, as mentioned above, the faba bean has a round shape. There are a variety of ways to calculate sphericity, one formula is shown as an example in Eq. 3.1, where the sphericity of a totally spherical food is equal to 1 (Sahin & Sumnu, 2006).

$$Sphericity = \left(\frac{Volume\ of\ solid\ sample}{Volume\ of\ circumscribed\ sphere} \right)^{1/3} \tag{3.1}$$

Volume

Another major physical property of faba bean is the volume; which can be generally determined by 3 methods (Sahin & Sumnu, 2006):

- Calculation of volume; by using the characteristic dimensions if the food has regular shape
- Experimental approach; by using liquid, gas or solid displacement method (if the food is solid.)
- Image processing methods; by using magnetic resonance imaging (MRI), if the food shape is especially ellipsoidal such as eggs, and peaches, confections or food has no specific shapes (Cikrikci & Oztop, 2017).

In order to determine the volume of faba bean, a liquid displacement method is appropriate (Mohsenin, 1970; Sitkei, 1976).

Density

Density is the ratio of a material's mass to its volume, and in SI unit, it is kg/m^3 (Srinivasan et al., 2008). For starches, bulk density and loss factor are important. Bulk density is the density of a material packed/stacked in bulk, which is directly related to loss factor for starches (Ndife et al., 1998). Loss factor will be explained in the Sect. 3.1.4.

Porosity

Porosity is another important parameter to characterize in terms of the quality of dry and intermediate moisture foods such as faba beans. It can be calculated by the proportion of the void volume to total volume of a material, and there are three different methods to measure which are namely: direct method, optical method or density method (Sahin & Sumnu, 2006).For instance, porosity of faba beans can be calculated by using the density method (Altuntaş & Yildiz, 2007).

The average size of 87% of Sakiz faba beans *(Vicia faba L. Var. major)* grown in Antalya, Turkey, was found to be 20.39 ± 0.02 mm in length, 14.54 ± 0.12 mm in width and 7.86 ± 0.06 mm in thickness. A digital camera was used to calculate the projected are of the randomly selected Sakiz faba beans which was found as 2.79 ±0.02 cm^2 (Haciseferoğullari et al., 2003). Moreover, weight, volume, sphericity, bulk density, and porosities of faba beans were calculated as 1.31 ±0.02g, 1210 ±16.65 mm^3, 0.651 ±0.003, 608.17 ±4.44 kg/m^3, 51.48 ±0.14%, respectively (Haciseferoğullari et al., 2003). Furthermore, the average length, width, thickness, unit mass of grain, sphericity and porosity of *Vicia faba L.* (Tokat, Turkey) varied between 18.40–19.77 mm, 12.54–13.66 mm, 7.00–8.03 mm, 1.147–1.301 g, 0.63–0.65, 63.09–67.21% respectively (Altuntaş & Yildiz, 2007).

In this section, foundational knowledge of physical characteristics of faba beans is presented. To gain a more in depth understanding, the rheological properties are discussed in the next section.

3.1.2 Rheological Properties of Faba Bean

The deformation of a material including flow is called as rheology (Taguet, 2020). Viscosity is a rheological term which is significant for starchy foods such as cereal (corn, rice), legumes (faba bean, pinto bean), and roots (potatoes, etc.) (Ashogbon & Akintayo, 2014; Santamaria et al., 2021). Therefore, to understand the rheological properties of faba beans, the chemical composition of starch, which is related to the viscosity, starch gelatinization, pasting properties, retrogradation phenomenon and more, needs to be explained.

Starch

Faba bean seeds are rich in carbohydrates and proteins which are between the range of 51–68%, and 30% respectively (Haciseferoğullari et al., 2003; Punia et al., 2019) and the main carbohydrate in faba bean is starch. The concentration range of faba bean starch is between 22–45% (Hoover & Sosulski, 1991).

Native starch, which has the functionality of a thickening agent, binding agent, and provides moisture control. It is composed of two chemicals: amylose and amylopectin (Sofi et al., 2013). Starch in general comprises 20–30% amylose related to the firmness, and 70–80 amylopectin related to staling of the food (Efe, 2018; Srinivasan et al., 2008). Furthermore, the amylose chain is linear and has $\alpha-1,4$ glycosidic linkage, whereas the chemical configuration of amylopectin is branched and has $\alpha-1,4$ and $\alpha-1,6$ glycosidic linkage (Coultate, 2002; Labropoulos & Anestis, 2012). Native starch is not soluble in cold water and is shear thickening (Sahin & Sumnu, 2006; Srinivasan et al., 2008).

Starch Gelatinization and Retrogradation

Starch gelatinization, an endothermic reaction, occurs when a starch slurry reaches a certain temperature and starch granules swell with water irreversibly by breaking down the intermolecular bonds and changing the order within the starch granules (Coultate, 2002; Srinivasan et al., 2008).

Starch retrogradation is another physical parameter, which affects the textural parameter and shelf life of the food (Coultate, 2002; Potter & Hotchkiss, 1995). Retrogradation occurs when there is no heat in the environment during storage, and linear chain of amylose and branched chain amylopectin results in disaggregation to form a different ordered structure (Wang et al., 2015). Since gelatinization and retrogradation are thermal phenomenon, they can be measured by using differential scanning calorimeter (DSC) which will be explained in the Sect. 3.1.3.

Viscosity

Viscosity is resistance to flow/agitation/shear and is basically thickness. As mentioned above, starch is shear thickening fluid (Sahin & Sumnu, 2006).

Viscosity is significant in understanding the behavior of the fluid. In this case the faba bean starch slurry, and viscosity is affected by the granule shape, granular interaction, amylose-amylopectin concentration, and amylose-amylopectin entanglement (Kumar & Khatkar, 2017). Viscosity increases with temperature so there is a direct relation between temperature and viscosity. This is also an indication of the starch stability (Kaur et al., 2010).

Pasting Properties

Pasting is a similar phenomenon to gelatinization, yet somewhat different because pasting occurs after gelatinization when there is excess water in the environment along with heat (Punia et al., 2019). Pasting occurs when the starch slurry is heated with constant rotational stress, which results in swelling similar to gelatinization. These starch granules then burst, and a linear chain of starch, primarily amylose, leaches out of the matrix and creates a viscous paste (Gani et al., 2017; Li et al., 2019; Sofi et al., 2013).

Furthermore, pasting properties can be determined by a Rapid Visco Analyser or Rheometer in order to obtain pasting viscosity profile (Gani et al., 2017). The primary outcomes of these profile are: peak viscosity, breakdown viscosity, final viscosity, and pasting temperature (Balet et al., 2019). Peak viscosity, which is the maximum viscosity, acquired by gelatinized starch in water during heating, shows the water binding capacity of starch granules (Shimelis et al., 2006). Breakdown viscosity, due to the rupture of swollen granules, indicates the stability and resistance of starch granules to sheer force at a constant high temperature (Balet et al., 2019; Sofi et al., 2013). Final viscosity is the plateau viscosity occurring after the holding period at a constant temperature (Balet et al., 2019). Additionally, the final viscosity can be related to the ability of starch to form viscous paste, which has a relation with the tendency of retrogradation of the soluble amylose during the cooling phase (Olkku & Rha, 1978). Viscosity starts to increase at critical temperature, which is called pasting temperature. The higher the pasting temperature, the higher the resistance to swelling and rupture (Kumar & Khatkar, 2017).

The pasting temperature of the faba bean was also found between 70.02 °C (Li et al., 2019; Zhang et al., 2019). Zhang et.al (2019) reported the peak viscosity, breakdown viscosity, final viscosity of faba bean as 3524 ± 60, 1247,±49, and 4814 ± 58 cp, respectively, and the peak time was reported as 4.2 ± 0.0 min. They reported that faba beans showed higher final viscosity than the other types of legume starches (red adzuki bean, baiyue bean and chickpea starches) and indicated that faba beans have a higher tendency of retrogradation during the cooling phase, owing to the recrystallization of leached amylose content (Zhang et al., 2019).

Gel Strength

Gel strength is one of the important textural parameters for starch paste, which can be analyzed in a compression test by using a textural analyzer (Sahin & Sumnu, 2006). The compression test is the method, which measures the distance that the food material can be compressed under a standard force.

Faba bean starch strength was reported as 727.4 g (Li et al., 2019). Strong gel network of faba beans can be correlated with the high final viscosity (Li et al., 2019). Additionally, strong gelling abilities of faba beans can be suitable for industrial food applications, such as producing the firm gels starch gels in jello-type desserts and glass noodles (Ai et al., 2013; Ring, 1985).

3.1.3 Thermal Properties of Faba Bean

Thermal properties are significant for food processing, which is related to the heating or cooling processing. Thermal property data is generated according to the thermal properties of food since the thermal properties are related to the intrinsic properties of food material such as: porosity, density, and composition (Sahin & Sumnu, 2006).

Starch gelatinization, the definition of which was mentioned in Sect. 3.1.2, is an important phenomenon for determining the important thermal parameters by generating gelatinization thermograms by using DSC (Zhang et al., 2019). Gelatinization thermogram shows gelatinization temperature range (ΔT_r), gelatinization enthalpy (ΔH), onset transition temperature (T_o), peak temperature (T_p), and conclusion transition temperature (T_c) (Sahin & Sumnu, 2006). Endothermic peak of DSC thermogram can be linked to starch gelatinization which express the loss of ordered structures, double helices/crystallites, of starch granules (Cooke & Gidley, 1992).

Zhang et al. (2019) reported that ΔT_r, ΔH, T_o, T_p, T_c values of faba beans as 11.09 ± 0.21 °C, 6.68 ±0.07 J/kg, 61.96 ± 0.09 °C, 66.38 ± 0.19 °C, 3.06 ± 0.00 °C respectively. In addition to this, three different type of beans (faba, black and pinto beans), and four different bean varieties in terms of physicochemical properties were studied. Faba bean varieties had lower mean values of ΔH, T_o, T_p, T_c, which are 8.61 ±1.03 J/g, 64.28 ± 0.09 °C, 69.54 ± 1.40 °C, 75.31 ± 1.26 °C respectively, than other bean types which can be related to the abundance of short amylopectin chains (Ambigaipalan et al., 2011; Noda et al., 1996). Additionally, lower T_o, T_p, T_c values mostly related to the perfectness of granule crystallinity (Ambigaipalan et al., 2011; Tester & Morrison, 1990). Sharma et al. (2020) were compared to faba bean starches with the modified faba bean starches. They found ΔH, T_o, T_p, T_c values as 9.47 J/kg, 62.7 °C, 68.4 °C, 73.3 °C for native faba bean starches, respectively, and gelatinization thermograms were shifted to higher temperatures for modified faba bean starches, which can be explained by the increase in cross-linking. The protein content in faba bean starches may cause an extension of endothermic peak, owing to the denaturation of proteins in higher temperatures during the starch gelatinization process (Setia et al., 2019).

3.1.4 Electromagnetic Properties

Color is significant for the consumer acceptance, and electromagnetic properties of foods are important for food applications such as microwave and radio frequencies. In this section, color systems and dielectric properties (dielectric constant and loss factor) of faba beans will be discussed.

Color

Color is important for food quality and consumer acceptance. Color can be measured by spectrophotometry and colorimeters. There are five types of color systems used for food systems which are: Munsell, CIE, CIE L^* a^* b^*, (CIELAB), Hunter Lab, and Lovibond. The most common methods are CIE L^* a^* b^* and Hunter Lab (Sahin & Sumnu, 2006). These methods help to determine the amount of red, green, and blue and match almost any spectral color by the different amount of light (Francis, 1983). CIELAB system is one of the more uniform, and it has more useful and accepted color describing. CIELAB has a color coordinating system which is represented as L^* a^* b^*. L^* represents lightness from 0 (L^* = 0, darkness) to 100 (L^* = 100, lightness), a^* represents the difference between red (+a^*) and green (−a^*), b^* represents the difference between yellow (−b^*) and blue (−b^*) (Efe, 2018). Moreover, the Hunter Lab color system, similar to CIELAB color system, is also based on L, a, b measurements. L value shows lightness from black (0) to white (100), a value represents greenness (−a) and redness (+a), and b value represents the blueness (−b) and yellowness (+b) (Sahin & Sumnu, 2006). Sofi et al. (2013) used the Hunter Lab color system to measure the color values of native and irradiated faba bean starches. They found the L, a, b values as 96.67 ± 0.50, 0.65 ± 0.12 and 6.02 ± 0.21 for native faba bean starch respectively (Sofi et al., 2013), and the yellowness value increased with the increased gamma irradiation due to the caramelization reaction caused by polysaccharide degradation during irradiation (Greenwood & Mackenzie, 1963).

Dielectric Properties

Dielectric properties, which are the dielectric constant and loss factor, are important properties for food to store energy during heating with microwaves or radiofrequency.

- Dielectric constant is the ability to absorb and store energy.
- Loss factor is the ability of a material to dissipate the energy into heat (Bou-Orm et al., 2021).

Dielectric properties are functions of temperature, moisture content and composition of the food material. For example, proteins, starches, and triglycerides have low dielectric activities; on the other hand monosaccharides, free water, or ions have high dielectric activities (Shukla & Anantheswaran, 2001). Therefore, moisture content has a direct relation with the dielectric constant and loss factor (Sahin & Sumnu, 2006). Furthermore, starch concentration has an indirect relation with the dielectric constant and loss factor due to the fact that starch molecules bind water molecules and decrease the amount of free water (Ndife et al., 1998). Lastly, bulk density and loss factor have a direct relation for granular starches as well (Sahin & Sumnu, 2006).

3.1.5 Water and Related Water Properties of Faba Bean

Water is the only chemical compound that is commonly found in solid, liquid and vapor forms in earth. It is composed of two hydrogen atoms and one oxygen atom, and it has a molecular weight of 18 g/mol (Ergun et al., 2010). Water is a polar molecule that is capable of forming a hydrogen bond that is stronger than van der Waals and it has nearly tetrahedral orbital arrangement, which allows water to have specific features (Ergun et al., 2010; Srinivasan et al., 2008).

Water can be found in the food system either in free or bound form (Mathlouthi, 2001). Free water is found in capillaries, but bound water is physically adsorbed to the surface of dry material (Sahin & Sumnu, 2006). Water content can be determined by many methods such as physical separation, chemical reactions, chromatography, and spectroscopy (Nuclear Magnetic Resonance (NMR) spectroscopy, near infrared (NIR) (Efe et al., 2019; Mathlouthi, 2001) and in this section solubility, swelling power, syneresis, and freeze-thaw properties of faba bean will be explained.

Solubility

Solubility is related to the presence of soluble molecules such as amylose (Tester & Morrison, 1990). High solubility means that when there is high amylopectin content in the starch granules, hydrogen bonds can be easily weakend. Solubility (%) of faba bean was reported as 2.29 ±0.05, 2.71 ± 0.07, 6.67 ± 0.15, 8.18 ± 0.03, 9.92 ± 0.09 for 50 °C, 60 °C, 70 °C, 80 °C, 90 °C respectively (Zhang et al., 2019). Zhang et al. (2019) also explained the rapid increase of solubility after 70 °C owing to the higher disorganization of starch granules around gelatinization temperature. Additionally, solubility (%) of native faba bean was reported between 1.06–20.60% and there were a rapid increase in solubility with respect to temperature (60–90°C) (Sharma et al., 2020). They also reported that, cross-linked faba bean starches (modified faba bean starches) had a reduced solubility due to the presence of cross-linking. Cross-linking caused an increase in the density of faba bean starches, which resulted in the reduction of the solubility because of the breakdown of starch granules upon gelatinization (Sharma et al., 2020).

Swelling Power

Swelling, which indicates the water holding capacity, is the ability of the starch to hydrate under specific conditions, such as: water content, and temperature (Crosbie, 1991; Zhang et al., 2019). Starch granules having greater swelling capacity will have weaker binding forces (Hoover & Manuel, 1996). Swelling power can be dependent upon intramolecular/intermolecular forces and amylose/amylopectin content since amylose act as a starch-swelling inhibitor (Hoover & Manuel, 1996; Tester & Morrison, 1990). Swelling power may increase with temperature, which can be related to the mobility of amorphous region due to the melting of double helices present within the amorphous and crystalline domains in starches (Ratnayake et al., 2001). Swelling power (g/g) of the faba bean was reported with the rate of temperature from 50°C to 90 °C with 10 °C increments as 1.09 ±0.05, 1.13 ± 0.19, 6.85 ± 0.15, 10.29 ± 0.36, 12.67 ± 0.02 respectively, and they also reported a rapid increase of swelling power between 70–90 °C (Zhang et al., 2019). Furthermore, swelling power of native faba bean starches and modified faba bean starches were reported between the range of 2.27 and 12.50 g/g, and swelling power was increased with respect to temperature (Sharma et al., 2020). The increase in cross-linking in faba bean starches and modified faba bean starches caused a reduction in swelling power by increasing the intramolecular and intermolecular forces between amylose and amylopectin chains, therefore preventing swelling of the starch granules (Sharma et al., 2020).

Syneresis & Freeze-Thaw Stability

The nature of starches is that they have a tendency to retrograde and undergo syneresis, affecting the quality and shelf life of the product such as the gel texture or film forming abilities of the starch paste (Ashogbon & Akintayo, 2014). The definition of retrogradation was mentioned in Sect. 3.1.2, and syneresis happens after the gelling network becomes more compact due to the growth of the junction zones in the network and reorganized the structure. The physical appearance will be seen as fluid droplets on the gel surface (Srinivasan et al., 2008). In other words, less polymer interaction with water molecules resulted in disaggregation of amylose/amylopectin, and is followed by a re-association of starch molecules in order to form more compact network are called as retrogradation and syneresis (Ilhan et al., 2020; Srinivasan et al., 2008; Wang et al., 2015). Native faba bean starch gels that increase in syneresis and gamma irradiation (15 kGy) may decrease the syneresis with respect to time (120 h) (Sofi et al., 2013).

Freeze-thaw stability is another important physical characteristic for starches in food industry because slightly cross-linked starches, called pre-gelatinized starches, can be used for various food products such as: instant soup, breakfast cereals and extruded snacks (Srinivasan et al., 2008). The freeze-thaw stability for native faba bean starch was reported as 6.84 ± 0.36, 22.08 ± 1.54, 28.92 ± 3.05, 33.22 ± 0.27, 35.16 ± 1.77, 41.77 ± 2.36 for 0, 1, 2, 3, 4, 5 thaws respectively (Sofi et al., 2013).

3.1.6 Morphological Characteristic of Faba Bean

Morphological characteristics of faba beans can be determined by using powerful tools such as an X-ray diffractometer, scanning electron microscopy (SEM), light microscopy (LM) confocal laser scanning microscopy (CLSM), and polarized light microscopy (PLM) and more (Punia et al., 2019; Zhang et al., 2019). Crystal packing arrangements can be found by using an X-ray diffractometer, and starch granule shapes, size, and distribution of amylose/amylopectin can be determined by using LM, SEM, CLSM, respectively. The shape of faba bean starches was found as round, elliptical, oval, and irregular under SEM (Ambigaipalan et al., 2011; Sofi et al., 2013). According to Zhang et al. (2019), faba bean starch granules had diameters between 10 and 30 μm. They also found many cracks or fissures on the surface of faba bean starch granules under LM and SEM. Cracking may reflect low granule integrity due to the weak interaction between amylopectin chains (Ambigaipalan et al., 2011). Additionally, faba bean starches exhibit both strong and weak birefringence patterns. Having weaker birefringence indicates disorganized amylopectin double helices within crystalline lamella under PLM (Ambigaipalan et al., 2011).

The X-ray diffraction method is a little different from the light microscopies because it is used in the determination and refinement of the crystal structure of conventional crystalline materials in nanomeric size. Starch is composed of amylose and amylopectin. Two diffraction patterns were observed for different starch patterns, A-amylose and B-amylose. A-amylose structure has right-handed parallel stranded packed double helices whereas B-amylose structure has left-handed double helices packed in parallel fashion (Rodriguez-Garcia et al., 2021). A-amylose can be called an A-type starch, and B-amylose can be called a B-type starch. C-type have both A and B type patterns in different proportions in the structure (Ambigaipalan et al., 2011). Faba bean starch shows C-type X-ray crystalline pattern with the 15.18°, 17.04° and 23.18° diffraction peaks at 2θ and degree of crystallinity (%) was reported as 18.50 ±0.73 (Zhang et al., 2019).

The summary of all physical characteristics of faba bean (FB) and faba bean starch (FB starch) is shown in Table 3.1.

Table 3.1 Physical properties of faba bean (FB) and faba bean starch (FB starch)

FB and FB starch	Characteristics	Source
Size	Length = 20.39±0.02 mm, width = 14.54±0.12 mm, thickness = 7.86±0.06 mm	Haciseferoğullari et al. (2003)
Projected area	2.79 ± 0.02 cm^2	Haciseferoğullari et al. (2003)
Weight	1.31 ±0.02 g	Haciseferoğullari et al. (2003)
Volume	1210 ± 16.65 mm^3	Haciseferoğullari et al. (2003)
Sphericity	0.651 ± 0.003	Haciseferoğullari et al., (2003)
Bulk density	608.17 ± 4.44 kg/m^3	Haciseferoğullari et al. (2003)
Porosity	51.48 ± 0.14%	Haciseferoğullari et al. (2003)
Pasting properties	Peak viscosity = 3524±60 cp, breakdown viscosity = 1247±49 cp, Final viscosity = 4814±58 cp, peak time = 4.2±0.0 min, Pasting temperature = 70.02 °C	Zhang et al. (2019)
Gel strength	727.4 g	Li et al. (2019)
Thermal properties	ΔT_r = 11.09 ± 0.21 °C, ΔH= 6.68 ±0.07 J/kg T_o = 61.96±0.09 °C, T_p = 66.38± 0.19 °C, T_c = 73.06±0.00 °C	Zhang et al. (2019)
Color	L = 96.67 ± 0.50, a = 0.65 ± 0.12, b = 6.02 ± 0.21	Sofi et al. (2013)
Solubility	1.06–20.60% with respect to temperature (60–90 °C)	Sharma et al. (2020)
Swelling power	12.67 ± 0.02 g/g at 90 °C	Zhang et al. (2019)
Freeze-thaw stability	6.84 ± 0.36, 22.08 ± 1.54, 28.92 ± 3.05, 33.22 ± 0.27, 35.16 ± 1.77, 41.77 ± 2.36 for 0, 1, 2, 3, 4, 5 thaws respectively	Sofi et al. (2013)
Granule morphology	C-type pattern	Zhang et al. (2019)

3.2 Milling Characteristics of Faba Bean

Milling can be defined as the process to break down materials, such as cereal or pulses, into smaller pieces and at the end into flour. A general milling process is given in Fig. 3.2. The milling process produces a food product, suitable for use after cooking processes, from raw material and this can be mainly examined in three titles: namely, decortication, splitting, and dehulling.

3.2.1 Milling Process

3.2.1.1 Decortication

Pulse seeds have three main parts: The inner part is the embryo that is going to sprout. The following part is cotyledons that contain the energy sources for embryonic growth in the form of protein bodies and starch granules. Pulses are dicots that have two separate cotyledon halves in the seed. The outer part is the seed coat that protects the seed (Fig. 3.3). These two cotyledons, the embryo, and the coat stand together in what is called a “whole pulse”.

To remove the coat from a whole pulse is called decortication. After this process, the two cotyledons remain together around the embryo. However, while

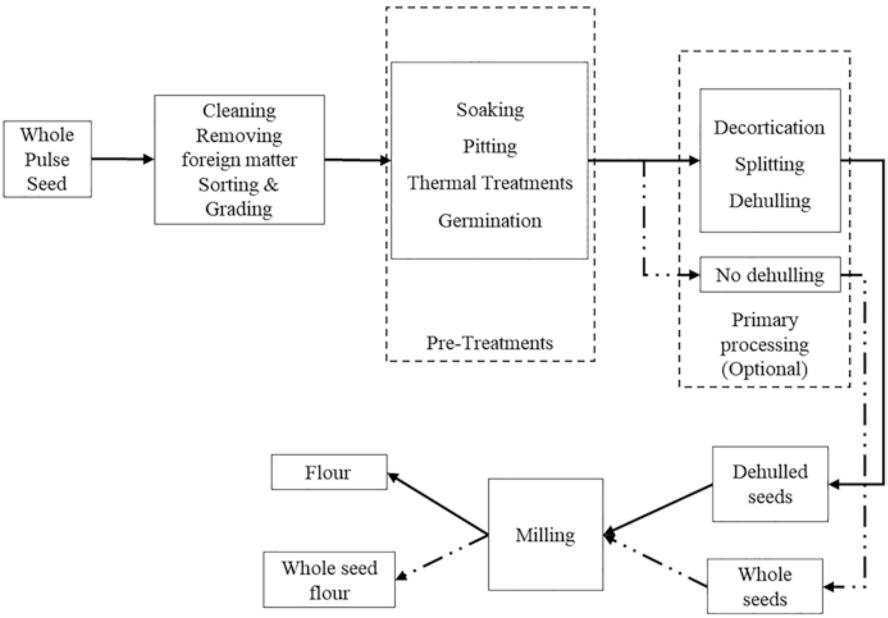

Fig. 3.2 The general pulse milling process. (Adapted from Sharan et al. (2021))

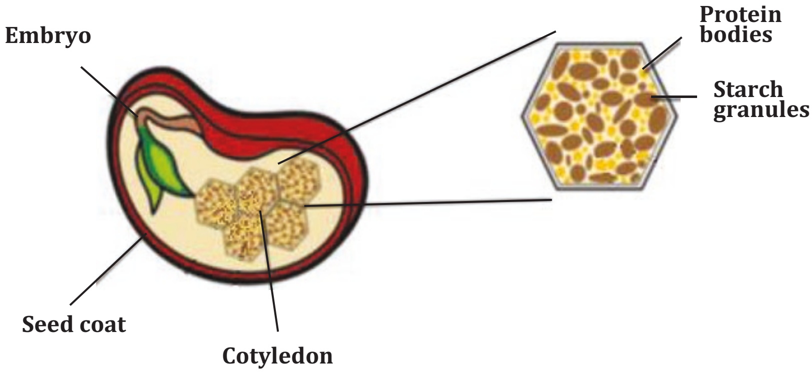

Fig. 3.3 The general structure of a pulse seed and cotyledon (Pallares Pallares et al., 2021)

two cotyledons of decorticated seeds remained attached, only cotyledons are very tightly held together. Therefore, decortication of the faba bean requires attention and care to prevent the splitting of cotyledons. As a result, decorticated faba beans can be classified as a premium product (Wood & Malcolmson, 2021). The reported advantages of the seed coats' removal can be listed as follows: (Dhull et al., 2021; Ravi & Harte, 2009; Saldanha do Carmo et al., 2020; Sharan et al., 2021; Thakur et al., 2019; Vishwakarma et al., 2018; Wood & Malcolmson, 2021).

- Increase in protein and amino acid content
- Reduction of anti nutritional factors (ANFs) such as phytates, protein-based enzyme inhibitors, lectins, tannins, etc. Therefore, the nutritional quality increases with the increased bioavailability and digestibility.
- Reduction in cooking time
- Increase in vitamin content (proportionally)
- Decrease in intestinal gas production due to the reduction of oligosaccharides (raffinose family) content
- Ease of milling

On the other hand, there are some disadvantages of the decortication process, reported as: the reduction in dietary fiber content, the mineral content, and the process also causes the minerals to mix into the cooking water during cooking (Wang et al., 2008, 2010).

3.2.1.2 Splitting

In the splitting process, the decorticated faba beans are separated into two cotyledons and this process generally occurs simultaneously as mentioned in the next title.

3.2.1.3 Dehulling

Dehulling is a process that removes the seed coat and splits the two cotyledons from each other simultaneously. Dehulled faba beans (in general, dehulled pulses) are called “dhal” or “dal” (Wood & Malcolmson, 2021). In South Asia, Egypt, Syria, and Turkey, dhal production is a common process. In India especially, 75% of the total pulses, also faba bean, are consumed as dhal (Rodiño et al., 2011; Vishwakarma et al., 2018). Although dehulling can be applied to any pulses, most of the beans are generally not dehulled and split to produce dhal (Wood & Malcolmson, 2021).

Dehulling and splitting have an additional advantage to the decortication, since the cotyledons are separated from each other, flatter products are formed, which reduces the storage area and respectively, storage and transportation costs (Wood & Malcolmson, 2021).

Faba beans, like all other pulses, are a major source of polyphenols. Since pulses are a rich source of protein and dietary fiber, they show a good nutritional value. In addition, polyphenols are one of the major components in the pulse seeds in the form of tannins, phenolic acids, and flavonoids. Anthocyanins are flavonoid structures mainly responsible for the seed and seed coat color. Besides their nutritional value, they contain a high amount and variation of antinutrients. Phenolic compounds (tannins, phytic acids or phytates, etc.), enzyme inhibitors, saponins, and lectins are some of the important ANFs in the pulse seeds, and their amount may vary both with the pulse types also in species level. Although most of the phenolic compounds are found in the cotyledons in faba beans, tannins are the most abundant (72–82% percent of the total phenolics of the seed coat) phenolic compounds in seed coats (Sharan et al., 2021). During the decortication or dehulling step, tannins are removed with the removal of hulls. Although tannins are classified as an antioxidant, they can bind protein structures and decrease their digestibility (Wang et al., 2010). With similar effects to tannins, phytates have an affinity to bind minerals, especially iron, and decrease mineral absorption and thus mineral bioavailability (Albuquerque et al., 2020). Since both phytate and tannins are mainly located in the seed coat, decortication and dehulling decrease tannins and phytate content, thus, protein absorption and mineral bioavailability increase, respectively (Albuquerque et al., 2020; Ravi & Harte, 2009). In addition, germination is stated as the most effective pre-treatment method to decrease the phytate level among the conventional (soaking, dehulling, etc.) and innovative (extrusion, microwave heating, etc.) pre-treatments independent from pulse types (Patterson et al., 2017).

3.2.1.4 Milling or Grinding

Milling is a process to reduce whole faba beans or dhal into flour. While faba flour can be used for food preparation, it can also be a raw material to produce protein or starch isolates. Processing types and conditions affect the product quality, efficiency, and functionality both of faba flour and protein or starch isolates (Jiang et al., 2016; Luo & Xie, 2013; Sharan et al., 2021; Sosulski & McCurdy, 1987; Thakur et al., 2019).

Faba bean primary processing (decortication, splitting, or dehulling) is an old processing method. Thus, several pre-treatments or variations in processing were developed to ease the primary processing, increase the decortication and dehulling efficiency, and dhal yield or modify the content and functionality of the isolates (Ravi & Harte, 2009).

After primary processing, milling or grinding may be applied to the seed or dhal to produce flour. The milling process can be generally separated into two main types: wet and dry milling. Milling can be conducted with different equipment, namely: stone mill, roller mill, pin mill, etc. (Thakur et al., 2019). These milling methods have different milling efficiencies and flour functional properties with respect to pulse types.

Several studies can be found in the literature that examines different pulse flours produced by using different milling methods. Guldiken et al. (2022) have compared the effect of the different mills (a knife mill and a roller mill) on the physicochemical properties of green lentil and yellow pea. In brief, they conclude that some of the flour functional properties, such as oil absorption capacity, starch gelatinization, etc., are affected by the particle size and starch damage level which may be altered by changing the mill type for a pulse. In the study, the knife mill produces a larger particle size in both green lentil and yellow pea. It is also seen that coarse flours (flour with larger particles) have a smaller amount of damaged starch, especially for green lentil. The main reason for the starch damage is the mechanical impact of milling (Pulivarthi et al., 2021). The protected structure of starch results in low viscosity, high oil absorption capacity, and high starch gelatinization values (Guldiken et al., 2022). In another study conducted by Maskus et al. (2016), the roller, pin (coarse and fine), hammer, and stone mill are compared throughout the particle size of yellow pea flour and the functional property alteration of these flour are evaluated. The particle size produced by different mills can be sorted from largest to smallest as: stone mill, hammer mill, coarse-pin mill, roller mill, and fine pin mill. Similarly, the smallest and most uniform particle size causes the highest starch damage, highest viscosity, and lowest water absorption capacity of whole yellow pea flour (Maskus et al., 2016). The study of Pulivarthi et al. (2021) on the red lentil and yellow pea flours shows that by adjusting the milling setting of a mill, final product properties and functionality can be altered due to changes in flour particle size. They gradually decrease the particle size of pulses and examine the mechanical effect of the milling. They highlight that flour moisture content decreases with the decrease in particle size due to increasing heat generation, especially in the production of fine flour (Pulivarthi et al., 2021).

The effect of the milling method depends on the pulse morphological and mechanical characteristics (will be discussed later) as well as the mechanical forces applied by the mill. The main forces applied in the milling process are: impact, compression, shear, and friction forces. Mills may use these forces separately or combined for grinding. Therefore, milling methods should be selected according to the pulse types and the desired functionality of the final product (Wood & Malcolmson, 2021).

3.2.1.4.1 Wet Milling

In wet milling, whole pulses are soaked in water and absorb a high amount of liquid, so the seeds are softened and then dried back to an appropriate moisture content to mill. This soaking and drying process is called wet milling.

Wet milling is generally used to produce flour used in starch isolation because starch isolation effectiveness and efficiency increase during wet milling (Punia et al., 2019). The detailed mechanism will be explained in the section on soaking.

In addition, wet milling may have detoxification effects on the seeds and the resulting products, such as flour or isolates (Boye et al., 2010).

3.2.1.4.2 Dry Milling

In dry milling, tempering with the addition of a small amount of conditioning agent that is conducted to the seed to optimize hull removal and particle size after the milling process (Saldanha do Carmo et al., 2020). For the easy-to-mill pulses or varieties conditioning may be applied directly, but for the hard-to-mill varieties pitting should be considered as an additional step. Since the absorption of conditioning agents (water, or oil) is limited for the hard seeds, partial destruction of seed coat or pitting may be required to increase it (Wood & Malcolmson, 2021). After conditioning, seeds are dried before milling. The conditioning/tempering moisture content is crucial, so this process may be prolonged up to 12 h because broken kernel in dry milling can decrease the dhal production efficiency (Saldanha do Carmo et al., 2020). However, the dry milling process produces higher quality dhal and is more suitable to produce flours used in protein isolation than wet milling (Wood & Malcolmson, 2021).

3.2.1.4.3 Drying

In both wet and dry milling techniques, seeds should be dried to a moisture content appropriate for milling. For faba beans this is generally 13% (Setia et al., 2019; Wood & Malcolmson, 2021). Along with sun-drying, hot-air drying may be applied. While sun-drying is a less expensive method, hot-air drying has more control over the final product characteristics. In both drying methods, prolonged and excessive heat treatment may decrease the splitting efficiency and final product sensorial quality (Wood & Malcolmson, 2021).

3.2.1.4.4 Pre-treatments

The processing of V. faba has been widely studied in the cited literature. However, most studies are focused on after the milling process. In other words, the focus is on extraction of protein and starch from faba beans to change the functionality and yield of the isolates (Sharan et al., 2021). These post-milling processes can be called wet and dry processing or fractionation (Wood & Malcolmson, 2021). Also, many studies are focused on the effect of pre-treatments on nutritional profile and the ANFs content of faba beans rather than milling properties. Therefore, the effects of storage conditions or pretreatments on the milling characteristics of faba bean have still need further studies (Thakur et al., 2019).

Soaking

Soaking is a process in which the seeds are immersed in water to absorb it. Excess water provides the hydration of the whole seed and softens it. The processing time and temperature can vary and be applied to soften and swell the seeds. Processing time for dry seeds is up to 16 h at room temperature. However, soaking at a temperature up to 100 °C can shorten soaking times (Pallares Pallares et al., 2021). Kurien and Parpia (1968) reported that the longer soaking time can cause a hollow heart between faba bean cotyledons that ease the splitting, but reduce the quality and acceptance of dhal. Also, although long soaking eases milling, the broken cotyledon percentage increases and may result in an unacceptably firm dhal after cooking (Wood & Malcolmson, 2021). Setia et al. (2019) revealed that soaking changes the protein, starch, and fiber interaction resulting in altering the matrix. Starch granules are entrapped by the protein-fiber matrix in raw faba bean cotyledons and granules have no surface contact. This entrapment of starch granules by fiber-protein matrix prevents water absorption by granules, and swelling. During soaking, while cotyledons are absorbing water and swelling, the protein-fiber matrix is disrupted and more starch granules are released. After soaking, the faba bean seeds are dried back to a 13% moisture content before dehulling. The fiber-protein matrix loosens physically, and drying after soaking prevents the restoring of the dense matrix. Therefore, soaking eases the removal of hulls by loosening the attachment between the hulls and cotyledons, increases the dehulling efficiency, and increases the removal of the protein-fiber matrix from the starch granules during milling that develops the flour characteristics such as viscosity increasing and pasting due to increasing water absorption and swelling ability of starch granules (Anderson et al., 1994; Brummer et al., 2015; Chung et al., 2008; Setia et al., 2019). Also, dissolution of the fiber-protein matrix with soaking prior to drying produces a more porous structure which also eases the fragmentation during pulse flour milling (Wood & Malcolmson, 2021).

From the nutritional point of view, soaking does not have any significant impact on macronutrient content such as protein or starch, but it can decrease the phytate content – main ANFs in faba bean- by removal with the soaking solution. Thus, the reduction of phytate content may result in increased iron bioavailability and protein digestibility (Dhull et al., 2021; Setia et al., 2019). Sharma and Sehgal (1992) report that soaking and dehulling provide the removal of saponin by 26–29% and phytic acid by 4%, but any loss in lectins content is not observed.

Soaking can also be conducted by using different liquids, such as edible oils (soybean oil, sesame oil, palm oil, etc.) or aqueous solutions (sodium bicarbonate solution, acetic acid solution, sodium chloride solution, etc.) (Vishwakarma et al., 2018). Pre-treatment with edible oil may ease the dehulling and reduce the cooking time compared to water soaking. Aside from the mechanism, soaking with edible oil is not well-established. Theoretically, edible oils dissolve the gums between the seed coat and cotyledons and ease the removal of the hull. However, edible oil may have an excessive loosening effect on the cotyledon structure so that during dehulling, cotyledon may be broken or powdered which increases the dehulling losses. Therefore, the edible oil concentration should be adjusted according to the seed structure, and the oil penetration through the seed coat may be provided by pitting the seed coat prior to oil application (Vishwakarma et al., 2018).

Another soaking method is aqueous chemical solution soaking. Different aqueous solutions for soaking purposes such as sodium carbonate (Na_2CO_3), sodium bicarbonate ($NaHCO_3$), and sodium chloride (NaCl) may induce faster softening and thus decrease the cooking time, especially when used in combination with the thermal process (Pallares Pallares et al., 2021). In addition, a study conducted with pigeon peas soaked in NaHCO3 and NaCl solutions resulted in an increase in dehulling efficiency in pigeon peas (Vishwakarma et al., 2018). Also, it is seen that the cooking time of cowpeas reduces when soaked in $NaHCO_3$ (Ávila et al., 2015). Li et al. (2019) report that alkaline solution usage for soaking increases the faba bean starch isolation. However, soaking in salt solutions is not very commonly studied with the pulses or used in industrial production, due to an increase in powdered or broken material ratio and nutritional loss (Vishwakarma et al., 2018).

Thermal Pre-treatments

Conventional (oven) heating, microwave heating, and roasting are some of the methods used as thermal pre-treatment of faba beans before milling (Jiang et al., 2016). Like the other pulses, the faba bean contains a high number of endogenous enzymes, which may result in a 'beany' flavor in the final product. Enzymes responsible for the beany flavor in the faba bean are mainly lipoxygenase and peroxidase, which can be inactivated by thermal pre-treatments (Jiang et al., 2016; Rahate et al., 2021; Wood & Malcolmson, 2021). One of the most important endogenous enzymes in plants are peroxidases, due to high heat stability. Therefore, in the thermal pre-treatment efficiency determination studies, generally, peroxidase activity is targeted and monitored (Akyol et al., 2006; Jiang et al., 2016). In the study by Jiang et al. (2016), it is shown that conventional and microwave heating decreases the peroxidase activity while causing a decreased protein extraction rate and loss of protein solubility. Also, enzyme inhibitors, such as trypsin, or amylase, are part of ANFs can be deactivated during thermal pretreatment. Therefore, loss of macromolecule digestibility could be prevented (Pallares Pallares et al., 2021).

In addition to product characteristics, milling properties are also affected by heat treatments. In the same study, milling quality is defined with seed hardness and flour particle size distribution, and it is seen that thermal treatments decrease the faba bean seed hardness and produce easy-to-mill seeds. As expected, flour particle size became finer and the milling quality of thermally pretreated faba bean improved (Jiang et al., 2016). Also, roasting faba beans as a pre-treatment may increase the milling quality by increasing dehulling efficiency (Anderson et al., 1994; Dhull et al., 2021). The study of Anderson et al. (1994) found dehulling efficiency has an increasing trend while increasing roasting temperature and decreasing roasting time. In another study conducted by Young et al. (2020), roasting is used as a pre-treatment process for yellow pea milling, and high protein content and low starch values are observed for all roasted pea flours compared to unroasted ones. Also, it is seen that roasting may decrease the starch damage during milling. Starch damage decreases with the increased roasting temperature due to partial disruption of starch surfaces during thermal treatment, which eases the particle size reduction and thus decreases the damages of starch granules (Young et al., 2020).

Germination

Germination has a very similar effect to soaking. Especially after soaking, germination deepens the fiber-protein matrix destruction and increases the surface faba starch granules. Also, it is thought that the activity of faba bean endogenous hydrolases increase the loosening of this matrix. However, the study of Setia et al. (2019) showed hydrolases had not effect on the starch structure. Therefore, it can be said that germination has no damaging effect on starch granule structure or swelling characteristics rather than liberating more of the starch granules from the protein-fiber matrix (Setia et al., 2019).

In addition to improvement in milling properties, germination has nutritional effects. Pulses contain different types and high amount antinutritional factors (ANFs), such as oligosaccharides, favism factor, trypsin inhibitors, lectins, tannins, etc. Among all pulses, faba beans have a considerable amount of lectin. Besides conventional cooking, partial germination and sprouting can reduce lectin amounts and thus the abdominal pain caused by gas production after human consumption (Dhull et al., 2021). On the contrary, germination may cause some adverse effects on baking properties, such as high starch damage, low viscosity, high water absorption, and decreased loaf volume for peas and lentils. However, it is stated that germination pre-treatment has not had that effect on the faba bean or its products (Wood & Malcolmson, 2021).

During germination faba starch is used as an energy source, so while starch digestibility is increasing, starch, phytic acid, and tannin content are reduced, protein content is elevated, and the activity of inhibitors is reduced (Beleia et al., 1993; Dhull et al., 2021).

Enzymatic Pre-treatment

Enzyme treatment aims to ease the dehulling process and increase dehulling yield. For this purpose, hydrolases are used to partially break down the bond between the seed coat and cotyledon. During enzymatic treatment, the moisture content and process temperature should be controlled to optimize the partial hydrolysis process. In the study of Sreerama et al. (2009), xylanase and protease pre-treatments were applied to several pulses (green gram, horse gram, black gram, and pigeon pea) and it is seen that both enzymatic pre-treatments have a significant effect on easing of dehulling green gram, black gram and pigeon pea. However, enzymatic pre-treatments cause the degradation of structural materials and may affect the final product quality. Since the literature is not very broad about enzymatic pre-treatment and its results, industrial application of enzyme pre-treatment is not common (Vishwakarma et al., 2018).

3.2.2 The Effect of Faba Bean Characteristics on Milling Properties

Value-added pulse products can be produced by primary processing besides the production of pulse protein and starch isolates. Therefore, dehulling, splitting, and milling process and their efficiencies gain importance. Milling process efficiency has been affected by pulse variation and seed characteristics as well as the pretreatment processes explained earlier (Wood & Malcolmson, 2021). The milling properties of different phenotypes may depend on the seed size and shape, seed coat and cotyledon content, seed coat to cotyledon ratio, seed moisture content, hardness, etc. (Wood & Malcolmson, 2021).

3.2.2.1 Variety and Morphology of the Seeds

The variety-depending dehulling and milling efficiencies of the pulse are generally originated by gum content between the seed coat and cotyledons. When the gum content increases in a variety, removal of seed coat becomes more difficult so dehulling efficiency decreases while broken dhal and powdered material ratio changes within the varieties. Studies reveal that several peas (field pea, pigeon pea, and cowpea) and green gram have also a varietal effect on dehulling efficiency (Vishwakarma et al., 2018). Also, the chickpea is one of the most studied pulses to observe the effect of the cultivar (Desi and Kabuli) on milling property. In several studies including Ravi and Harte's (2009), it is seen that among the cultivars, Kabuli-type chickpea has higher ash, protein, and fat content. However, it has lower dehulling efficiency and higher powder content due to low fiber and starch content. The effect of seed protein content is also reported in another study conducted on red lentil as increasing protein content or decreasing starch content, decrease the dehulling efficiency (Wang, 2008).

Seed size of the same pulse variety has a different effect on dehulling efficiency. Several studies were conducted with different pulse varieties, and the results from these studies show that pigeon pea, cowpea, and green gram show higher dehulling efficiency with decreasing seed size. Lentils and field peas show higher dehulling efficiency with increasing seed size, and it is seen that seed size of chickpea does not affect dehulling efficiency (Wang, 2008; Wang et al., 2008).

Faba bean *(Vicia faba)* specie has two main varieties, namely, *Vicia faba L. major* (broad bean, large-sized faba beans), *Vicia faba L. equine* (medium-sized faba beans), and *Vicia faba L. minor* (horse, tick bean, small-sized faba beans) (Nadal et al., 2003; Pietrzak et al., 2016; Sharan et al., 2021; Wood & Malcolmson, 2021). Although three varieties are reported, studies are focused generally on two varieties, major and minor (Holopainen-Mantila et al., 2021; Wood & Malcolmson, 2021). These two phenotypes differ from each other by the size and shape of their seeds (Holopainen-Mantila et al., 2021). The shape of the pulse seed can be spherical, cylindrical, flat-oval, or pyramidal as a characteristic of the pulse type. These different morphologies affect both dehulling and splitting characteristics. More spherical and small varieties have higher dehulling and splitting efficiency than the longer and larger varieties, which can be easily broken during splitting, especially (Vishwakarma et al., 2018; Wood & Malcolmson, 2021). Also, sharper edges of the seed may more easily broken and reduce the dhal efficiency and flour yield (Vishwakarma et al., 2018).

In milling, more elliptical and regular-shaped varieties show higher milling efficiency and homogeneous particle size due to increased contact area with the mill (Wood & Malcolmson, 2021).

3.2.2.2 Mechanical Properties

Several studies conducted on different pulses revealed that the milling of harder pulses results in smaller flour particle size regarding average volume particle diameter (Dhull et al., 2021; Indira & Bhattacharya, 2006; Thakur et al., 2019). Pulses are classified according to their seed hardness as easy-to-mill and difficult-to-mill. While lentils, desi chickpea, field pea, are generally classified as easy-to-mill, Kabuli chickpea, pigeon pea, cowpea, mung beans, and black gram are classified as difficult-to-mill (Thakur et al., 2019; Vishwakarma et al., 2018; Wood & Malcolmson, 2021).

Seed moisture content is one of the main factors affecting seed hardness. High moisture content decreases the seed hardness regardless of pulse-type (Vishwakarma et al., 2018). Moisture content also affects the cotyledon strength, seed coat brittleness, and gum adhesiveness which may alter the dehulling and milling yield (Fernando, 2021). Similarly, in the literature it is stated that lower faba bean seed moisture content results in finer particles due to increasing brittleness (Pelgrom et al., 2015; Wood & Malcolmson, 2021). However, higher moisture content from a critical level differs for different pulses, because the seed coats and cotyledons are smashed rather than ground. Therefore, drying pulse seeds to an optimum moisture content before milling is crucial (Wood & Malcolmson, 2021).

Seed content is another reason for the alteration of seed hardness. In the study of Pelgrom et al. (2015), pea, bean, lentil, and chickpea are compared to each other for seed composition, seed size, and moisture content. They highlighted that seed hardness may be affected by the type and amount of insoluble fiber, as well as the seed moisture content. In addition, the study of (Wood et al., 2017) shows that not only the amount, but also the location of fiber, influences the milling properties.

Also, the hull and cotyledon ratio of the seeds can influence the milling characteristics. Since faba bean hulls contain a high amount of fiber, it affects the milling yield and thus whole pulse flour has a larger particle size (Wood & Malcolmson, 2021).

3.3 Conclusion

Faba beans are generally round in shape and the size of faba beans was found to be 20.39 ± 0.02 mm in length, 14.54 ± 0.12 mm in width, and 7.86± 0.06 mm in thickness. Projected area was found as 2.79 ±0.02 cm^2. Furthermore, weight, volume, sphericity, bulk density, and porosities of faba beans were calculated as 1.31 ±0.02g, 1210 ±16.65 mm^3, 0.651 ±0.003, 608.17 ±4.44 kg/m^3, 51.48 ±0.14%, respectively (Haciseferoğullari et al., 2003). Moreover, to understand the rheology, viscosity, gelatinization and pasting properties of faba beans were discusses. Peak viscosity, breakdown viscosity, final viscosity, and peak time of faba bean were determined as 3524 ± 60, 1247,±49, and 4814 ± 58 cp, 4.2 ± 0.0 min respectively by using a Rapid Visco Analyser (Zhang et al., 2019). Faba bean starches were compared with red adzuki bean, baiyue bean and chickpea starches and faba bean starch showed higher final viscosity than the other types of legume starches. Higher viscosity of faba bean starches was explained by higher tendency of retrogradation during the cooling phase, owing to the recrystallization of leached amylose content. Higher final viscosity can be correlated to higher gel strength, which was reported as 727.4 g for faba bean starches (Li et al., 2019). Furthermore, the thermal behavior of faba bean was determined by DSC and faba bean showed lower mean values of ΔH, T_o, T_p, T_c, which can be related to the abundance of short amylopectin chains and perfectness of granule crystallinity. Lastly, faba bean starches had round, elliptical, oval, and irregular shape under SEM and starch granules had diameters between 10 and 30 μm (Ambigaipalan et al., 2011; Zhang et al., 2019). Faba bean starches C-type crystalline pattern under X-ray diffractometer.

Milling process can be divided as primary and milling or grinding processing. Primary processing generally includes the dehulling and splitting. Since hulls are rich in fibers, dehulling have an important effect on the pulse products' nutritional and antinutritional factors as well as the milling characteristics. In addition, some treatments may be applied prior to the primary processing to ease, are called as pre-treatments. Dehulling and splitting yields can be improved by pre-treatment such as soaking, pitting, and germination. Also, thermal pre-treatment may ease the milling and affect the flour particle size after milling. In the literature, it is stated that the flour particle size may affect the protein or starch isolation yield from the pulse flour. Therefore, pre-treatments should be selected according to the desired pulse products' characteristics.

In literature, pulse milling, and pulse products are very common working areas but limited with some pulse types, such as chickpea and yellow pea. Since faba bean has many varieties, the comparative studies will be enlightened the change in the milling properties with the changing treatment properties and seed characteristics.

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Chapter 4
Chemistry, Nutrient Composition and Quality of Faba Beans

Vandana Chaudhary, Priyanka Kajla, and Shobhit

4.1 Introduction

Faba bean (*Vicia faba L.*), frequently referred to as the broad bean is an annual legume of the family Fabaceae/Leguminosae and is one of the major winter-sown legume crops with widespread cultivation around the world (Dhull et al., 2021). The bean is also known by different names: broad bean, horse bean, windsor bean, tick bean, fava bean, etc. In Hindi, the national language of India, *V. faba* is prevalent as 'kalamatar and bakala' Singh et al. (2013b).

The beans have a high nutritional value and are opulent in proteins, carbohydrates, volute vitamins, folic acid, niacin, vitamin C, dietary fiber, and macro and micronutrients. Majorly, the seedy part of the *V. faba* was opulent in carbohydrates (51–68%), followed by proteins (20–41%). The fractions of proteins were isolated from the components of the V. faba, and it was composed of globulins (79%), albumins (7%), and glutelins (7%). Singh et al. (2014) assessed three promising lines and found that they are rich in dietary fiber, total soluble sugar, total starch, phosphorus, iron manganese, and zinc. El Naim et al. (2014) analyzed some quality aspects and proximate composition of different legumes and observed that Faba bean seeds had the highest achievement in terms of quality attributes in comparison to other legumes.

Faba bean oldest known crop that ranks sixth in production among different legumes grown after soybean, peanut, beans, peas and chickpeas. Faba bean is

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Table 4.1 Harvested area, yield and total production of *Vicia faba* (Faba Beans) in world (FAOSTAT, 2021)

Element	Value	Unit
Area harvested	2,671,497	ha
Yield	21,221	kg/ha
Production	5,669,185	tonnes

grown as commercial crop in many nations, including China, Ethiopia, Egypt, but commonly cultivated in the Mediterranean region and parts of Latin America for food purposes. But, on the contrary in the United States and Northern Europe, faba bean is grown on a large scale exclusively for purpose of animal feed. Cultivation data of faba beans in the world in 2020 as presented by FAOSTAT is produced in Table 4.1. Around 90% of faba bean production is concentrated in the Asian, European Union (EU), and African regions (Fig. 4.1) (2021). China is a major shareholder in production (1,723,598 tons), other important producers are northern Europe, the Mediterranean, Ethiopia, Central Asia, East Asia, and Latin America (Rahate et al., 2021). It has been utilized as a primary source of protein for human and animal sustenance since prehistoric times in the Middle East (Multari et al., 2015). It is a versatile crop that delivers diverse services to the ecosystem, predominantly as a source of nutrition for the people subsisting in Africa and Asia, also finds its usage as livestock forage or silage in Europe (Etemadi et al., 2019), and improving the soil prolificacy by fixation of atmospheric nitrogen by establishing a symbiotic relationship with *Rhizobium* bacteria, thereby restricting the application of chemical-based fertilizers (Karkanis et al., 2018).

In India, usage of the bean is not fully exploited for food and feed purposes, while, Egyptians are leading consumers of faba bean. Mediterranean countries, Egypt, Ethiopia, China, India, Afghanistan, Northern Africa, and Northern Europe are the major faba bean-producing countries. The countries with the largest pulses consumption are Egypt and India, where pulses are used as a crucial source of essential nutrients, especially protein. In developed countries, animal protein is the main source of protein (Rahate et al., 2021).

This crop is categorized under the category of "break crop" as it aids in boosting grain output by reducing the incidence of cereal cyst nematode (*Heterodera avenae*) and take-all (*Gaeumannomyces graminis*), two nematodes that attack cereals. It also offers an upper edge in comparison to other leguminous crops like lentils, chickpeas, etc., being more tolerant to waterlogging. In addition, it can also withstand acidic soils better than other leguminous crops (Etemadi et al., 2019).

The term food quality represents the sum of all properties and attributes of a food item that are acceptable to the customer. Besides safety, quality attributes include: nutritional value; organoleptic properties such as appearance, colour, texture, taste; and functional properties. Additionally, several factors which can

Fig. 4.1 Top ten countries production of faba beans in world in 2020 (FAOSTAT, 2021)

affect food quality of processed foods are: composition, physical and structural properties, processing operations and storage and packaging conditions (time, temperature and Relative humidity). Faba beans with medium-sized beans and broad, large beans (e.g. Aquadulce) are most acceptable by consumer because of their size and color. Among functional properties high hydration and swelling co-efficient of cooked faba beans are considered as good quality as this produce greater quantity. Faba beans quality might also degrade due to some physical and structure alterations such as shriveling, seed discoloration, breakage, and insect damage.

4.2 Botanical Characteristics

4.2.1 Botany and Cytology

V. faba belongs to the genus Vicia, tribe Fabeae (syn. Vicieae), family Fabaceae (syn. Leguminosae, Papilionaceae), order Fabales. The name Faba emanated from a Greek verb variant φάγέώ which means "to eat", thereby emphasizing its importance for Greeks and Romans for usage as food and feed (Duc et al., 2010). *V. faba* is an annual forage legume with gritty, upright stems that grow to be 0.3–2 m tall with one or more vacuous stems from the base forming a bushy habit (Hickman, 2012). The stems are square in cross-section. The leaves are alternating, pinnate, and consist of 2–6 oval or round leaflets with a length up to 8 cm long. The appendages at the base of leaves have extrafloral, purple nectar secreting glands on the undersurface. One contrasting feature of this plant is it is deprived of or has rudimentary tendrils contrary to other representatives of the genus. The plant produces

Fig. 4.2 Faba bean plant. (**a**) Flowers, (**b**) Pod, (**c**) Seeds

a lot of blooms, but only a small percentage of them develop pods. The plant produces a lot of blooms, but only a small percentage of them develop pods Singh et al. (2013a).

Flowers are big, fragrant, arise in clusters at the axil of leaves, and possess short pedicels usually between the 5th and 10th node. The corolla of the flowers are white or dark purple and may display dark brown, black, or purple markings (Fig. 4.2a). Each flower consists of 10 male reproductive units, stamen. Out of these ten, nine are integrated and the tenth one is free. The female reproductive unit is located above the stamen. Each cluster of the flowers produces 1–4 cylindrical pods, with green and smooth outer surface when young (Fig. 4.2b), and turns dark brown or black on maturity. Seeds come in a variety of sizes and hues, including cream, brown, reddish, greenish, and purple, with a huge dark-colored hilum towards the short side (Fig. 4.2c) (McVicar et al., 2013).

V. faba can flourish in almost any type of soil but it thrives best in fine textured soils. Optimum pH of soil for faba bean cultivation should be equal to or more than 7 (Köpke & Nemecek, 2010). In terms of the root system, fava beans comprise a large, robust, and shallow taproot with multiple lateral roots. The roots possess nodes imbibing nitrogen-fixing bacteria *Rhizobium leguminosarum* bv *viciae* (Guinel, 2009). Faba beans are generally sown directly into the soil. Faba bean, on the other hand, may benefit from transplanting rather than direct seeding to ensure early sowing in shorter-season locales. In areas with a shortened growth cycle, such as the Northeastern United States, transplanting faba beans allows for double cropping and prevents diseases like chocolate spot (*Botrytis fabae*) (Etemadi et al., 2018). *V. faba* has a diploid (2n) chromosome number of 12 (six homologous pairs). Five pairs of chromosomes are acrocentric with a centromere near the end while one pair is a metacentric having a centromere in the middle of the chromosome (Zhao et al., 2018).

4.2.2 Origin

Despite its commercial, nutritional and economic importance, wild progenitor and region of the genesis of fava beans, as well as the successive treads in domestication are very limited and controversial (Shiran et al., 2014). Certain wild species (*Vicia narbonensis* L. and *Vicia Galilaean Plitmann* and *Zohary*) are taxonomically identical to cultivated fava beans, but they have 2n = 14 chromosomes, while farmed fava beans have 2n = 12 chromosomes (Cubero, 1974). However, it is believed that faba bean was domesticated with the commencement of agriculture in the Fertile Crescent of the Near East, approximately around 9000–10,000 BC, eventually unfurling all over the world (Tanno & Willcox, 2006). According to Maxted (Maxted, 1993), countries namely Iran, Iraq, Armenia, Georgia, Azerbaijan, Turkey, and Syria are all integral parts of diversification in faba beans. Near East is thought to be the origin of fava beans. Cubero (1974) proposed that there are diverse pathways emanating from the North East to Europe and further to several regions of the globe. The first route might go across Anatolia to Greece and other Mediterranean countries, eventually leading to Europe. The second might originate from the Nile delta and move to the coasts to Iberian and Maghreb lands. The third probable route is envisaged to move along the Nile River to Abyssinia, which is today Ethiopia and the last may extend from Mesopotamia to India. In confirmation of Cubero's observations, Caracuta et al. (2015) discovered seeds of a probable ancestor of the faba bean near Mount Carmel, Israel, with a C-dating of 14,000 years. A contradiction to this postulation was by Ladizinsky (1975), who proclaimed that fava beans originated in Central Asia. Moreover, the most appropriate method to study the domestication pattern of legumes like fava beans is centered on apparent alterations in plant characteristics such as enlargement of seed size as well as a decrement in the seeds' natural dissemination method. Seed parameters are marked as the favorite feature for the identification of domesticated legumes as pods are seldom found in archaeological studies (Smartt, 1985).

4.2.3 Structure of Faba Beans

Faba beans come under the category of dicots and the embryo is composed of an embryo axis and two cotyledons. The cotyledons are typically fleshy and are bloated giving a bulging appearance as they help in accumulation of food for the developing baby plant. Embryo axis depicts two distinct ends: plumule which develops in shoot and radicle develops in roots. The seed is enclosed by a protective layer, seed coat which is further composed of an external membrane testa and internal membrane tegmen. Hilum is a scar like depression present on the seed coat representing the site of attachment to the ovary wall. A little above the hilum is a tiny opening called micropyle, which helps in controlling the moisture permeation into the seed (Fig. 4.3) (Flexiguru, 2015).

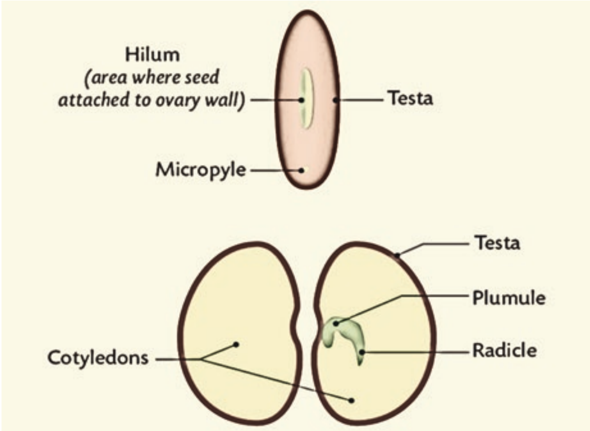

Fig. 4.3 Structure of faba bean

4.2.4 Germplasm Resources

There is a lot of genetic variation in *Vicia faba*. In accordance to Duc et al. (2010), there are over 38,000 accessions of faba bean germplasm maintained worldwide, including at the International Center for Agricultural Research in Dry Areas (ICARDA). The items in this global collection come from 71 nations, with a high percentage of unique accessions. Out of the whole collection, 10,320 accessions are from the international collection, preserved in trust for the global community. In addition, the collection also hoards more than 6000 accessions of other Vicia species, which further encompasses roughly 3000 accessions of wild Vicia (Redden et al., 2018). Faba beans have four subspecies, namely minor, equaine, major, and paucijuga (Cubero, 1973). The common name, seed, pod attributes, area of cultivation, and applications of these subspecies are depicted in Table 4.2.

Contemporary cultivars are more predominantly in Europe, Australia and Canada, conventional varieties are cultivated in many countries, while a combination of traditional and contemporary variants is grown in others. High yielding varieties of *V. faba* namely Basabeer, Hudeiba93, and 'Ed-Damer,' were launched in Sudan, which exhibited higher survival rate at high temperatures (upto 35 °C). As a result, the total yield augmented by 40% in Sudan. Drought tolerant variety Nubaria 3 was introduced in 2011 in Egypt (ICARDA, 2018).

4.3 Nutritional Profile

The nutritional profile of fava beans is excellent as they contain an adequate quantity of proteins, carbohydrates, vitamins, minerals, and a variety of polyphenols. (Table 4.3.) Green pod of fava bean is utilized as vegetable and its dry beans are

Table 4.2 Attributes of pods and seeds of four subspecies of *V. faba* (Maalouf et al., 2013; Fouad et al., 2013)

Subspecies	Common name	Seed attributes: size and shape	Seed attributes: Weight (mg)	Pod attributes	Area under cultivation	Application
Minor	Bell bean, tick bean	Small, ellipsoidal, cylindrical, round	30–50	The size of the pod is small consisting of 3–4 seeds; possesses a cylindrical shape	Ethiopian area	Animal feed; forage crop
Equine	Horse bean, field bean	Flattened	50–100	Medium-sized; plate-shaped pod with 3–5 seeds	Middle-east and North Africa with a major concentration in Egypt	Animal feed; forage crop
Major	Windsor bean, broad bean	Large, very flattened	≥100	Size ranges from small to large; the of seeds varies from 2–10	South Mediterranean countries and China	Human consumption
Paucijuga	–	Very small, rounded	20–30	Very small in size;	Northwest India and Pakistan	Animal feed; forage crop

categorized as one of the cheapest sources concentrated source of protein varying from 20% to 41%.

4.3.1 Protein

Faba beans contain an adequate amount of protein ranging from 20% to 41% (Table 4.3) which is almost double the protein content found in cereals (Rahate et al., 2021). The wide variations in protein are attributed to different types of varieties and portions of the bean, viz., flour, any particular fraction, or its isolate/concentrate (Yang et al., 2018), additionally fertilization method, growing season, as well as soil type, irrigation and other cultivation practices also contribute to variations in protein content (Multari et al., 2015). Faba bean protein is of exceptional quality as it contains all the essential amino acids required for humans except cysteine and methionine. Therefore, this bean protein is popularly enunciated as poor man's meat as it is nutritionally at par with meat and fish protein (Macarulla et al., 2001). The protein fava bean is fractionated into globulins (60%), albumins (20%), glutelins (15%), and prolamins (8%) (Rahate et al., 2021). Albumins are water-soluble protein fractions that contain enzymes, protease inhibitors, amylase inhibitors, and lectins with molecular weights ranging from 5, 000 to 80, 000 Da. These fractions are

Table 4.3 Nutritional profile of fava beans

S.No.	Nutrient	Concentration	References
1.	Moisture	10–12%	Moussou et al. (2019), Kamboj and Nanda (2017)
2.	Protein	25.3–27%	Moussou et al. (2019), Setia et al. (2019), Kamboj and Nanda (2017)
3.	Lipids	1.4–3.2%	Kamboj and Nanda (2017), Setia et al. (2019)
4.	Carbohydrates Starch	45–49% 37–43%	Millar et al. (2019), Moussou et al. (2019), Setia et al. (2019)
5.	Minerals		Millar et al. (2019), Moussou et al. (2019)
	Ca	117–172 mg/100 g	
	P	1100–1117 mg/100 g	
	Mg	76–102 mg/100 g	
	Fe	5.44–5.48 mg/100 g	
	Cu	1.48–2.01 mg/100 g	
	Na	25–27 mg/100 g	
	K	1220–1285 mg/100 g	
	Zn	4.18–5.67 mg/100 g	
6.	Vitamins		Dhull et al. (2021), USDA (2021)
	Vitamin C	33 mg	
	Folic acid	96 μg	
	Tocopherol	0.08 mg	
	Vitamin B6	1.6 mg	
	Vitamin A	350 IU	
7.	Antinutritional factors		Moussou et al. (2019)
	Trypsin inhibitors	2.84 (TIU/g)	
	Chymotrypsin inhibitors	1.77 (CIU/mg)	
	Phytic acid	2.40%	
	Tannins	151 mg/100 g	

rich in lysine and sulfur-containing amino acids. The 7S, 11S, and 15S proteins, with molecular weights ranging from 8, 000 to 600,000 Da, make up the salt -soluble globulins and contain legumin, vicine, and convicine (Klupsaite & Gražina, 2015; Vioque et al., 2012). In faba bean, the legumin–vicilin ratio in the globulin fraction is a critical contributor to physiological functions and functional properties (Yang et al., 2018).

Essential amino acids such as isoleucine, leucine, lysine, methionine, tyrosine, phenylalanine, valine, histidine, tryptophan, and threonine, as well as non-essential amino acids such as aspartic acid, glutamic acid, alanine, arginine, glycine, proline, and serine, are found in fava bean (Khalil & Mansour, 1995). Arginine (6.9–12.6 g/kg) is the most abundant amino acid in different faba bean genotypes as reported by Nosworthy et al. (Nosworthy et al., 2018). Because of its balanced amino acid profile, faba bean is used as a protein supplement in a variety of foods, including bread, biscuits, and oil-in-water emulsions (Liu et al., 2022; Osman et al., 2014; Rosa-Sibakov et al., 2016).

4.3.2 Lipids

Faba beans serve as a calorie-dense diet for humans because of their high lipid content. The lipid content of beans as depicted in Table 4.2 varies from 1.40 to 3.20% (Moussou et al., 2019). Palmitic, stearic, myristic, pentadecanoic, arachidic, behenic acids, oleic acid, linoleic acid, and linolenic acids make up the fatty acid composition of bean lipid. The major lipid components comprise of 47.7–50.1% triacylglycerols and 47.5–50.5% phospholipids, with relatively small amounts (1.8–2.4%) of hydrocarbons, steryl esters, free fatty acids, diacylglycerols, and monoacylglycerols. Phosphatidylcholine, phosphatidylethanolamine, and phosphatidylinositol are the major phospholipids reported in faba beans. Phosphatidylinositol is found to be unique among the three phospholipids owing to the presence of the highest concentration of saturated fatty acid (Yoshida et al., 2009).

4.3.3 Carbohydrates

Faba bean seeds contain a good amount of carbohydrates (45–49%) out of which 37–43% is starch. Raffinose, stachyose, and verbascose are soluble sugars that are recognized to be present in faba bean (USDA, 2021; Millar et al., 2019; Setia et al., 2019). The major compounds of the carbohydrate fraction are starch and non-starch polysaccharides, but also oligosaccharides constitute a significant part (Moussou et al., 2019). According to the rate of degradation of the starches in the gut and thus the gastrointestinal absorption of glucose and its release in the bloodstream, starch is categorized into rapidly digestible starch (RDS), slowly digestible starch (SDS), and resistant starch (RS). Both RDS and SDS are entirely digested in the small intestine, with the exception that SDS is digested at a slower rate than RDS. Ingestion of RDS induces a quick spike in blood glucose because of its rapid digestion (Punia et al., 2019).

In fava bean carbohydrates, dietary fibre, starch content, and sugar type are the most important nutritional components. The principal soluble sugars are oligosaccharides from the raffinose family: raffinose, stachyose, and verbascose, which are known to cause flatulence and restrict faba bean consumption from digestion standpoint (Vidal-Valverde et al., 1998).

The fava bean is a very good source of dietary fiber, containing both soluble as well as insoluble fiber. The dietary fiber content of the whole fava bean varied from 15% to 30%, with hemicellulose, cellulose, and lignin being the predominant components. The seed coat of the faba bean contains a substantially larger amount of dietary fibre (82.3%) (Çalışkantürk Karataş et al., 2017; Vidal-Valverde et al., 1998). Therefore, it is recommended that the consumption of whole fava bean is beneficial for health since it is a good source of dietary fibre, phenolic compounds, and minerals.

4.3.4 Vitamins and Minerals

This bean also serves as a good source of different minerals (Table 4.3) viz., phosphorus, potassium, calcium, sulfur, and iron. Most of the phosphorus in fava bean is unavailable, as it exists as phytates responsible to pose adverse effects on human health (Luo & Xie, 2012). Faba bean is a good source of folate, an essential cofactor involved in the synthesis of pyrimidines, purines, and amino acids. The beans also contain pyridoxine, thiamine and riboflavin in adequate amounts. Minor quantities of tocopherols (0.08 mg), are also reported to be present in beans (USDA, 2021; Dhull et al., 2021).

4.3.5 Bioactive Compounds

Major bioactive compounds identified in faba beans are polyphenols, flavonoids, phenolic acids, lignans, terpenoids (Dhull et al., 2021). The polyphenol content in *V. faba* seeds has been reported to be more than double that of the two other legumes (*Cicer arietinum and Pisum sativum*), Vioque et al. (Vioque et al., 2012) concluded that faba bean is a very good source of polyphenols with high antioxidant activity. Phytochemicals such as phenolic substances, flavonoids, lignans, and terpenoids have been revealed in fava beans. Protocatechuic acid, ferulic acid, vanillic acid, caffeic acid, sinapic acid, salvianolic acid, cis- and trans-p-coumaric acid, hydroxyeucomic acid, eucomic acid, caffeoylquinic acid, and dicaffeoylquinic acid are among the free and esterified phenolic compounds found in fava beans. The total phenolic content of different kinds of fava bean pod extract ranged from 4.8 to 13 mg gallic acid equivalent (GAE)/g. (Valente et al., 2018).

4.3.6 Antinutrients

Many antinutritional factors include phytic acid, protease inhibitors, trypsin inhibitor, tannins, haemagglutinins (lectins), and oligosaccharides particularly stachyose, raffinose, and verbascose are reported to be present in beans (Samtiya et al., 2020). Different research studies revealed the adverse impacts of these antinutritional factors on human health.

Protease inhibitors are widespread anti-nutrient substances that can obstruct the proteolytic activity of certain enzymes, thereby reducing digestibility, particularly found in legumes (Moussou et al., 2019). Moussou et al. (Moussou et al., 2019) reported a trypsin inhibitor activity and chymotrypsin inhibitor units of faba bean seeds of 2.84 TIU/g and 1.77 CIU/mg, respectively (Table 4.1). In fava beans, the concentration of trypsin inhibitor is two times as big in the hull compared to the cotyledon. These components are relatively thermolabile, therefore, thermal treatments can reduce the inhibitory activity significantly (Moussou et al., 2019).

These antinutrients possess two contradictory properties which raise the attention of plant breeders; first these compounds have a negative effect on the nutritional quality, but on the other hand, these play a considerable role in defense mechanisms against pathogens and pests in plants and also possesses high antioxidant activity (Robinson et al., 2019).

Condensed tannins are polymers of flavonols that are primarily abundant in the seed coats. They are relatively heat-labile and water-soluble These polyphenols can cause dark colors or spotted patterns in some bean varieties (Robinson et al., 2019). A study by Moussou et al. (Moussou et al., 2019) shows that the tannin content in fava beans is comparable to that of chickpeas, common beans, and peas, but almost three times lower compared with common bean.

Faba beans are relatively rich in phytic acid composed of mixed Ca and Mg salts of myo-inositol-1, 2, 3, 4, 5, 6- hexa-kis (dihydrogen phosphate). They are the major storage form of phosphorus in many seeds (Askar, 1986). Phytins can chelate di- and trivalent mineral ions, such as Ca^{2+}, Mg^{2+}, Zn^{2+}, and Fe^{2+} which cause a reduction in the availability of these mineral elements in the intestinal tract (Robinson et al., 2019).

The pyrimidine glycosides, vicine and convicine (VC), have been studied extensively in faba beans. Their biosynthetic pathways have not yet been clarified (Robinson et al., 2019). In contrast to tannins, which are located in the seed hulls, VC is located in the cotyledons and therefore they cannot easily be removed by technological processes (Vilariño et al., 2009). VC are heat-stable constituents, so cooking does not destroy these substances (Askar, 1986; Vilariño et al., 2009). Favism is a form of anemia that only occurs in people who have inherited the genetic deficiency of glucose-6-phosphate dehydrogenase. The term indicates a severe reaction occurring after ingestion of foodstuffs that contain fava beans, or after inhaling fava bean pollen. Symptoms appear within 5–24 h of consumption. Headache, vomiting, nausea, stomach cramps, pain followed by raised temperature are the common symptoms. These symptoms may vanish naturally if consumption is in less quantity or, in severe cases, lead to hemolytic anemia, followed by hemoglobinuria. Favism is more common and more life-threatening in children. However, a full recovery is usually made once the attack is over. The illness is triggered by certain substances that are present at high levels in the beans (Robinson et al., 2019; Ahmed, 2013). These active substances are divicine, isouramil, and L-dopa. Divicine and isoumaril can be obtained from the respective glycosides, vicine and convicine (Askar, 1986). Favism can recur when the beans are eaten, although this is greatly dependent on the amount of ingested beans and probably by many other factors (Luzzatto, 2001). Favism is common in the Mediterranean area, co-occurring with high fava bean consumption (Robinson et al., 2019).

Trypsin inhibitors could interfere in the digestion of proteins thereby affecting the bioavailability of protein and amino acids thus, hindering its utilization as a source of quality protein. On the other hand, phytic acid and tannins are known to form complexes with divalent mineral cations thus posing a hindrance in the bioavailability of the minerals that are required for normal metabolic activities thus affecting the overall health (Luo & Xie, 2012). Haemagglutinins (lectins) also termed protease inhibitors, are found in all legumes, but the concentration is comparatively more in faba beans. These antinutritional compounds adversely affect the availability as well as digestibility of proteins. Similarly, stachyose, raffinose, and verbascose, having glucose and galactose residues, interfere with sugar metabolism and undergo fermentation to produce gases causing flatulence and gastric discomfort, and pain (Vered et al., 1997). Therefore, it is evident from the literature that the presence of these antinutritional factors is one of the major constraints on fava bean utilization.

4.4 Quality Attributes

4.4.1 The Texture of Faba Bean

Producing fava beans for human consumption can be achieved consistently through a management package that focuses on choosing the right variety, strategic use of fungicides, windrowing, and attention to header settings. Variety choice affects market acceptability and influences susceptibility to external factors that downgrade grain quality. Disease resistance assists greatly now. Small beans like the old variety Fiordare are less acceptable in major export markets now. Medium-small beans (eg Nura, Farah) are sought because of their size and light color. Our medium-sized beans (eg Manafest) and broad, large beans (eg. Aquadulce) remain acceptable also because of their size and color. While seed size and color are factors influencing quality, and these are largely determined by genetics, sound management from seeding to delivery can certainly affect quality factors caused by shriveling, seed discoloration, breakage, and insect damage. Discolored and small, shriveled fava beans may not only result in seed being down-graded from human consumption but may also result in poor emergence and vigor for next year's crop.

4.4.2 Cooking Quality

The cooking quality of faba bean products such as medammis, falafel, tablet, and bears, can be evaluated by the following parameters as suggested by Shehata (Shehata, 1982):

(i) **Seed size and weight:** One thousand seeds are weighed and their volume is determined by measuring the change in the level of water in a graduated cylinder. The relative density of beans can be calculated by dividing the weight of 1000 beans by their volume. As small seeds are believed to be hard to cook, people prefer medium seeds. The weight of seeds is related to their size and chemical composition.

(ii) **Percentage of hulls**: The percentage of hulls affects the nutritional value of products from the whole seeds. The net yields of the dehulled seeds (cotyledons), protein, and starch per unit weight of fava beans, are inversely related to the hull content. The percentage of hulls can be determined either on the dry seeds directly or, following a few hours of soaking before removing the hull, followed by drying.

(iii) **Hydration coefficient:** The hydration coefficient of raw beans after soaking in distilled water for a defined period, is calculated as the percentage increase in weight of beans:

$$\text{Hydration coefficient} = \frac{\text{Weight of soaked beans}}{\text{Initial weight of beans}} \times 100 \quad (8)$$

The hydration coefficient of cooked beans e.g. stewed whole beans is calculated by weighing the beans before cooking and after cooking under specified conditions. In the case of stewed beans, the raw beans are mixed with tap water (1: 4) and autoclaved at 120 °C for two hours.

(iv) **Swelling coefficient**: The volume of raw beans, before and after soaking, is determined by the absolute displacement method, using water in a graduated cylinder:

$$\text{The swelling coefficient} = \frac{\text{Volume of soaked beans (for a defined period)}}{\text{Volume of beans before soaking}} \times 100$$

Both consumers and processors prefer beans that have high hydration and swelling co-efficient as this produce greater quantity.

(v) **Colour:** The color of raw and cooked beans can be measured objectively by color measuring instruments. Like Gardner Color Difference Meter, and Lovibond Tintometer type D. Spectrophotometer was also used to measure the reflectance of fava beans hulls and cotyledon powders. The C.I.E. characteristics were calculated as described by Sheheta (Shehata, 1982). Colour can be evaluated by panelists using a 5-point scale with the highest score indicating the lightest color that consumers prefer.

(vi) **Percentage of germination**: Three hundred seeds are soaked in water for 4 h before placing them in a container with wet sand or covered with a wet cloth and stored at room temperature (about 20 °C). Beans are examined every 2 days for 2 weeks, to count and remove the germinated seeds when the radicle is about 5 mm long. The degree of germination is important for the production of germinated fava beans (nabet).

(vii) **Texture:** Texture is one of the most important cooking characteristics of fava beans. Farmers, processors, and consumers value seeds that can be cooked quickly and cooked products which become homogeneously soft without any granulation. Methods of assessment are based on measuring or evaluating the texture of beans, subjectively or objectively, after cooking under standard specified procedure either for a definite time or for various successive intervals to determine the cooking time.

4.4.3 Quality Attributes of Unprocessed Faba Bean

Flours were made from the sprouted seeds of the low- and high-tannin fava bean cultivars Fabelle, FB9–4, Snowbird, and Snowdrop. Headspace measurements on sprouted flours found the most favorable aroma pro-files following 48 h sprouting and 24 h drying at 60 °C. Lipoxygenase activity, and the tannin, protein, and moisture contents were determined for unsprouted and sprouted fava bean flours. Lipoxygenase activity was higher in sprouted seeds before drying. Protein content increased after sprouting, whereas the tannin content decreased, especially for high-tannin varieties. Key volatile flavor compounds of fava bean flour included pentanal, hexanal, heptanal, octanal, nonanal, decanal, 1-hexanol, 1-often-3-ol, 3-methylbutanal, phenylacetaldehyde, 3-methyl butyric acid, D-limonene, β-linalool, menthol, and estragole; these include oxidative degradation products of oleic, linoleic, and some amino acids. An overall flavor improvement was achieved after germination, as indicated by a decrease in bitter compounds (tannins) and beany flavors (hexanal, nonanal, 2- heptanone, and 2-pentylfuran) (Akkad et al., 2021).

4.4.4 Quality Attributes of Processed Faba Bean

The Quality Faba Bean process is being used at the Fraunhofer IVV to manufacture fava bean meal and concentrate having improved sensory properties and lower concentrations of antinutritive ingredients. Different bean varieties are being screened to identify the differences in the fava beans concerning their agronomic data (yield, reliability), analytical composition, anti-nutritive ingredients, and techno-functional properties. Then, using a technical processing approach, the concentration of the anti-nutritive substances is being reduced. As well as the separation of these quality-lowering ingredients, analyses are being undertaken for the presence of endogenous enzymes and enzyme inhibitors. By varying relevant process parameters the endogenous enzyme activities will be deactivated via a hydrothermal process. The result will be fab bean fractions and concentrates having improved sensory properties and improved storage stability. The effect of different processing strategies (whole seed, shelled seed, meal, concentrate) on the effectiveness of enzyme deactivation will also be evaluated. Finally, these processing steps will be tested on a small pilot plant scale and product trials will be undertaken in model food formulations. New potential uses of the protein meal and concentrate for the food industry will be demonstrated.

In a recent study of volatiles from fava beans with only an approximately 1% lipid content (Akkad et al., 2019) it was suggested that lipase and lipoxygenase (LOX) activities strongly promoted the formation of hydroperoxide intermediates, which in turn lead to volatile oxidation products causing off-flavors (Yang et al., 2017). It has been suggested that the very high lipid hydrolyzing activity that is present in fava bean may affect not only lipids from the seeds, but also other lipids in food products (Lampi et al., 2020). In addition, dehulling may reduce beany flavors in the raw flour, and the action of endogenous oxidase enzymes which ultimately contribute to be any flavors can be removed through heating fava beans (Jiang et al., 2016). Tannins are anti-nutritional factors that affect digestion in animals (Jansman et al., 1993). Their presence in faba beans can reduce the solubility of proteins as well as the activity of the digestive enzymes (Griffiths, 1984). The perceived bitterness of fava beans may be enhanced due to the presence of high levels of tannins along with other compounds including saponins, phenolic compounds, and alkaloids, in addition to various volatiles that is known to result in off-flavors in pulses (Roland et al., 2017). Historically, sprouted grains have been widely used as food ingredients due to the common belief that germination imparts significant nutritional flavor and textural benefits over their counterparts that are not germinated. During a controlled germination process, plant hormones begin to be released along with digestive enzymes. The latter include amylases, proteases, and lipases, which lead to the degradation of starch, protein, and lipids, respectively. This significantly impacts the function and quality of sprouted pulse flour for example. In particular, an increase in lipase content can result in greater potential for lipid autoxidation to occur, hence, producing off-flavors in sprouted products (Gan et al., 2018). Certain of these volatile flavor compounds can be used as key markers of the beany flavor present in pulses. Examples of this include 2-methyl furan, 2-pentyl-furan, hexanal, nonanal, and 2-heptanone in fava bean flour (Jiang et al., 2016). Some of these volatile compounds are therefore indicators of the activities of peroxidases and lipoxygenases on the available unsaturated fatty acids, especially oleic, linoleic, and linolenic acids. In addition, the suggested high lipid hydrolyzing activity in faba beans may also affect other lipids present in food products (Yang et al., 2017).

Sprouting is a biological process in which the bioavailability of nutrients like protein will be increased, and on the other hand, the antinutrients like tannins that are known as contributors to the bitterness of fava bean will be decreased. Sprouting has been shown to improve the flavor quality of the resulting fava bean flour by decreasing the bitterness and beany flavors, accompanied by a small increase in protein content. Most of the identified key volatiles (ROAV $\geq$1) in the unsprouted flour, were found to decrease significantly after sprouting, and those aromas which do increase after sprouting are generally more pleasant. Sprouting fava beans, followed by drying and milling, will have a great impact on the volatile flavor profile of the flour. A previously reported headspace-chromatographic method (Akkad et al., 2019), was used in this work to characterize and monitor the changes in the volatile flavor profiles of sprouted fava bean flours. Four different fava bean cultivars representing low- (Snowbird and Snowdrop) and high-tannin (Fabelle and FB9-4) varieties were investigated. The effect of sprouting and drying conditions were studied to elucidate the changes in the final flour product which contribute to the beany flavor in both low- and high-tannin fava beans. The very high lipid hydrolyzing activity that is present in fava beans may affect not only lipids from the seeds, but also other lipids in food products (Lampi et al., 2020). In addition, dehulling may reduce beany flavors in the raw flour, and the action of endogenous oxidase enzymes which ultimately contribute to be any flavors, can be removed.

Flours were obtained from the dried sprouted seeds, as well as from the unsprouted seeds, by milling using an impact mill (Fitzpatrick D- DAS06, Waterloo, ON, Canada; screen size: 0.33 mm). Sprouting times of 48, 54, 60, and 72 h were tested, and the properties of the resulting flours were compared against those of the unsprouted seed flour.

4.5 Food Applications

As evident fava beans contain a good quantity and quality protein therefore when fortified in different food recipes it accounts for increasing the protein content of the composite product, thereby, balancing the amino acid profile. The fortification of raw and processed fava bean flour in bread, pasta, and extruded snacks resulted in a composite food product having improved nutritional, functional, and technological qualities. Several researchers and nutritionists studied various levels of substitution/fortification of fava beans and their different functional constituents in various traditional baked and extruded products (Table 4.4). As it is evident from the table presented, the use of processed bean flour (at levels varying from 10 to 30%) seems to be an appropriate replacement for wheat flour in bakery and pasta products. Therefore, faba bean could also be utilized for the manufacturing of gluten-free baked and pasta products. Furthermore, fava beans proteins are also being utilized in meat products as binders and extenders to improve texture and other organoleptic characteristics, in addition to this, these binders are also known to decrease the fat content thereby improving the nutritional value and shelf stability of meat and meat products (Serdaroğlu et al., 2005). Thus, it can be concluded that fava beans could be envisaged as newfangled food or food ingredient to replace conventional staple foods thus offering more healthier and sustainable choices. Faba beans also serve as a nutritional valuable feed for animals (Laudadio & Tufarelli, 2011).

Table 4.4 Food applications of faba beans

Faba beans	Applications	References
Dehulled, milled beans	Fermented and unfermented bread	Sozer et al. (2019))
Dehulled beans	Extruded pet foods	Corsato Alvarenga and Aldrich (2019))
Flour	Spaghetti, and other pasta products	Giménez et al. (2012), Petitot et al. (2010)
Protein isolate	Edible films	Saremnezhad et al. (2011)
Protein isolate and concentrates	To improve functional properties as emulsifiers, oil, and water absorption capacity and also utilized to combat protein malnutrition	Multari et al. (2015)
Native and esterified proteins	As antimicrobial agents in the preservation of raw milk and increased shelf stability of pasteurized milk	Sitohy and Osman (2011)
Amaranthus flour fortified with 10.7% fava bean flour	Pasta prepared had good cooking performance and sensory properties.	Chillo et al. (2008)
Faba bean proteins	As binders and extenders in meat products	Serdaroğlu et al. (2005)
Mayonnaise with broad beans protein isolate	Exhibited excellent antidiabetic, antihypertensive and antioxidant characteristics	Alu'datt et al. (2017)

4.6 Conclusion

The faba bean is one of the ancient crops and is utilised as a protein source in human nutrition, as cattle feed and a pasture crop, and as a source of nitrogen for plants. The faba bean is one of the most significant pulse crops in the world due to its exceptional nutritional properties, which include protein, carbs, B-group vitamins, and minerals. As a result, faba beans (Vicia faba L.) can now be classified as a potential source of lysine-rich proteins, carbohydrate, and dietary fibre. Inspite of the health benefits offered by it, the nutritional profile is obliterated by the antinutritional factors associated with it. Studies should be conducted to investigate effective and efficient the processing methods used for the reduction or elimination of the antinutritional factors of faba bean to enhance its nutritional value and wide utilization as food to combat protein and mineral malnutrition for the poor section of the population.

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Chapter 5
Anti-nutritional Attributes of Faba-Bean

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Abbreviations

ANF	Antinutritional factor
BBI	Bowman-Birk inhibitors
bHLH	Basic Helix loop Helix
CDA	Apparent digestibility coefficient
CWANA	Central and West Asia and North Africa
DDMP	2, 3-dihydro-2, 5-dihydroxy-6-methyl-4H-pyran-4-one
DNA	Deoxyribonucleic acid
G6PD	Glucose-6-phosphate dehydrogenase
GABA	Gamma-aminobutyric acid
GMO	Genetically engineered organisms
GSH	Glutathione
GTP	Guanosine-5′-triphosphate
IL-4	Interleukin 4
ITAP	Targeted amplified polymorphism
KASP	Kompetitive Allele specific PCR
MCF-7	Michigan cancer foundation-7
MW	Molecular weight
NAG	N-acetyl D-acetylglucosamine
NAM	N-acetyl-D-muramic acid
PI	Protease inhibitors
RAPD	Random amplified polymorphic DNA

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RFO	Raffinose family of oligosaccharides
RNA	Ribonucleic acid
SCFA	Short-chain fatty acids
SNPs	Single polynucleotide polymorphisms
SSR	Simple sequence repeat
v-c	Vicine and convicine

5.1 Introduction

Over time diet of an individual has influenced by various factors such as economic the geographical; environmental to culture but a healthy diet is always being a concern. Consumption of a healthy diet not only fills the stomach but also prevent malnutrition. But nowadays due to the rapid urbanization and changing lifestyle we are leaning toward unhealthy food. A balanced diet must contain all the nutrients for optimal nutrition. To maintain a healthy lifestyle one adult should consume carbohydrates of 45–60%, protein of 10–35% and fat 20–35%. According to WHO, around 400 gm per day of fruits and vegetables should be present in our diet to reduce the risk of non-communicable diseases such as heart disease, stroke, cancer, diabetes and so on. By definition, a plant-based diet can be several types such as Vegan, Lacto Vegetarian, OvoVegetarian, Mediterranean and many more. A healthy plant-based diet mainly comprises with consumption of nutritious plant food and minimizes the dependency on animal-based food. A plant-based diet includes fruits, vegetables, whole grains, legumes, and nuts.

Among the family of flowering plants, the legume is the 3rd largest family where the fruits are technically named as legumes. Chickpeas, soybean, groundnuts, lentils, pigeon pea, kidney bean, fava bean are some examples of this family. Legumes are a rich source of proteins, carbohydrates, vitamins, fibre, and minerals but they contain a lower amount of fats, which act as substitutes for meat and dairy products.

Although the legumes are nutritional as well as require low production cost, nutritional bioavailability is very less because of antinutritional factors present in them. The bioavailability of food defines the portion of nutrients which are readily digested, absorbed and ultimately utilized by the body. So, the presence of bulk nutrients is not only the major factor but their bioavailability in the human body is also important. In rural areas, micronutrients deficiency is the major cause of health-related problems and this condition can be improved by discarding the anti-nutrients which can be possible for improving the bioavailability of the nutrients (Samtiya et al., 2020).

Anti-nutrients which can be in the form of proteins or phenolic compounds or glycosides, are used by the plant as their defence mechanism and reduce the maximum utilization of micronutrients. Hence, overexploitation of vitamins or minerals does not happen and the energy is stored inside the seed for their germination. Every plant has developed a system for the defence that protects it from predators and save their future progeny. Anti-nutrients that reduce the digestibility of the food consumed by rodents, birds, insects or other herbivores, thus protect their seeds from them (Gemede & Ratta, 2014). These antinutritional factors show both adverse and useful effects on human health depending on their amount of consumption. Sometimes, these chemicals are also known as non-nutritive or bioactive compounds as their consumption even in small amounts prevent some major diseases such as cancer and coronary diseases. They are the secondary compounds synthesised as side products of primary metabolites; hence, they are sometimes referred to as secondary metabolites (Vikram et al., 2020).

In legumes, nuts, beans, and grains, the anti-nutrients are found in ample amounts and they are mainly present in roots, leaves and other parts of plants. Lectins, phytates, tannins, saponins, oxalates, protease inhibitors and so on are the major anti-nutrients found in plant-based foods. The symptoms that are seen in the body for the overconsumption of anti-nutrients are nausea, anaemia, bloating, rashes, headaches, nutritional deficiencies and so on. Excessive consumption of lectins and phytates present in tomatoes, eggplants and grains, seeds, nuts can cause intestinal damage and lower mineral absorption respectively. Absorption of protein may be disturbed due to the tannin consumption which can be found in tea, chocolates wine and so on and whereas saponins can cause disruption of red blood cells and inhibit enzymatic activity. On the other hand, oxalates present in soybeans, raw spinach and broccoli, reduce calcium absorption (Popova & Mihaylova, 2019). Faba bean also contains several antinutrients such as lectins, vicine and convicine, phytic acids, trypsin inhibitor, condensed tannins, saponins and hence, by consumption of faba beans it may cause several health diseases such as haemolytic, anaemia and favism.

The Vicia genus belongs to the Fabaceae family, which has a large number of species with a global distribution. There are about 750 genera and 16,000–19,000 species belongs to this family. Faba bean (*Viciafaba L.*), is also known as horse bean or broad bean, is one of the oldest cultivated crops found mostly in Asian territories, European Union and African rain-fed and irrigated regions with harvested area around 2.56 million ha and the production rate of 4.56 million tons approximately. China, Ethiopia, France, and Australia were the top faba bean producers. Asia and Africa hold almost 72% of the total land area and 80% of the total faba bean grain production. Following the Neolithic-era approximately 9000–10,000 BC, the Fertile-Crescent of the Near East saw the commencement of agriculture, which led to the domestication of the faba bean. Its cultivation has now expanded all over the world. The genus Vicia has its origins in south-eastern Europe and south-western Asia. The faba bean‘s migration to South America, particularly the Andean area, most likely took place in the fourteenth century, with the assistance of Spanish and Portuguese travellers. Small-seeded varieties in south-western Asia, such as India, Afghanistan, and the bordering areas of Kashmir and Bukhara, and large-seeded varieties in the west, have been identified by trait analysis. The Eastern group has a long history, dating back to Neolithic-agriculture. This group has the most native forms and the widest range of peculiarity, with several unique characteristics not found in other groups (few to several pairs of foliole and green-grey colour, presence of pod valves, a broad range of maturation periods, size, shape and colour of seeds, size of foliole, height, and stem branching etc.). This group may be found all over the place (from Himalayas to Spain). Ethiopia is the largest producer of summer-sown faba bean in East Africa, with 0.52 million hectares in the highlands and 0.62 million tonnes produced. Morocco, Egypt, Sudan, and Tunisia are the top producers in the CWANA region, with 0.48 million hectares of winter-sown faba bean and 0.76 million tonnes produced (Singh et al., 2013). Germination of faba bean seeds takes 10–14 days under ideal growth conditions. Conversely, under dry conditions or when the soil temperature is low, it will take considerably longer. A faba bean plant produces one node every week on average. The stems of faba beans are generally sturdy and grow erect and depending on the varieties the plant can reach a height of 90–130 cm. Faba bean develops its first blooms around the 8–10 node growth stage, when the plant is roughly 30 cm tall, which is normally in June in the North-eastern United States. Around 20 cm above the ground, flowers and pods appear. Approximately one-fourth of the blooms will yield pods and they on an average contain 3–6 seeds. As a result, good management methods such as soil fertility, irrigation, and planting timing can greatly minimise the amount of underdeveloped blooms, resulting in increased seed/pod production. The temperature of the soil should be low for the germination of most legume seed. On the other hand, the germination of faba bean seed is more resistant to cold soil temperatures than other grain legumes. Faba bean is largely self-pollinating; its blossoms attract a variety of pollinators, including honey bees. Faba beans are considered as their excellent Nitrogen fixation capacities, which are the greatest among cold season legumes. They can fix 50–330 kg $N \cdot hm^{-2}$ depending on crop management and climatic circumstances (Etemadi et al., 2019). Faba bean can be eaten as a vegetable, or in the form of cooking, or the form of canned processed product. Faba bean is one of the most significant pulse crops in the world due to its exceptional nutritional properties, which include protein, carbohydrates, B-complex vitamins, and minerals. Faba bean contains around 22–36% of protein which is rich in amino acids, 27–33% of starch and 15–25% of dietary fibre. Despite these entire benefits, fababean is still an underutilized crop due to the presence of high antinutritional factors (Warsame et al., 2018).

5.2 Antinutritional Factors Present in Fava Bean

As we discussed earlier the presence of antinutritional factors in faba bean restrict the bioavailability of nutrients present in it and due to which it shows indigestible to mono-gastric animals such as humans, horses, pig and so on. Thus, along with these antinutrients, the consumption of fava bean is not advisable. The antinutritional factors and their amounts present in Fababean are present in Table 5.1. The molecular Structure of major antinutrients compounds of faba bean is present in Table 5.2.

Table 5.1 List of antinutritional factors and their amounts present in Faba beans (weight based on dry basis)

Antinutritional factors present in Faba bean	Units	Quantity
Vicine	mg/g	4.96 ± 1.97
Convicine	mg/g	1.98 ± 0.84
Lectin	Hemagglutinin units/mg	1.37 ± 1.06
Saponin	mg/g	0.05 ± 0.02
Trypsin inhibitors	Trypsin inhibitors units/mg	8.01 ± 6.04
Phytic acid	mg/g	21.70 ± 11.05
Condensed tannins	mg equivalent catechin/g	1.95 ± 0.88
Raffinose	mg/g	1.88 ± 0.77

5.2.1 Lectins

In 1988, one medical student named ‘Still marks’ first identified a toxic proteinaceous factor in castor bean which can agglutinate red blood cells and after many years ‘Boyd’ coined the name lectins to it. In 1998, Lis and Sharon defined lectin as – “proteins or glycoproteins of non-immune origin with one or more binding sites per subunit, which can reversibly bind to specific sugar segments through hydrogen bonds and Van Der Waals interactions”.

The term “lectin” comes from the Latin word “Legere” and which denotes “to select”. Lectins can be subdivided into four major categories named merolectins, hololectins, chimer lectins and super lectins depending on their carbohydrate-binding sites. Lectinscan be further subdivided into five classes named D-glucose/D-mannose, L-fucose, N-acetyl-D-glucosamine, D-galactose/N-acetyl-D-galactosamine, and N-acetylneuraminic acid based on the affinity of monosaccharide. Lectins can be found abundantly in seeds but they are also present in other plants parts such as leaves, flowers, roots, bulbs and rhizomes. In the seeds they are mainly present in the vacuoles and may account for 1–10% of total seed protein.

Lectins have piqued the curiosity of biologists, who are particularly interested in their studies and uses in medicine and agriculture. These compounds with distinct properties have received applications in a variety of domains of bioscience, and when more lectins can be extracted and their natural roles understood, they will continue to play an essential part in agricultural and medicinal research. During seed development, lectins are formed as a precursor molecule, and broken down during seed germination to provide necessary amino acids. Lectins show antibacterial activity, as they have the affinity towards the carbohydrate site of the bacterial cell wall, such as they and they bind with N-acetyl-D-muramic acid (NAM), N-acetyl D-acetylglucosamine (NAG), and tetrapeptide which are found in the cell walls of both gram-positive and gram-negative bacteria.. They also show antifungal and antiviral activity. The interaction of lectins with hyphae prevents fungus growth, limits the absorption of nutrient, and prevents spore formation as lectin can cause

Table 5.2 Structure of major antinutrients compounds found in faba bean (*Vicia faba L.*)

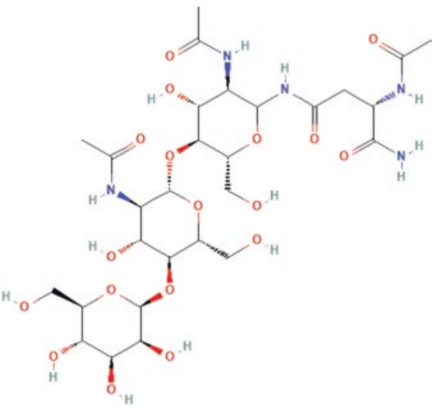
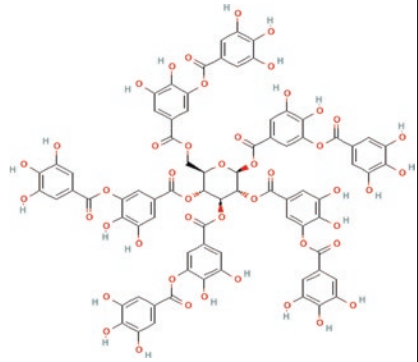
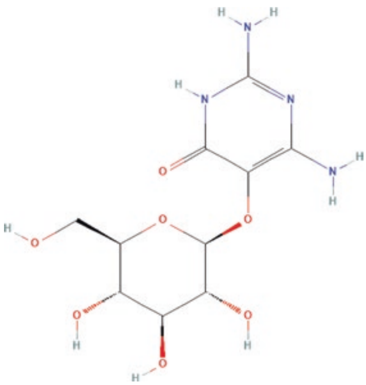
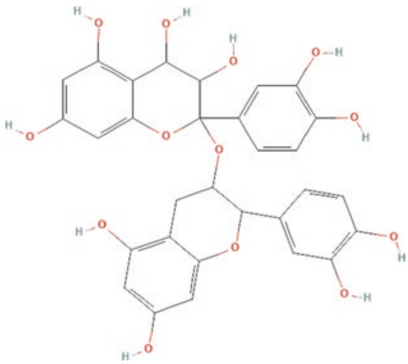
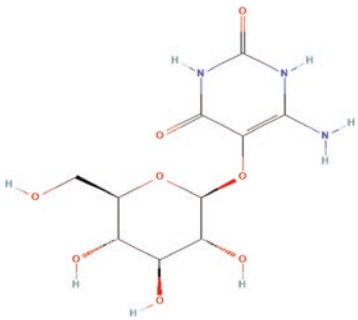
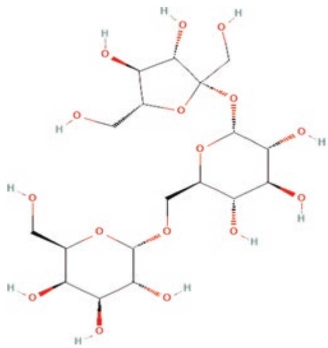
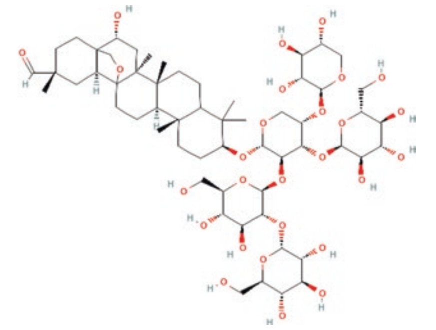
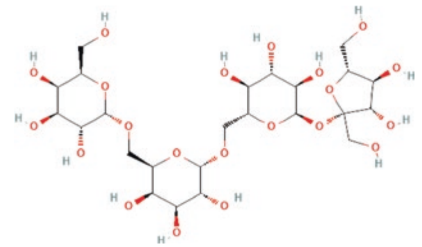
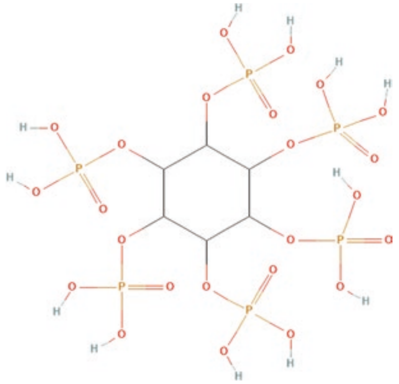
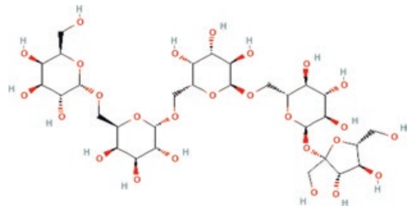
	
Lectin	**Hydrolyzable tannin**
	
Vicine	**Condensed tannins**
	
Convicine	**Raffinose**

Table 5.2 (continued)

	
Saponin	**Stachyose**
	
Phytic Acid	**Verbascose**

Source: https://pubchem.ncbi.nlm.nih.gov/

lysis of hyphal cell wall. Viruses have glycoprotein envelopes, and lectins can bind to complex glycans, modified the viral envelope proteins, preventing interactions with host cells. Lectins act as a defensive mechanism for the plant, in which the compound protects them from herbivores animals, phytophagous insects and phytopathogenic microorganisms by showing fungitoxic, anti-nematode, cytotoxic and anti-insect properties (Katoch & Tripathi, 2021).

Nausea, stomach ache, bloating, vomiting, diarrhoea is some are the common symptoms when a human consume lectins. Lectins can directly bind to the intestinal mucosa combines with enterocytes, preventing 0.01% free gossypol from being absorbed and transported within certain low gossypol cotton nutrients (particularly carbohydrates) during digestion, resulting in epithelial lesions in the intestine. When the animals are fed with lectins, they suffer from loss of appetite and body weight leading to death. The lectins are partially digested by the proteolytic enzymes and they bind with the gut's membrane, intestinal mucosa, showing deleterious effects to the membranes, bacterial flora present in the intestine. Hence, this lethal effect of lectinis a function of resistance offered by it towards the proteolytic enzymes.

When lectin is not degraded, it may bind with the epithelial cells of the gastric tract and disturb the metabolism. It affects cellular proliferation and gastro-intestinal function; absorption, secretion and protection. Lectins bind with their carbohydrate moieties to the receptor site of the intestinal lining and exhibit an unwanted modification of the small intestine, and inhibit the function of the enzyme. It leads to thinning the microvilli, decreasing the villus height, increasing crypt depths, shedding the brush border membrane, reducing vacuole size and decreasing the absorption of nutrients.

After binding with the epithelial cell, the lectins enter into the cell by endocytosis and then by exocytosis it reaches the intracellular space. Through systematic circulation, it is accumulated in the lining of blood and lymphatic capillaries. The Lectins trigger the production of histamine and IL-4, responsible for the type I allergy and type 2 immune response. This antinutrient can cause hormonal imbalance, pancreas and lung hypertrophy, hepatomegaly, rheumatoid arthritis, fat catabolism and glycogen loss, depleting the body storage and so on (Vasconcelos & Oliveira, 2004).

5.2.2 Vicine and Convicine

As per the study, vicine, and convicine are the most toxic substances found in faba beans, and also observed in different species, such as *Vicia narbonsensis* (<0.1 mg/g). They are pyrimidine glycosides that are produced through the orotic acid pathway. Vicine and convicine content is roughly around 1% of the total weight of faba bean and they can also be present around 3–4% of the dry weight of fresh green seeds. They can be found at the early developmental stage of seed and is also present in ample amounts in the roots. Young fresh green seeds have the highest vicine and convicine content, which is dropped with maturation until stabilising at a particular level till the harvest time. Vicine and convicine can be found throughout the cotyledon, where they are present abundantly in embryo radicals, and they are either missing or present in modest amounts in the seed coat and pod walls. Vicine and convicine levels in the cotyledon decrease with cultivars, but they are still abundant in the embryos. They are the bioactive chemicals which may help in the defence system of plant, against plant pathogens, and exhibits fungicidal effects.

The molecular weight (MW) of vicine and convicine are 304.2 and 305.2 g/mol, respectively. The functional group at the 2nd position of the pyrimidine ring in vicine and convicine is an amino group (-NH_2) and a hydroxyl group (-OH), respectively. Both compounds are water-soluble; however, their solubility varies depending on pH. Vicine has the maximum solubility at acidic pH, whereas convicine has the highest solubility at alkaline pH. Vicine and convicine both exhibit keto-enol and amine-imine tautomerism. In this, keto form is more stable while the enol forms more reactive which is being formed via protonation and deprotonation in acidic and alkaline conditions respectively and deprotonation in alkaline ones. In vicine and convicine, keto-enol tautomerism may be found at positions 3 and 4, and it can also be found at positions 1 and 6 in convicine.

Vicine and convicine have been shown to have detrimental effects on monogastric animals as they are hemotoxic to humans. Vicine and convicine are hydrolysed in the liver or in gastrointestinal tract, forming their corresponding reactive divicine, isouramil and aglycones which have strong oxidative capacity. Divicine and isouramil cause haemolytic anaemia called favism in people who have a genetic disorder named glucose-6-phosphate dehydrogenase deficiency because they have the ability to destroy red blood cells through the oxidative-reductive cycle. The earliest signs of favism are nausea, vomiting, headache, stomachache, and fever. Jaundice and haemoglobinuria emerge at a later stage (Pulkkinen et al., 2019).

The fast decline in glutathione GSH levels is the primary cause of favism development. In healthy people, GSH regeneration occurs quickly following a drop in GSH, however, this regeneration is too delayed in G6PD-deficient people. The amount of oxidised haemoglobin rises due to the oxidative condition, and erythrocytes experience deleterious modifications such as cross-bonding and the production of Heinz bodies, which are the precipitates of denatured haemoglobin and initiate haemolysis.

One approach for the removal of these antinutrients is heat treatment but as they are thermally stable; hence their complete removal is quite challenging. Wet protein purification procedures, such as isoelectric precipitation, can eliminate antinutrients like v-c but they are expensive and high energy-consuming. Another way to remove vicine and convicine is by hydrolysing them into aglycones with the help of the β-glucosidase enzyme or by fermenting by microbes that can synthesize β-glucosidase. Because of their instability, aglycones should react and disintegrate quickly. At 37 °C and in the pH of 5, with the addition of the β-glucosidase enzyme, the aglycones can be fully destroyed within 2 h. Vicine and convicine of faba bean can be destroyed by fermenting with *Fusarium graminearum* (25 °C for 72 h) or *Lactobacillus plantarum* (30 °C, 48 h).

5.2.3 Phytic Acid

Phytic acid and phytates (salt of Phytic acid) are the storage of phosphorus, mineral, and nutrients of the plants. They are necessary for plant nutrition and are especially sensitive during germination. The phytic acid concentration varies according to genotype, climate, soil type, and year. It builds up in the seeds as a salt of monovalent and divalent cations throughout the ripening period. Plants produce phytate by phosphorylating inositol in a series of reactions. Phytate is dephosphorylated in a series of steps by phytases found in plants, microbes, and certain mammalian tissues, thus from penta- to mono-phosphoinositol, a variety of partly phosphorylated molecules exist, each with a different cation or protein binding capability. Phytates are found in the germ of seed as well as the aleurone or bran layer of monocotyledons such as wheat and rice. On the other hand, phytates are tightly connected with proteins in dicotyledon seeds like legumes, nuts, and oilseeds (Gemede & Ratta, 2014). Because the edible cotyledon contains the majority of the phytate, there is no appreciable decrease in phytate levels after mechanical processing. Furthermore, cooking or heat processing of foodstuffs destroys just a small fraction of phytate as they are heat stable but the phytase enzymes that are needed to break down the phytate are heat-labile. However, when phytic acid is exposed to phytases through extended soaking, fermentation, or germination, it drops down the phytate levels in the ingested meal.

Because of its starch binding characteristics, high mineral and protein content, phytate is considered an antinutrient, which lowers its bioavailability. The phosphorus linked to phytate is often not bioavailable to non-ruminant animals. Sheep and cows, for example, chew, swallow, regurgitate, then chew their food again and they are capable to isolate phosphorus from phytates because of an enzyme rumen, found in their first stomach chamber. But in this case, non-ruminant animals, including humans, cannot do so. Because phytate is a strong negatively charged ion that functions throughout a broad pH range, the presence of it in the diet reduces the bioavailability of positively charged mineral ions including Ca^{2+}, Zn^{2+}, Mn^{2+}, Mg^{2+}, $Fe^{2+/3+}$, and Cu^{2+} and causes mineral deficiency. Phytic acid inhibits the absorption of postprandial glucose. Phytic acid can also form complexes with proteins, lowering their solubility. On the other hand, phytate binds with proteins directly to it or by a cation bridge which varies with pH, time, and relative concentrations. In vitro, adding phytate to multienzyme-proteolytic assay systems inhibited casein breakdown significantly (up to 20–25%). As a result, phytates inhibit enzyme activity and have a deleterious influence on digestive enzymes for example, α-amylase, lipase, trypsin, chymotrypsin and pepsin. When the pH of the stomach is low, phytic acid establishes electrostatic bonds with arginine, lysine, and histidine, resulting in insoluble complexes.

Phytate is also known as myo-inositol1,2,3,4,5,6-hexakis dihydrogen phosphate. DNA repairing, endocytosis, chromatin remodelling, nuclear messenger RNA export, chromatin remodelling and hormone signalling are all regulated by these antinutrients, which is vital for plant and seed development. Phytic acid has been shown as a strong anticancer (both preventative and therapeutic) effect in both in vivo and in vitro investigations. It increases host defence systems and tumour abrogation by reducing cell proliferation and increasing the differentiation of malignant cells. Phytic acid lowers the absorption of harmful heavy metals including lead and cadmium. It provides a lot of health advantages, including a reduced risk of heart disease by preventing atherosclerosis and hypercholesterolemia, lowering kidney stones, and reducing the colon cancer (Muzquiz et al., n.d.). The activity of phytase may be responsible for the phytate content which can be decreased in legumes using . During germination, 20–70% phytic acid is hydrolyzed depending on the kind of bean and the rise in phytase activity.

5.2.4 Protease Inhibitors (PI)

Proteases, also referred as peptidases and/or proteinases, are enzymes that catalyse the breakdown of peptide bonds during proteolysis. From seed germination until senescence, they are essential in every step of plant life. Similarly, in animals, they play a significant part in a variety of physiological and pathological processes such as food digestion, tissue remodelling, host defence, and so on. In contrast, protease inhibitors (PIs) are the compounds that inhibit proteases from performing their functions and show deleterious effects on human and animal proteolytic enzymes.

Most of the storage organs of plant such as seeds and tubers contain protease inhibitors (1–10% of total protein). It can be found in various plant seeds such as soybean, cowpea, faba bean, pigeon pea, navy bean, tepary bean, bambara groundnut and this may differ according to location of the active site, amino acid composition and molecular weight. The Bowman-Birk inhibitors (BBI) of molecular weight 8 kDa and Kunitz trypsin family inhibitors of molecular weight 20–24 kDa, are the most common forms of PI found in legumes. BBI is a serine proteinase inhibitor with two independent protease inhibitory sites, a trypsin reactive site (Lys 16 and Ser 17) and a chymotrypsin-reactive site (Leu 43 and Ser 44). It comprises 71 amino acids that are rich in di-sulphide bonds. The Kunitz family of proteins has 170–200 amino acids and one or two intra-chains disulphide bonds, showing specificity against trypsin. This molecule forms a stoichiometric bond with trypsin, inactivating one molecule of trypsin for every molecule of the inhibitor. The interaction of PIs with their substrate is mediated by two processes. The first is irreversible trapping reactions, in which a PI binding causes the inhibitor to rupture an internal peptide bond, causing a conformational shift. Since of their irreversible nature, inhibitors are often known as suicide inhibitors because they never return to their previous form. Second, inhibitor interaction in reversible tight-binding interactions is comparable to enzyme substrate interaction. Both the unmodified and the modified forms of the inhibitor coexist in equilibrium in the protease inhibitor complex.

Protease inhibitors are engaged in various proteolytic processes, including signal initiation, transmission, and cellular apoptosis. They are also responsible for blood coagulation and show the deleterious effect on different hormone processing pathways and inflammatory responses. The trypsin inhibitor inhibits the development of human health by interfering with dietary protein digestion. When the protease inhibitors, including trypsin inhibitors and chymotrypsin inhibitors are present in the food they develop irreversible enzyme–inhibitor complexes which reduce the amount of trypsin in the gut as well as reduce the dietary protein digestibility, which ultimately results in slower growth in rodents and birds. As a result, the pancreas secreting activity raises, potentially leading to pancreatic hypertrophy (enlargement of the pancreas) and hyperplasia (an increase of pancreatic acinar cells). Kunitz and Bowman-Birk suppress the negative feedback of pancreatic secretion and increase the release of the hormone cholecystokinin from the intestinal mucosa.

Protease inhibitors, on the other hand, have been demonstrated to be effective in the treatment of cancer and infectious disorder such as multiple sclerosis. Human prostate cancer cells are decreased in their growth and survival when BBI is used. BBI inhibits the activity of membrane-type serine protease 1, which is important for cancer invasion and metastasis as well as proteasome function, preventing breast cancer cell proliferation. BBI also promotes apoptosis and permeabilization of the lysosome membrane in MCF-7 breast cancer cells (Gulewicz et al., 2014).

Due to its effects on limiting the protein availability in legumes, several investigations have been done to find an efficient method for removing the PI. Dehulling, soaking, cooking, autoclaving; extrusion can be done for the removal of PI. The most effective method for removing these heat-sensitive chemicals is thermal treatment (such as cooking and autoclaving) and soaking is considered the least effective process. Cooking or autoclaving raw and pre-soaked seed samples results in a significant decrease in trypsin inhibitor concentration (92–99%). The action of trypsin inhibitors is also reduced by dry heat treatment (93%). PI may also be extracted with alkaline pH solvents, alkaline salt solutions, or water.

5.2.5 Tannins

Tannins may be described as water-soluble, polyphenolic chemicals of molecular weights ranging from 0.5 to 3 kDa that may precipitate proteins in aqueous solutions. The term ‘tanning’ was previously used in scientific papers to define “the process of employing plant extracts to turn raw animal hides or skins into durable, non-putrescible leathers”. However, the word is frequently used to refer to a large polyphenolic substance having enough hydroxyls and other appropriate groups which establish strong complexes with macromolecules especially with proteins. They can be found in a variety of plant species, such as cereal grains and legume seeds. Tannins can restrict the digestibility of protein, carbohydrates, and minerals in human and monogastric animal diets. These can also diminish the function of digestive enzymes and disrupt the mucosa of the gastrointestinal system. Tannins are secondary chemicals found in the leaves, fruits, and bark of plants. Hydroxyl group present in the tannin and protein‘s carbonyl group forms reversible and irreversible tannin-protein complexes which decrease protein digestibility and cause a loss in important amino acids. Proteins that form tannin complexes are typically big and hydrophobic, having a flexible and open structure enriched in proline. Tannins are divided into two types: those that can be hydrolysed or those that can’t. Acids, alkalis, and enzymes may easily hydrolyse some types of tannins such as gallotannins and ellagitannins, releasing glucose or another polyhydroxy alcohol, as well as gallic acid or other phenolic acids which are called hydrolysable tannins. But on other hand, condensed tannins are resistant to hydrolyse and are also known as flavolans or procyanidins. They have typically polymerized derivatives of flavan-3-ol (catechin) and flavan-3,4-diol, or a combination of these. Dicotyledonous plants are the most prevalent source of condensed tannins. Furthermore, condensed tannins are the primary polyphenols in regularly consumed food products, while hydrolysable tannins are only found at minimal levels. Both forms of dietary tannins have antinutritional effects due to their capacity to complex and precipitate proteins. The interactions between tannins and digestive enzymes, tannins and dietary proteins or both, are thought to be the main cause of increased faecal nitrogen after consuming tannin-containing diets.

Growing broiler cockerels were fed diets containing vegetable tannins, mostly hydrolysable gallotannins, at doses of 13.5, 25, and 50 g/kg tosee how they affected enzymes in the pancreas, intestinal lumen, and mucosa. When dietary tannins are increased, pancreatic weight is increased significantly, nearly doubling in comparison to individuals who are fed a tannin-free control diet. The inhibition of trypsin activity in the intestinal lumen increases as the amount of dietary tannin rises. Tannins also inhibit dipeptidase and sucrose α-glucosidase in the intestinal mucosa. Tannin-rich meals reduce protein digestion and restrict the bird's development. In the same way, feeding high tannin faba-bean hulls to young pigs inhibitsamino-peptidase activity in jejunal mucosal homogenates and shows poorer protein digestibility.

Dietary tannins found in fababeans (*Viciafaba L.*) are seen in animal models to affect protein and amino acid digestibility. In-vitro protein digestibility and dietary tannin concentration are also found to have a negative connection. When the amount of tannin-rich fababean husk extract was increased, the perceived digestibility of individual and total amino acids decreased linearly. Essential amino acids'apparent digestibility is influenced less than that of some non-essential amino acids (Gilani et al., 2005).

5.2.6 Saponins

Saponins are non-volatile chemicals that have a water-soluble or polar saccharide chain (pentose, hexose, or uronic acid) connected to a non-polar or fat-soluble aglycone. Saponins, which comprise a steroid aglyconeor triterpene within their chemical composition, are powerful surface-active compounds with an amphiphilic character. One or may be more linear oligosaccharides with chain lengths ranging from two to five sugar units make up the saccharide chain. D-galactose, D-glucose, L-arabinose, D-xylose, L-arabinose, and D-glucuronic acid are the most frequent saccharide sugars. Saponin's aglycone has a polycyclic ring structure (either 30 carbon triterpene or 27 carbon sterol). By the glycosidic linkage, sugar moiety of the saponin molecule is connected to the aglycone at one or two glycosylation sites. Saponins, which are glycosylated molecules or glycosides, can be classified into 3 classes based on the non-polar aglycone region's carbon skeleton: steroidal glycosides, triterpenoidal glycosides and steroid-alkaloidal glycosides. Triterpene glycosides are saponins that are often found in pulses. They can be two types such as monodesmosides (aglycones with a single sugar chain connected to carbon-3) and bidesmosides (aglycones with two sugar chains linked to carbon-3 and carbon-22). The structure of these molecules varies between plant species, depending on the kind and content of the aglycone and saccharide chains.

They can be found in beans, peas, black grams, lentils, pigeon peas, chickpeas and lupins. Saponins are classified into three groups based on their aglycone structures: A, B, and E. The chemical structure of two saponins isolated from faba bean is comparable to that of group B saponins. Sapogenol B is included in the structure of group B saponins, which differs from group Asaponins in that its aglycone has a hydrogen atom at carbon-21. The DDMP saponins are Group B saponins having a 2, 3-dihydro-2, 5-dihydroxy-6-methyl-4H-pyran-4-one (DDMP) group at carbon-22. Soyasaponin αa, αg, βa, βg, γa, and γg are all DDMP saponins. Soyasaponin I (Bb), II (Bc), III (Bb′), IV (Bc′), and V (Ba) are monodesmosides having one glycosyl group connected at the carbon-3 position of the aglycone (Ba). Under normal food processing conditions such as high temperature, acidic and alkaline pH, DDMP saponins become unstable and are transformed to saponin B after losing their DDMP moiety. In faba bean, soaking and dehulling may lower saponin levels by 26–29%, while boiling soaked and dehulled seeds further reduce saponin levels by 35% (Singh et al., 2017).

Because saponins are appeared to be particularly poisonous to fish and cold-blooded animals and several of them have considerable haemolytic activity, they areconsidered toxic. Saponins give food plants a bitter taste and astringency when present in large amounts. The bitter taste is one of the main factors that restrict its usage. Saponins are assumed to be antinutrient elements because of their negative effects, such as stunting development and reducing food intake owing to the bitterness and throat-irritating action. Saponins diminish nutrient bioavailability and enzyme activity, as well as affect protein digestibility by inhibiting digestive enzymes such as trypsin and chymotrypsin. Saponins have the ability to interact with the cholesterol group on the membranes of erythrocytes, resulting in haemolysis. Consumption of saponin in less quantity may not be harmful but in excess, it may be poisonous. Researchers showed that sheep may die if they are fed with a saponin content of 150 mg/kg body weight or more than that. Saponins inhibit vitamin absorption and can create complexes with sterols that have structures comparable to fat-soluble vitamins, interfering with sterol action and absorption.

Saponins also have anti-inflammatory, hypocholesterolemic, immune-stimulatory properties, as well as lowering blood cholesterol, blood glucose levels and risk of cancer. Saponins are used in a variety of commercial applications, including food additives, steroid hormone synthesis, fire extinguishers, and photographic emulsions. Saponins in food reduce blood lipids and blood glucose response. They are effective in decreasing blood cholesterol in people by inhibiting cholesterol absorption or bile acid reabsorption in the body, which lowers the risk of coronary heart disease. Saponins have an important role in cancer prevention in which they can kill cancer cells in the body. Saponins' anticarcinogenic abilities are based on processes including acid and neutral sterol metabolism, cancer cell cytotoxicity, immunological modulatory actions, and regulation of carcinogen-induced cell proliferation.

5.2.7 α-Galactosides

'α -Galactosides', commonly named as the raffinose family of oligosaccharides (RFO), which are non-reducing trisaccharide that water-soluble and also soluble in water-alcohol solution. Their molecular weights are very low and found frequently in plant. They are found in small amounts in the leaves of the plants and accumulate in storage organs throughout development. Many leguminous plants produce α-galactosides and during the developing phase, they accumulate in the storage organs such as seeds, roots, and tubers, where they conduct protective physiological roles such as desiccation tolerance and frost resistance. Raffinose, verbascose, stachyose, ciceritol, and ajugose are the most well-known α-galactosides. For the first time from chickpeas, ciceritol was isolated. α-Galactosides have been found to protect protoplasmic membranes of plant cells against damage caused by cold and drought. During temperature and water stress, raffinose is more efficient than sucrose or glucose in stabilising chloroplast membranes by two processes. The first process is based on carbohydrate hydroxyl groups replacing water, resulting in the essential hydrophilic reaction that stabilises cellular membranes and proteins. In the second process, α -galactosides synthesis suppresses sucrose crystallisation and promotes the creation of a stable glassy state during desiccation. α–Galactosides promotes seed storability which is influenced by the sucrose to total α–galactosides ratio. If the sucrose to total α–galactosides ratio is <1.0, it imparts a half-viability period of seed is >10 years and if the sucrose to total α–galactosides ratio is >1.0, it imparts half-viability period of seed is <10 years.

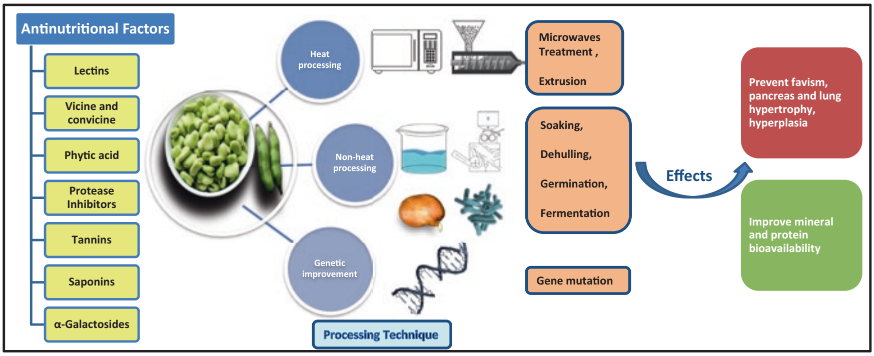
In humans and monogastric animals, excessive doses of α-galactosides are known to create abdominal rumblings, flatulence causing discomfort, cramps, agony, and diarrhoea. The intestinal mucosa is devoid of the hydrolytic enzyme α-galactosidase and the trisaccharide themselves cannot be absorbed in the intestinal wall that is why the RFOs are not digested by humans. The raffinose family oligosaccharides are subsequently metabolised by the microflora in the lower intestine tract, which produces substantial amounts of hydrogen, carbon dioxide, and short-chain fatty acids and minor amounts of methane and, lowering the pH. When animals were served a meal containing α-galactosides due to their laxative qualities, a considerable fermentation occurred in the lower gastrointestinal tract. The apparent digestibility coefficient (CDA) for α -galactosides was found to be quite high in chickens and adult cockerels, indicating substantial microbial fermentation in the lower intestine. But In pigs, α-galactosides get metabolised by microbial fermentation, mostly in the large intestine. The true metabolizable energy and digestibility of leghorn roosters' diets were reduced when raffinose concentration exceeded 0.45%. In the lower stomach, an increase in fermentable carbohydrates causes a microbial imbalance, resulting in diarrhoea. If the concentration of raffinoseis high enough in the food (>6.7%), it causes an imbalance in the osmotic pressure of the body, lowering its absorption ability. The presence of α-galactosides also has a detrimental impact on protein consumption.

Digestive enzymes are unable to digestα-galactosides and it is also not absorbed in the upper portion of gastrointestinal tract. Then they pass through the large intestine where they support the development of Bifidobacterium and Lactobacillus, which then dominate over harmful micro-organisms and improve human health. Bifidobacteria inhibit the growth of harmful foreign and indigenous microflora, resulting in the formation of short-chain fatty acids (SCFA), mostly lactic acid and acetic at a 2:3 mole ratio, as well as the capacity to create antibiotic compounds which are effective against *Shigella dysenteries, Staphylococcus aureus, Salmonella typhosa* and other non-desirable bacteria. These probiotics are effective against colon cancer and increase mineral availability which postpones or/and prevent osteoporosis and anaemia in females. They can also affect lipid metabolism, increase the immune response, reduce blood pressure and help in liver detoxification (Martínez-Villaluenga et al., 2008).

5.3 Inhibition of Antinutritional Activities in Fava-Bean

We can observe that anti-nutrients have a negative impact on diet value by lowering the nutritional content of meals. Apart from their ability to reduce certain minerals and nutrients, these anti-nutrients may induce toxicity if they are consumed in large amounts. Reduced anti-nutritional content of foods is of major significance for these reasons. To reduce these anti-nutritional components in foods, many traditional and technology processing procedures including soaking, dehulling, germination, and fermentation have been applied. For inactivation, temperature, heating time, particle size, moisture and crop species are the main factors while considering heat processing treatment in Faba beans. On the other hand, the solubility, digestibility, time of treatments, enzymatic activities are some major factors affecting during non-thermal processing of inactivation. Following are some processing procedures described here that are used to reduce antinutrient concentrations.

In this section, the antinutrients are reduced to some extent so that the food can be consumable. Mainly the beans are consumed after treatments or during the storage period. The factors are inactivated in such a way that after the storage period is over, they will not be increased. Both non-thermal and thermal processing methods are used for the inactivation of antinutrients.



5.3.1 Non-heat Processing

The non-thermal treatments are adopted for the inactivation of antinutrients where the temperature has no role inthereduction. These are some traditional methods mainly operated for small scale purposes. Soaking (imbibition), dehulling, fermentation, germination are some non-thermal treatments mainly used for the inactivation of antinutrients in Fababeans.

5.3.1.1 Soaking

Cooking, dehulling, canning, germination and all need soaking. It entails immersing the seeds in water for an extended period, generally until reach their saturation zone. The conventional process for domestic preparation involves soaking the seeds in tap water for a length of time (typically overnight, 12 h), then heating the rehydrated seeds after discarding the soaked water. The type of faba bean used the length of the procedure, pH, temperature and soaking media's salinity may influence the outcome. As a result, as the temperature rises, the rate of water absorption reduces, while the concentration of sodium bicarbonate ($NaHCO_3$) in soaking solutions rises.

The data reveal that after soaking, there are almost no changes in lipid content. In addition, the protein present in the cotyledons is decreased. But the significant loss in crude fibre content is seen and this is caused due to the leaching of the compounds in the water. Total content of sodium, calcium, and zinc in the soaked beans are essentially unchanged, while potassium, copper, and magnesium levels are significantly reduced. These is also because of the leaching out of those minerals in the soaking medium which is based on the soaking media and the amount of time spent in soaking. However, several minerals have better hydrochloric acid HCl extractability, and phytic acid levels are decreased after soaking. While soaking in tap water or sodium bicarbonate solution, the thiamine content declines; however, when soaking in citric acid solution, the thiamine level remains the same. But in basic solutions, the highest vitamin losses were observed. When the pH increases, because of the chemical instability of thiamine and, to a lesser extent, riboflavin, they disintegrate at quicker rates.

Soaking significantly decreases tannins and phytic acids due to the leaching out process that occurs during hydration. The concentration of tannins is lowered by nearly half, and the longer is the soaking duration, the greater will be the reduction. During soaking the phytase get activated and phytic acid gets hydrolysed into free orthophosphate and myo-inositol, which results in changes in phytic acid concentration. The action of trypsin inhibitors and saponin reduce dramatically because of soaking, which increase the water solubility of them andthey leach out from seeds to the soaking media. Despite the fact that lectins are leached out because of soaking, but they remain in seeds in such an adequate amount that they cause agglutination of rabbit erythrocytes, but the activity of hemagglutinin is almost unchanged.

5.3.1.2 Dehulling

The goal of a dehulling is to remove the husk from any grain or seed with the least amount of damage to the bran layer and as little breakage as feasible. It can be subdivided into two methods for example wet milling method and dry milling method. It is a mechanical procedure that involves removing the hulls from the beans, which are mostly made up of tannins. Thephytic acid concentration increase per unit mass after dehulling, but the tannin and the polyphenol content may decrease, despite the fact that both are largely present in the hull. Dehulling cause the lowering of tannin contain up to 95% while it reduces the polyphenol content to 81%. Because oligosaccharides, resistant starch, and protease inhibitors are found in the cotyledons, dehulling does not eliminate their effects. Dehulling process increases the protein and amino acid content while lowering the fat, sugar, and crude fibre levels in the fababean. After dehulling, there is an improvement in in-vitro protein and starch digestibility, which might be due to the partial elimination of these antinutrients (Rahate et al., 2021).

5.3.1.3 Germination

Germinating legumes are some of the most effective strategies to improve their nutritional content and reduce the harmful effects of antinutrients. Germination mobilises the reserve resources necessary for plant development by hydrolysing proteins and storing carbohydrates in order to obtain the requisite nutrients for the development of seed. Seed's enzymatic activity increases during germination, increase protease activity and, as a result, protein nitrogen declines, while peptides, polypeptides, and non-protein amino acids rise. For example, after 3 days of germination, Viciafaba beans have been recorded the highest protein mobilisation by hydrolysis. During germination, carbohydrates are hydrolysed and used, and digestibility of starch increases in legumes. Simultaneously, the amount of various other nutrients, such as vitamins and minerals including ascorbic acid and B-group vitamins, and simple carbohydrates, is raised. Moreover, germination boosts seed sprouts' antinutritional capability and improves their organoleptic qualities.

The calcium concentration of germinated vs. cooked samples is increased by around 6%, which might be connected to the reduction in phytic acid. The reduction in hemicelluloses content enhancescalcium absorption and bioavailability. The phytic acid acts as a phosphorus reserve, which is unregulated during germination by phytase activity and can enhancephosphorus bioavailability. The levels of phytic acid, polyphenols, and condensed tannins, as well as the activities of trypsin, chymotrypsin, and α-amylase inhibitors, are decreased after 24–72 h of germination. In comparison to raw faba beans, the germinated seeds have revealed no variations in haemagglutinating activity. InVitro Protein Digestibilityis enhanced during germination due to a reduction in antinutritional agents (Gulewicz et al., 2014).

5.3.1.4 Fermentation

Fermentation is among the most ancient and cost-effective methods of food processing and preservation. Fermentation is the chemical breakdown of a material, which is mostly accomplished by microbes. Fermenting legumes improves their sensory qualities, such as flavour and taste, as well as the concentration and nutrient availability. Fermentation also prevents the multiplication of pathogenicfungiand acid-intolerant bacteria by raising the titratable acidity and lowering pH below 4.5, allowing the fermented legumesto last longer. The nutritional value of grains is found to be improved by fermenting them to increase the level of key amino acids such as lysine, methionine, and tryptophan. Fermentation also creates ideal pH environment for enzymatic phytate breakdown, which is found in grains, legumes as complexes with polyvalent cations such asmagnesium, zinc, iron, calcium and proteins. The quantity of soluble iron, zinc, and calcium may rise by many folds as phytate levels are reduced. Tannin levels may be lowered by lactic acid fermentation, resulting in the enhancement of iron absorption.

To see if the chemical changes that occur during fermentation alter the antinutritional components contained in faba beans, researchers used lactic acid bacteria *Lactobacillus plantarum* (*VTT E 133328*) to ferment the beans. Fermentation is found to be helpful in lowering antinutritional elements in faba beans, as well as fully eliminating the favism-causing chemicals. Not only this treatment reduces ANF concentration, but it also increased protein and starch digestibility, as well as increased the number of free amino acids and amino butyric acid (GABA) present in faba bean. The hydrolysis index is reduced by GABA, a non-protein amino acid that acts as a neurotransmitter in mammal's brains. Natural fermentation has been shown to eliminate tannins, phytic acid, and trypsin inhibitor activities partially or completely. Fermentation at 30 °C for 48 h with a final pH of 4.1 can decrease the concentration of Vicine and Convicine by 91% and the amount of trypsin inhibitor and condensed tannins is lowered by more than 40% (Rahate et al., 2021).

5.3.2 Heat Processing

In thermal treatments, the temperature plays an important role in the inactivation of antinutrients of Faba beans. These treatments are mostly used in large scale industries to achieve nutritional beans in less time. Although the treatments have been adopted in most of the processing sectors, the major drawback is the reduction of some thermolabile compounds atvery high temperatures. Cooking, autoclaving, microwave roasting, extraction are some thermal treatments operated for the inactivation of antinutrients in Faba beans.

5.3.2.1 Cooking and Autoclaving

Cooking is possibly the earliest method of preparing legumes for consumption. It generally involves soaking the seeds first and at around 30–90 min cooks them into the boiling water. It is seen that heating can decreases antinutritionalvalue and so improves the bioavailability of nutrients. The lengthy boiling period diminishes the nutritive quality of food stuffin comparison of withthe short period of treatment. Salts of mineralifadded in cooking media, they might help to speed up the cooking process. Autoclaving or sterilisation techniques, on the other hand, employ greater temperatures (around 121 °C) and lesser timeframes (around 15–45 min), boosting nutritional value and extending shelf life. As per study, there are no significant variations in crude protein content were observedbetween untreated and heat-treated faba beans, whereas autoclave treatment leads to decreasethe protein content. Furthermore, cookedfaba beans showed higher availability of essential amino acids and also enhance the in vitro protein digestibility. However, they reduce the amount of sulphur-containing amino acids by a little amount. In contrast, these phenomena help to reduce the ANFs compounds (like: tannin, phytic acid, and trypsin inhibitor) in cooked sample.

After heat treatment, the lipid content, reducing sugars, and total carbohydrates exhibit essentially little change. On the other hand, hydrothermal processing promotes the starch retrogradationwhich could be attributed to the formation of helix structure and leaching of amylose as a result starch digestibility may decrease. Interestingly, prior soaking processmayreducethe crude fibre contentup to 35%. Hydrothermal processing depolymerises the pectin components, converts them from insoluble to soluble dietary fibre fraction ratio. Mineral contents, such as sodium, magnesium, and manganese, are also decreased slightly as a result of the heat treatment. Cooking after soaking reduces vitamin content even more than soaking alone. In addition, the longer the cooking time, the more vitamins are lost. This is why autoclaved faba beans contain and retain more B-group vitamins than cooked fababeans. In terms of antinutrients, heated beans have much fewer tannins and phytic acid, and autoclaving reduces both substances more effectively than cooking. Autoclaving and a long enough cooking time eradicate hemagglutinin activity altogether. Becauselectin activity is generally heat-resistant, the low duration heating by cooking treatment after soaking, there is chance to detect lectin in faba bean. Autoclave treatment is more effective than cooking when compare to lowering the trypsin inhibitor activity. In most of the cases, higher cooking temperature having shorter durationcould be minimize the protease-inhibiting activity rather than lower cooking temperature for longer period of time. As saponins are thermolabile, thesaponin content of soaked seeds is reduced by heating and autoclaving; the longer the autoclaving duration, the greater the saponin losses.

5.3.2.2 Microwaves Treatment (Roasting)

Microwaves are a region of the electromagnetic spectrum with frequencies ranging from 0.3 to 300 GHz that are employed in a wide variety of food applications by encroaching on dielectric food materials. Microwave roasting has various advantages over traditional techniques, including heating at high-temperatures short-time, less nutritional degradation, and a greater end product quality. In food items such as kabuli chickpea, horse chestnut, velvet bean, buckwheat, fababean, black soybean and others, microwave application has been observed to alter ANFs such as saponins, phytic acid, tannins, trypsin inhibitors, and oxalate. A portion of the energy in microwave heating is absorbed, while the rest is transmitted and reflected and these energies dissipate the heat. The working principle of microwave heating is based on "dipole rotation" and "ionic conduction." Water is the most common polar molecule in food, and it plays an important role in microwave treatment. Water molecules' dipoles try to align themselves with the applied electric field. Because the electromagnetic field of the microwave changes it direction continuously from positive to negative and repeat again, the dipoles reverse their orientations at the same frequency, creating frictional heat. Ionic compounds are also heated by microwaves and as per microwave frequency and the net electric field; the positive ions accelerate in one direction and the negative ions in the other way. When charged ions hit a neighbouring particle, their kinetic energy is converted to thermal energy, which generates heat. Because ANFs are heat-labile, the heat created within the food stuff by microwave treatment decreases the ANFs. Deamidation (breaking of covalent bonds), peptide bond's hydrolysis, and destruction or transfer of disulphide bonds are all involved in the heat degradation of ANFs.

Microwave treatment may largely affect the phytic acids as they are heat-labile in nature and may develop in soluble complexes with other compounds. Free radicals produced by microwave treatment result in low amounts of inositol and inositol phosphate, lowering phytic acid concentration. The inactivation of trypsin inhibitors is caused by the denaturation of thermally unstable proteins and the degradation of sulfhydryl and disulphide (-S-S-) groups that are vulnerable to microwave damage. Additionally, microwave treatment can reduce tannins and saponins as they also exhibit thermo-labile properties (Suhag et al., 2021).

5.3.2.3 Extrusion

Food extrusion processing is a completely automated method that allows for improved process control and energy efficiency while cooking. Extrusion processing is ideal for achieving a higher level of nutrient retention since it operates at a high temperature and for a short period. This process causes the covalent bonds in biopolymers to break down and the structural disturbance to intensify, allowing the end products to be more texturized. It was first confined to combining and creating ready-to-eat cereal pellets and macaroni in the 1980s. This processing treatment, on the other hand, has been popularised and used for a variety of applications, ranging from the development of sweet and salty snacks to ready-to-eat cereals, bread crumbs, expanded products, croutons for salads and soups, dried and expanded pet foods, texturized meat and vegetable proteins, co-extruded snacks, pasta, precooked baby food, dry beverage mixes, chewing gum, confectioneryitems and many more. The use of the extrusion technique offers various advantages, including starch gelatinization, reduced lipid oxidation, increased soluble dietary fibres, and decreased ANFs.

Extrusion is a process using high temperature for short time period that combines heat and mass transfer, blending, reduction of particle size, shearing, texturizing, melting, caramelising, and shaping. During the process of extrusion, extrudate passes through the extruder while being driven through an aperture or a die by a large piston or a big, tight fitted revolving screw placed within a stationary barrel. Along the barrel, the screw's role is to transport, compress, and then knead the extrudate into a plasticized material. The cooked extrudate is forced through a tiny die with a design/shape specific to the desired extruded product at the end of the barrel and then cut with a sharp blade to produce the required size/length. Single and twin-screw extruders are the most regularly used extruders in the food sector.

The process factors such as barrel temperature, screw speed, moisture content of feed, and the extrusion pressure determine the efficiency of extrusion process and the reduction of ANFs. The extrusion technique has raised the enzymatic digestibility of starch in faba beans from 11.39% to 85.05%. Extrusion can efficiently inactivate trypsin, chymotrypsin, α-amylase inhibitors and haemagglutinin activity in food items without changing the protein content. Preconditioning before extrusion processing may increase the nutritional value of the components by lowering trypsin inhibitor levels considerably. After extrusion, phytic acid concentration in faba beans has significantly reduced up to 26.7%. Extrusion results in a considerable decrease in condensed tannins of around 54.4%. Because the distribution of specific ANFs in a seed varies mostly in different species (e.g., phytate is found in the aleurone layer and bran, tannins are primarily found in the Testa), pre-treatment such as milling (a process of size reduction) and dehulling (removal of hull) may be required to adequately reduce some ANFs before using them as a raw material for extrusion.

5.3.3 Genetic Improvement

Non-nutritive substances can be altered by improving nutritive value genetically. Genetic improvement in plant breeding reduces vicine and convicine and tannin levels in faba. Genetic change may occur naturally in nature in classical plant breeding, and humans are tried the same in their genetically engineered plants for crop developments. Plant breeding in the classical sense is more commonly done in a controlled environment, with planned and particular crossings to optimise the benefits of each parent into a new genotype. This strategy can only be used when there is considerable genotypic diversity within the species or among wild species belonging to the same family. By inserting or removing known single genes, genetic engineering allows for selective mutation. Modern genetic research looks at the prospect of responding more swiftly to the information stored in genetic code by combining genes from various species or altering gene expression to create genetically engineered organisms (GMO). GMOs, particularly genetically modified plants, offer a significant field that is one of the most promising study topics in agriculture, food, and health.

Viciafaba L. is a diploid plant having 6 pairs of exceptionally large chromosomes with approximately 13 Gbp of haploid genome. In this chromosome 1 is metacentric whereas the other chromosomes are sub-metacentric. The first Faba bean molecular marker is made on the basis of both Isozymes and RAPD markers. The molecular marker map of faba bean is composed of 66 markers adorn in 11 linkage group. According to (2008), gene based genetic map of *Viciafaba L.* consists of 127 Intron Targeted Amplified Polymorphism Markers (ITAP). Currently 551 single polynucleotide polymorphisms (SNPs) and 71 Simple sequence repeat (SSR) molecular markers are recognized in genetic map of Faba bean (Kaur et al., 2014).

The presence of antinutritional factors curtailed the cultivation and consumption of faba bean albeit it has great economic and environmental benefits. As vicine and convicine has a negative impact on nutritional value and digestibility of monogastric animals, development of vicine and convicine free cultivar is the primary motive to ameliorate the nutritional quality and expand the use of this legume crop as a feeding material. In faba bean, low vicine-convicine phenotype is under control of two recessive genes $vc^{-}$and *vcr.* These genes are identified by screening a large number of *ViciafabaL.*germplasm throughout the world in between the time period 1970–1980. This vc^{-} is present at 0.21 cM locus on chromosome number 1. In the recent year, (Björnsdotter et al., 2021) identified a gene *VC1* which is involved in the biosynthesis of vicine and convicine. They found that an insertion in the coding sequence of *VC1* gene inactivates theVC1 and GTP Cyclohydrolase enzyme, which further lowers the level of vicine and convicine in faba bean cultivar. A silent mutation within the *evg 1250620* gene fragment coded by a single nucleotide polymorphism differentiates a low vicine-convicine cultivar from the wild one. From the current studies it was found that the insertion of AT sequence in the GTP Cyclohydrolase 2 domain of VC1 gene is one of the reasons of low vicine convicine phenotype in different cultivar (Björnsdotter et al., 2021).

In faba bean, zero tannin phenotype (i.e. white colored flowers) are under the control of two recessive genes *zt1* and *zt2*, these two genes are present on chromosome 2 and chromosome 3 respectively. These two genes are also complementary to each other, i.e. if any of them present in the faba plant, low tannins are produced. Expression of *zt1* gene depends on the transcription factor WD40. This WD40 protein is produced by transcription and translation of *TTG1* gene which is present on Chromosome number 2. Furthermore this *TTG1* gene have two alleles *ttg1-a* and *ttg1-b*; *ttg1-a* arises from mutation in the promoter region of wild genes while *ttg1-b* arises from deletion in the 5′ end of wild genes. In *Viciafaba L. TTG1* gene and its open reading frame is made up of 1605 bp and 1032 bp respectively. Sequence alignment between low–tannin cultivar and wild types revealed 3 single nucleotide polymorphisms (SNP). In the first one adenine (A) is replaced by guanine (G) at a position of 244 bp, resulting in the change glutamic acid to glycine in the amino sequence of *zt1* lines. In the second cytosine (C) is replaced by thymine (T) at a position of 469 bp, resulting in the change of leucine to proline in zt1 lines. Above two mutations are missense mutation and lastly at a position of 855 bp, adenine (A) is replaced by cytocine (C) and shows no effect on the amino acid sequence (i.e. Silent mutation) found on low-tannin phenotype faba plant. Difference between dominant *ZT2* and recessive *zt2* gene, is the presence of KASP marker (one kind SNP marker) on *zt2* located on 10.5 cM of Chromosome 3. For the expressions of zt2 gene, bHLH (basic Helix loop Helix) transcription factor is required which is further coded by TT8 (Transparent testa 8) gene located on Chromosome3 (Gutierrez et al., 2020).

5.4 Conclusion

Though legumes are the third-largest producing crop around the world, the presence of antinational factors pressurizes the nutritional availabilities of those. Faba beans are, one of the legumes mainly found in most Asian countries, known for their high protein content; but the bioavailability of unprocessed beans is very less due to the presence of antinutrients- lectins, saponins, trypsin inhibitors, phytic acid, vicine and co-vicine and son on. While consuming along with these antinutritional factors, several diseases such as vomiting, diarrhoea, abdominal cramps, fever, chronic diseases and so on are generally seen in humans as well animals. Besides, enzymatic inactivation, obstruction of cellular proliferation, initiation of haemolysis, reduction of protein digestibility and solubility, lowering of mineral absorption are some endogenous destructive activities are caused by consuming the beans along with antinutrients. Thus, the reduction of antinutrients to some extent amounts by means of some treatments in which the consumption of beans may advisable. Non-thermal and thermal treatments are operated in both small scale and large-scale processing industries. Temperature, treatment time, moisture, solvent, particle size, type of crop are some factors affecting the inactivation of antinutrients by several treatments. Soaking, dehulling, fermentation, germination, cooking, autoclaving, roasting, extrusion are some of the treatments to inactive the antinutrients in Faba beans. Furthermore, genetic improvement is an advanced reduction method in which the amount of antinutrients is diminished almost. By inserting and removing the gens from several breeds of Faba beans can produce a new gene of the breed with the improvement of nutritional availability and inactivation of antinutritional factors.

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Chapter 6
Faba-Bean Antioxidant and Bioactive Composition: Biochemistry and Functionality

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Abbreviations

ABTS	2,2-azino-bis (3-ethylbenzothiazoline-6-sulphonic acid)
ACE	Angiotensin Converting Enzyme
AChE	Acetylcholinesterase
ALA	Alanine aminotransferase
ALKP	Alkaline phosphatase
AD	Alzheimer Disease
AST	Aspartate aminotransferase
b.w	Body Weight
BHA	Butylated hydroxyl anisole
BHT	Butylated hydroxyl toluene
bis-HHDP-glucose	*bis* (hexahydroxydiphenoyl)-glucose
DNA	Deoxyribonucleic acid
DPPH	2,2-diphenyl-1-picrylhydrazyl
DW	Dry weight
EAA	Essential amino acids
FFAs	Free fatty acids
FRAP	Ferric Reducing Antioxidant Power
FST	Forced swimming test
GABAA	γ-aminobutyric acid A
GC-MS	Gas Chromatography-Mass Spectrometry
H_2O_2	Hydrogen peroxide
HIV-1	Human Immunodeficiency Virus-1

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IC_{50}	Inhibitory Concentration in 50% of Population
15-LOX	15-lipoxygenase
LAA	Limiting amino acids
L-Dopa	β-(3,4-Dihydroxyphenyl)-L-alanine
$MBIC_{50}$	Minimal Biofilm Inhibition Concentration 50%
MCF7	Michigan Cancer Foundation-7
PD	Parkinson's disease
s.c.	Subcutaneous
TEAA	Total essential amino acids
TMTT	(*E, E*)-4,8,12- trimethyl-1,3,7,11-tridecatetraene
TST	Tail suspension tests
UFA	Unsaturated fatty acids
V.f	*Vicia faba*
w/w	Weight by weight
WHO	World Health Organization
µg	Microgram

6.1 Introduction

Vicia faba (L) commonly known as Bell Bean, Broad Bean, Fava Bean, Faba Bean, Field Bean, Horse Bean, Tick Bean, Windsor Bean and it belongs to the Fabaceae family. The only way to grow the *V. faba* is to cultivate it. Some scholars, however, believed its origins can be traced back to South West Asia and North Africa. Near Eastern is the origin center of *V. faba* and Afghanistan and Ethiopia are the secondary centers of diversity (Cubero, 1973). However, Ladizinsky (1975) proposed Central Asia as the origin of faba bean. *V. faba* is widely grown vegetable in many nations namely China, India, South America and Middle-Eastern Europe (Ladizinsky 1975; Duc et al., 2010).

6.1.1 Botanical Description

Vicia faba is a self-fertile, hard, erect plants, and 0.5–1.8 m tall, containing one or more hollow but straight stems (Fig. 6.1).

The leaves are distichous, pinnate with 2–7 leaflets. Leaf is 10–25 cm long and green in colour (Kay, 1979; Duke, 1981; Bond et al., 1985; Heath et al., 1994). The flowers of the faba bean are big and white with dark purple spots. Flowers range in length from 1.0 to 2.5 cm and have five white petals. Faba bean plant produced a pod with three to eight seeds. Pods grow up to 15–25 cm in length and seeds are 2.0–3.0 cm long, 5–10 mm thick, and oval usually flattened (Patrick & Stoddard, 2010). Roots are taproot with branched secondary roots. *Rhizobium*

(1) *Vicia faba* Linn. (Faba bean) Plant

(2) *Vicia faba* Linn. (Faba bean) Flower

(3) *Vicia faba* Linn. (Faba bean) Pods

(4) *Vicia faba* Linn. (Faba bean) Fresh Seeds

(5) *Vicia faba* Linn. (Faba bean) Dried Seeds

Fig. 6.1 Pictures of different parts of *Vicia faba* Linn. (Faba bean) plant

leguminosarum bv. Viciae, a rhizobial bacteria which is capable to fix atmospheric N_2, forms symbiotic nodules with Faba bean roots (Bond et al., 1985).

V. faba seeds are having high nutritional value because of rich content of amino-acids and starch, and is widely utilized as a food and feed legume (Asaduzzaman & Asao, 2012; Duc et al., 2010). It was also discovered that *V. faba* seeds are a potential dietary fiber source as well as a number of macro and micro-nutrients for both humans and animals (Hacıseferogulları et al., 2003). Faba beans are the good source of phenolics compounds and have strong antioxidant activities. Furthermore, high phenol consumption has been linked to decrease the risk of heart & cancer disease. Fruits and vegetables' phenolic content and antioxidant activity are influenced by a variety of variables, such as stage of maturity & heating (Han & Baik, 2008; Maisarah et al., 2013; Wolosiak et al., 2010).

6.1.2 Edible Parts

The dry, mature seeds are used in cuisines all throughout the China, Ethiopia, Mediterranean countries, and Middle East, and green immature seeds and pods are consumed as a vegetable in many other nations.

6.1.3 Traditional Uses

In the developing nations, faba bean is used as a while in the developed nations, used as feed for animals, primarily for horses, pigeons, pigs, and poultry. Green or dried faba beans are used as a vegetable. Broad bean is a popular breakfast meal in the Mediterranean countries, China, Ethiopia, & Middle East (Bond et al., 1985). Different species of *Vicia* genus have been traditionally utilized as a well-known drug for a wide range of health issues around the globe (Mejri et al., 2018). As per the WHO report, majority of the people from the developing countries still relies on traditional cures prepared from natural sources for their primary health care needs. A large number of people especially in areas that have difficulty to access modern pharmaceuticals completely depend on traditional uses of natural medicine for acute and chronic ailments (Carmona & Pereira, 2013).

Plants from the genus *Vicia* have been used to cure a variety of chronic illnesses, namely; cancer, diabetes, and cardiovascular diseases (Spanou et al., 2008).

The Traditional Uses of *Vicia faba* Linn. plant is presented in the Table 6.1.

6.1.4 Phytochemistry of Vicia faba *Linn. Plant*

The phytochemistry and related aspects of all the parts of *Vicia faba* Linn. plant have been extensively studied over the past six-seven decades. The phytochemical analysis has resulted in the isolation, separation and characterization of hundreds of minor and major phytoconstituents of diverse chemical classes. *V. faba* is reported to contain organic acids, amino acid and peptide derivatives, alkaloids, flavonoids, triterpenic acids, phenolic acids, tannins, volatile oils, fatty acids, saponins etc. However, maximum numbers of compounds have been isolated from the *Vicia faba* pods (Tables 6.2, 6.3, 6.4, 6.5, 6.6, 6.7, 6.8, 6.9, 6.10, 6.11, 6.12, 6.13, and 6.14) Fig. 6.2.

Table 6.1 Traditional uses of *Vicia faba* Linn. plant

Country	Part used	Ailments/medicinal uses	References
China	Seeds	Loss of appetite, splenic impairment, and stomach disturbances	Singh et al. (2012a)
China	Leaves	To stop bleeding	Au et al. (2008)
India	Seeds and fruits rind	Control of hemolytic anemia, hypertension, malaria, and Parkinson's disease	Sumitra et al. (2010)
Turkey	Seeds and fruits	In the folk medicine, used as depilatory and diuretic	Güler et al. (2015)
Turkey	Fruits, aerial parts	As a carminative herb, for treatment of athetosis, costiveness, dyspepsia, and intestinal spasm	Sargin et al. (2015)
Turkey	Leaves	Remediation for Alzheimer Disease (AD)	Sargin (2015)
Spain	Seeds	Anemia infusion	Alarcón et al. (2015)
Balearic Islands (Spain)	Seeds	Purgative anti-metrorrhagia	Carrió and Vallès (2012)
Palestine	Plant	Prostate disorders	Ali-Shtayeh et al. (2000)
Latium: Central Italy	Seeds	To remove of thorns on the skin	Guarrera et al. (2005)
Central Italy	Seeds	Eyewash	Leporatti and Pavesi (1990)
Central-Eastern Italy	Fruits	To stop bruising	Pieroni et al. (2004)
Morocco	Seeds	Ailments of the respiratory system, allergies, & diabetes mellitus	Fakchich and Elachouri (2014)
Spain: Southern	Leaves	Pimples treatment, blisters, and infections of nails	Benítez et al. (2010)
Canary Islands (Spain)	Seeds	For burns healing	Darias et al. (1989)
Bosnia and Herzegovina	Flowers and seeds	Kidney disease and inflammations of urinary bladder, and disorders of the skin	Šaric-Kundalic et al. (2011)
Bolivia	Inflorescence	Cough relieving	Macıaa et al. (2005)
Belarus	Seeds	Diarrhea	Sõukand et al. (2017)
Pakistan	Leaves	Also used as a diuretic and to treat eye infections	Zahoor et al. (2017)
Pakistan	Seeds	Stomach ulcer	Abbas et al. (2017)
Pakistan	Leaves	Kidney pain and eye infection	Abbasi et al. (2015)
Tigray region, Ethiopia	Seeds	External wounds and swelling caused by anthrax	Teklay et al. (2013)
Greece and Rome	Seeds	Diuretic, expectorant, tonic, cirrhosis of the liver, Parkinson’s disease, kidney failure, hypertension and as an alternative to Viagra	Singh et al. (2012a, b)

Table 6.2 Organic acids

S. No.	Plant parts used	Chemical compound	Reference
1.	Pods	Citric acid, Fukiic acid & 3′-O-Methyl (3′,4′-dihydroxybenzyl tartaric acid), Hydroxyeucomic acid, Malic acid, and Oxalo-succinic acid	Abu-Reidah et al. (2017), Abozeid et al. (2018), Amarowicz and Shahidi (2018), Boukhanouf et al. (2016), Choudhary and Mishra (2018), Hoganesyan et al. (2004), Kwon et al. (2018), Lee et al. (2017), Megías et al. (2016)

Table 6.3 Amino acid and peptide derivatives

S. No.	Plant parts used	Chemical compound	Reference
1.	Pods	Dipeptide (Aspartyl-proline), Fructose-leucine, (Iso)leucine, *L*-dopa-glucoside L-tryptophan, Monosaccharide-amino acid, *O*-glycoside non-proteogenic amino acid, Tyrosine, and Vicine	Abu-Reidah et al. (2017), Abozeid et al. (2018), Amarowicz and Shahidi (2018), Boukhanouf et al. (2016), Choudhary and Mishra (2018), Hoganesyan et al. (2004), Kwon et al. (2018), Lee et al. (2017), Megías et al. (2016)
2.	Seeds	Alanine, Argenine, Aspartic acid (AA), Cysteine, Glutamic acid (GA), Glycine, Histidine, Iisoleucine, Leucine, Lysine, Mmethione, Phenylalanine, Proline, Serine, Threonine, Tyrosine, & Valine	Kasim (2006)
3.	Testa-free broad-bean seeds	Lectins (Glycopeptide)	Anthony et al. (1976)
4	Seed-cotyledons	***EAA*** Cystine, Histidine, Isoleucine, LAA, Leucine, Lysine, Methionine, Methionine + Cystine, Phenylalanine, TEAA, Threonine, Tyrosine, & Valine ***Non-EAA*** Alanine, Aspartic acid (AA), Arginine, Glutamic acid (GA), Glycine, Proline, & Serine	Golam et al. (2009)
5.	Seeds	***EAA:*** Arginine, Histidine, Isoleucine, Leucine, Lysine, Methionine, Phenylalanine, Threonine, Tryptophan, & Valine ***NEEA:*** Alanine, Aspartic acid (AA), Cystine, Glutamic acid (GA), Glycine, Proline, Serine, & Tyrosine	Alghamdi (2009)
6.	Seeds	Convicilin, vicilin, legumin and defensin	Warsame et al. (2020)

Table 6.4 Phenolic compounds and derivatives

S. No.	Plant parts used	Chemical compounds	Reference
1.	Pods	Caffeoylhexose, Caffeoylmalic acid (phaseolic acid), Coumaroyl hexose I, Coumaroylhexose II, Cutaric acid hexoside, Ellagic acid, Ferulic acid hexoside I, Ferulic acid hexoside II, Fukiic acid, Gallic acid, Methyl fukiic acid, *p*-Coumaroyl-malic acid I, *p*-Coumaroyl-malic acid II, *p*-Coumaroyl-malic acid III, Piscidic acid, Quercetin-rhamnoside, Salicylic acid hexoside, Salicylic acid, Syringic acid, Vanillin hexoside, Caffeoyl hexose, Coumaroyl hexose II, Coutaric acid or Phaseolic acid, Di-*O*-feruloylsucrose, Ferulic acid, Feruloyl-malic acid, Hydroxytrimesic acid trimethyl ester, Methylferulic acid, *O*-Methylpiscidic acid, Sinapic acid, and Sinapoylhexose	Abu-Reidah et al. (2017), Abozeid et al. (2018), Amarowicz and Shahidi (2018), Boukhanouf et al. (2016), Choudhary and Mishra (2018), Hoganesyan et al. (2004), Kwon et al. (2018), Lee et al. (2017), Megías et al. (2016)
2.	Pods	Dihydrochrysin (or pinocembrin), (Epi) gallocatechin, Eucomic acid, Homovanillic acid hexoside, Protocatechuic acid hexoside, Salicylic acid glucoside, Syringic acid hexoside, and Taraxafolin B	Abu-Reidah et al. (2014)
3.	Pods	Cutaric acid hexoside	Baxter and Harborne (1999)
4.	Fruits	4-Amino benzoic acid, Benzoic acid, Caffeic acid, Caffeine, Catechein, Catechol, Chlorogenic acid, Cinnamic acid, α-Coumaric acid, Ferulic acid, Gallic acid, α-Hydroxy benzoic acid, *Iso*-ferulic acid, 3,4,5-Methoxycinnamic acid, Protocatchuic acid, and Pyrogallol	El-Feky et al. (2018)
5.	Pods	(*Epi*) Catechin, (*Epi*) Gallocatcehin, 3-Procyanidin dimer, Apigenin-O-dihexoside, *bis*-HHDP-glucose, Caffeic acid hexoside I, Caffeic acid hexoside II, Catechin, Delphinidin rhamnoside, Diosmetin-pentoside-hexoside, Kaempferol-3-O-rutinoside, *Iso*-rhamnetin diglucoside, Kaempferol dihexoside, Kaempferol-3-O-gucoside, *p*-Coumaroyl-malic acid, Pelargonidin-3-O-glucoside, Quercetin-hexose-deoxyhexose, Quercetin-rhamnoside, Salicylic acid hexoside, Tryptophan, and Verminoside	Mejri et al. (2018)
6.	Pods	3-Hydroxy-4-methoxyphenyllactic acid 3-*O*-Methylfukiic acid, 4-Caffeoylquinic acid, 5-Caffeoylquinic acid, Caffeic acid, *cis*- and *trans*-caffeic acid, *cis*-*p*-coumaric acid, Dicaffeoylquinic acid I, Dicaffeoylquinic acid II, Dihydrochrysin (pinocembrin), Eucomic acid, Ferulic acid, Feruloyl glycerol, Feruloyl malate, Guaiacyl (8-*O*-4) ferulic acid, Hydroxycinnamic acids derivatives of caffeic, coumaric & ferulic acids, Hydroxyeucomic acid, Hydroxyl methoxyphenyllactic acid, *p*-Coumaroyl malate (isomer 1), *p*-Coumaroyl malate (isomer 2), Piscidic acid ((*p*-Hydroxybenzyl) tartaric acid), Protocatechuic acid, Quercetin-3-*O*-rhamnoglucoside, Dicaffeoylquinic acid III, Salvianolic acid F, Sinapic acid, *trans*-*p*-coumaric acid, and Vanillic acid	Valente et al. (2018)

Table 6.5 Flavonoids and derivatives

S. No.	Plant parts used	Chemical compound	Reference
1.	Leaves	Kaempferol-3-glucoside-7-rhamnoside	Arisawa et al. (1971)
2.	Leaves	Kaempferol-3-*O*-*β*-D-glucosyl-7-*O*-rhamnoside, Quercetin-3-*O*-*β*-D-glucosyl-7-*O*-rhamnoside, Kaempferol 3,7-*O*-*bis*-*β*-D-glucoside, and Rutin (quercetin-3-rutinoside)	Knackstedt and Herrmann (1981)
3.	Seed coat	Quercetin, Kaempferol, Malvidin, Delphinidin, Petunidin, and Cyanidin glycoside	Nozzolillo et al. (1989)
4.	Leaves	Hyperoside, Kaempferol -3-rutinoside, Quercetin, Quercetin-3-arabinoside, Robinin,and Rutin	Perrino et al. (1989)
5.	Pods	Homoeriodictyol- (hydroxybutanoyl) hexosyl-hexoside, Kaempferol hexoside rhamnoside, and Phloretin	Hargreaves and Mansfield (1975), Baxter and Harborne (1999)
6.	Pods	Quercetin rhamnoside, 7-neohesperidoside of hesperetin or 7-rutinoside of hesperetin	Saber et al. (1998)
7.	Pods	Procyanidin B4, (−)- Epicatechin, Quercetin di- hexoside, and Myricetin rhamnoside	Baxter and Harborne (1999)
8.	Pods	Hexosylrutin, Kaempferol 3- (2-xylosylrutinoside), Kaempferol xylopyranosyl rhamnoside rhamnoside, Myrciacitrin I, Myricetin-*O*-hexoside, Phloretin glucoside, Quercetin hexoside, Quercetin rhamnosyl rutinoside, Quercetin-arabinofuranoside, Geraldone (7,4′-dihydroxy-3′-methoxyflavone), *cis*- & *trans*-isomers of geraldone, Luteolin, Trihydroxy-methoxyflavones, Diosmetin or Chrysoeriol, and Dimethoxypterocarpan-hexo-acetate	Abu-Reidah et al. (2017)
9.	Aerial parts	Kaempferol rhamnosyl galactoside rhamnoside, and Quercetin rhamnosyl acetyl hexoside rhamnoside	Spanou et al. (2008)
10.	Seeds	Eriodictyol di-*C*-glucoside, Taxifolin hexoside, Catechin, Vicenin 2 (Apigenin 6,8- di-*C*-glucoside), Faralatroside, Apigenin disaccharide, Phloretin di-*C*-hexoside, Quercetin hexose deoxyhexose, Quercetin hexose deoxyhexose III, Quercetin pentose deoxyhexose, Myricetin dihexoside, Apigenin 8-*C*-glucoside (Isovitexin), Myricetin dihexoside II, Kaempferol deoxyhexose, Quercetin deoxyhexose, and Kaempferol rhamnoside	Abu-Reidah et al. (2014)

(continued)

Table 6.5 (continued)

S. No.	Plant parts used	Chemical compound	Reference
11.	Aerial parts (leaves and branches)	Kaempferol 3-*O*-(5-*O*-acetyl-α-D-apiofuranosyl)-7-*O*-α-L-rhamnopyranoside, Kaempferol 3-*O*-[α-L-rhamnopyranosyl(1→2)-β-D-galactopyranosyl]-7-*O*-α-L-rhamnopyranoside, Kaempferol 3-*O*-[α-L-rhamnopyranosyl(1→2)-β-D-glucopyranosyl]-7-*O*-α-L-rhamnopyranoside, Kaempferol 3-*O*-α-L-arabinopyranosyl-7-*O*-α-L-rhamnopyranoside, Kaempferol 3-*O*-α-L-rhamnopyranosyl-7-*O*-α-L-rhamnopyranoside, Kaempferol 3-*O*-β-D-apiofuranosyl-7-*O*-α-L-rhamnopyranoside, Kaempferol 3-*O*-β-D-galactopyranosyl--7-*O*-α-L-rhamnopyranoside, Kaempferol 3-*O*-β-D-glucopyranosyl-7-*O*-α-L-rhamnopyranoside, and Quercetin 3-*O*-[α-L-rhamnopyranosyl(1→2)-β-D-galactopyranosyl]-7-*O*-α-L-rhamnopyranoside	Tselepi et al. (2011)
12.	Seeds	Isoorientin, Kaempferolacetylhexoside, Neohesperidin dihydrochalcone, and Pelargonidin rutinoside	Prati et al. (2007)
13.	Fruits (eels)	Apigenin-6-arabinose-8-galactose, Apigenin-6-rhamnose-8-glucose, Naringin, Hesperidin, Rutin, Apigenin-7-*O*-neohespiroside, Kaempferol-3,7-dirhamnoside, Apigenin-7-glucose, Acacetin-7-*neo* hesperside, Acacetin *neo* rutinoside, Quercetin, Naringenin, Hespirtin, Kaempferol, Rhamentin, and Apigenin	El-Feky et al. (2018)
14.	Seeds	1,2,6-Trigalloylglucose dimer, 6,8-*C*-diglucosyl apigenin, Apigenin 7-*O*-galactoside, Epicatechin, Epicatechin isomer 1, and Epicatechin isomer 2	Kwon et al. (2018)
15.	Immature seeds	Gallotannin, Kaempferol 3-*O*-acetyl-dirhamnosyl hexoside, Kaempferol 3-*O*-acetyl-dirhamnosyl hexoside dimer, Kaempferol-3-*O*-*p*-coumaroyl hexoside, Kaempferol-3-*O*-rhamnosyl galactoside, Kaempferol-3-rutinoside, Luteolin-7-*O*-hexosyl-8-*C*-(6″-acetyl)-hexoside, Luteolin-7-*O*-hexosyl-8-*C*-(6″-acetyl)-hexoside isomer, Myricetin-3-*O*-glucoside, Myricetin-3-*O*-glucoside dimer, Procyanidin dimer 1, Procyanidin dimer 2, Prodelphinidin, Quercetin 3-*O*-rutinoside, Quercetin 3-*O*-rutinoside isomer 1, and Quercetin 3-*O*-rutinoside isomer 2	Cecilia et al. (2013)
16.	Beans & Pods	(−) Epicatechin, (+) Catechin, Myricetin, Quercetin-3-*O*-glucoside, Rutin, and Syringic acid	Loizzo et al. (2021)
17.	Leaves	Quercetin-3-*O*-rhamnoglucoside	Neugart et al. (2015)
18.	Pods	Kaempferol 3-*O*-glucoside, Kaempferol 7-*O*-glucoside, Apigenin glucoside, and Vicenin 2 (Apigenin-6,8-*C*-diglucoside) ***Quercetin di- and triglycosides:*** Quercetin-3-*O*-rhamnoside-7- *O*-rhamnoside, and Quercetin-3-*O*-rhamno arabinoside-7-*O*-rhamnoside	Valente et al. (2018)

(continued)

Table 6.5 (continued)

S. No.	Plant parts used	Chemical compound	Reference
19.	Pods	***Five flavonoid aglycons:*** 7,3′,4′-trihydroxy flavone, 7,4′-dihydroxyflavone, Geraldone, Butein, and Kaempferol ***Eight flavonol glycosides:*** Kaempferol 3-glucoside, 7-glucoside, 3-(2″-rhamnosyl) galactoside 7-rhamnoside, 3-galactoside 7-rhamnoside, 3-rhamnosyl-(6″-acetyl) galactoside 7-rhamnoside, and 3-(6″-acetyl) galactoside 7-rhamnoside and as Quercetin 3-galactoside 7-rhamnoside and 3-(6″-acetyl) galactoside 7-rhamnoside), Rhoifolin glucoside, Kaempferol 3-rhamnosyl acetyl galactoside rhamnoside I, Kaempferol hexoside rhamnoside I, Kaempferol rhamnosyl galactoside rhamnoside, Kaempferol- (rhamnosyl acetyl galactoside)-rhamnoside II, Kaempferol-acetyl glucoside-rhamnoside II, Kaempferol acetyl glucoside rhamnoside, Kaempferol 3- *O*-glucoside, Kaempferol 7- *O*-glucoside, Methyl epicatechin hexoside, Kaempferol-(rhamnosyl-acetyl-galactoside)-rhamnoside II, Noricaritin hexoside, and Luteolin	Tomas-Barberan et al. (1991)
20.	Leaves	Kaempferol 3-*O*-(2″-α-*l*-rhamnopyranosyl-6″-acetyl-β-*d*-galactopyranoside)-7-*O*-α-*l*-rhamnopyranoside, Kaempferol 3-*O*-(6″-acetyl-β-*d*-galactopyranoside)-7-*O*-α-l-rhamnopyranoside, Quercetin 3-O-(6″-acetyl-β-d-galactopyranoside)-7-O-α-l-rhamnopyranoside and their deacylated derivatives	Tomás-Lorente et al. (1989), Tomás-Lorente et al. (1990)

Table 6.6 Lignan derivatives

S. No.	Plant parts used	Chemical compounds	Reference
1.	Pods	(*Iso*)lariciresinol hexoside, Prinsepiol hexoside	Abu-Reidah et al. (2017)
2	Seeds	Guaiacylglycerol (8-*O*-4) ferulic acid, & ether hexoside of Guaiacylglycerol (8–*O*–4) ferulic acid	Valente et al. (2018)

Table 6.7 Terpenoids

S. No.	Plant parts used	Chemical compounds	Reference
1.	Pods and immature seeds	Gibberellin A29 and gibberellin A98	Abu-Reidah et al. (2017), Valente et al. (2018), Sponsel et al. (1979)

Table 6.8 Furanoacetylenic phytoalexins

S. No.	Plant parts used	Chemical compounds	Reference
1.	Pods	Wyerone acid and its methyl ester wyerone	Buzi et al. (2003), Fawcett et al. (1971), Ingham (1982), Letcher et al. (1970)
2.	Pod endocarp	Wyerone, Wyerone acid, Wyerone epoxide and Medicarpin, (3-hydroxy-9-methoxypterocarpan)	Hargreaves et al. (1976a), Hargreaves et al. (1976), Hargreaves et al. (1976c)
3.	Pods	PA_1 & PA_2	Hargreaves and Mansfield (1975) Mansfield et al. (1973)

Table 6.9 Oligosaccharide

S. No.	Plant parts used	Chemical compounds	Reference
1.	Pods	Raffinose, stachyose, and verbascose	Buzinet al. (2003); Fawcett et al. (1971), Ingham (1982)
2.	Seeds	***Oligosaccharides:*** Galactoinositol, Galactopinitol, Raffinose, Stachiose, Sucrose, and Verbascose ***NSP:*** Arabinose, Fucose, Galactose, Glucose, Mannose, Rhamnose, Uronic acids, and Xylose	Jolanta and Lucyna (1997)

Table 6.10 Alkaloids

S. No.	Plant parts used	Chemical compounds	Reference
1.	Pods	Convicine [2,4,5-trihydroxy-6-aminopyrimidine 5-(β-D-glucopyranoside)] and Vicine [2,6-diamino-4,5-dihydroxypyrimidine 5-(β-D-glucopyranoside)]	Ronald et al. (1983)

Table 6.11 Steroids

S. No.	Plant parts used	Chemical compounds	Reference
1.	Seeds	Free stigmasterol, Sitosterol ester, Campesterol, Stigmasterol and Sitosterol	Cerri et al. (1985)

Table 6.12 Saponins

S. No.	Plant parts used	Chemical compounds	Reference
1.	Seeds	***Group B saponins:*** Ba958, Bb – 942, Be – 912, Bd – 956 and Be 940 Compound 1 (MW 980) Compound 2 (MW 962) -CH_3 group in the sugar ring of saponin 2 instead of a -CH_2OH in saponin 1 Compound 1 (mw 978) compound 2 (mw 962)	Amarowicz et al. (1997), Amarowicz et al. (1998)

Table 6.13 Plant growth regulators

S. No.	Plant parts used	Chemical compounds	Reference
1.	Immature fruit	(−)-Jasmonic acid, (+)-7-*iso*-jasmonic acid, (+)-6-*epi*-7-*iso*-cucurbic acid, & (−)-9,10-dihydrojasmonic acid, 3,7-didehydrojasmonic acid	Miersch et al. (1989)

Table 6.14 Other phytochemicals

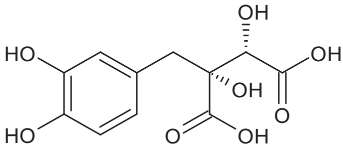
S. No.	Plant parts used	Chemical compounds	Reference
1.	Pods	Procyanidin B4 Cowanol and pelargonidin rutinoside	Baxter and Harborne (1999)
2.	Seeds	Phytic acid	Carnovale et al. (1988)
3.	Seed-coat	Dopa-O-β-d-glucoside	Nagasawa et al. (1961)
4.	Pods	(L-Dopa):β-(3,4-Dihydroxyphenyl)-L-alanine	Torquati (1913), Andrews and Pridham (1965), Guggenheim (1913)
5.	Seed globulins	Vicilin and legumin	Scholz & Manteuffel (1975)

6.1.5 *Essential Oil composition of* Vicia faba *Linn. Plant*

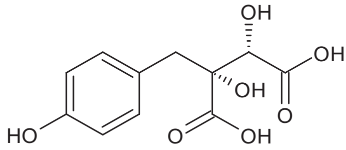
Among different phytoconstituents, one of the most intriguing types of natural substances for assuring a better and more ecologically friendly approach with proven anti-pest and antibacterial properties is essential oils (Christaki et al., 2012; Singh et al. 2012a, b)

Hampton attempted to identify the aroma of faba bean flowers for the first time in 1925. In the early 1920s and 1930s, the fragrance of faba bean flowers has been defined as aromatic., with a sweet aroma and a spicy quality. Eugenol and cinnamyl alcohol were commonly found in *Vicia faba* essential oils (Hampton, 1925).

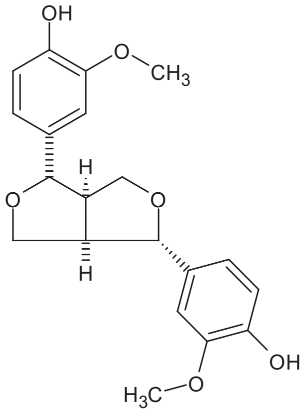
Monoterpene hydrocarbon (*E*)-ocimene was detected in quantifiable proportions of faba bean volatile (Sutton et al., 1992).



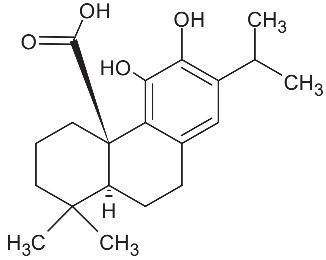
Fukiic acid



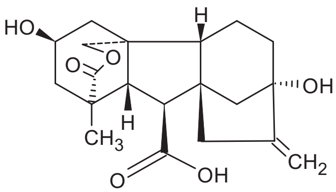
Piscidic acid



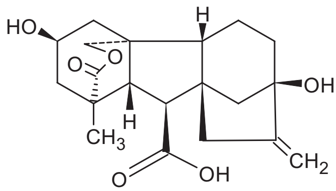
(+)-Pinoresinol



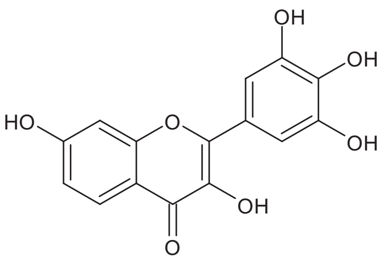
Carnosic acid



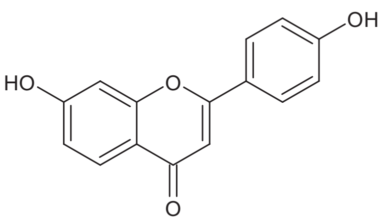
Gibberellin A98



Gibberellin A29

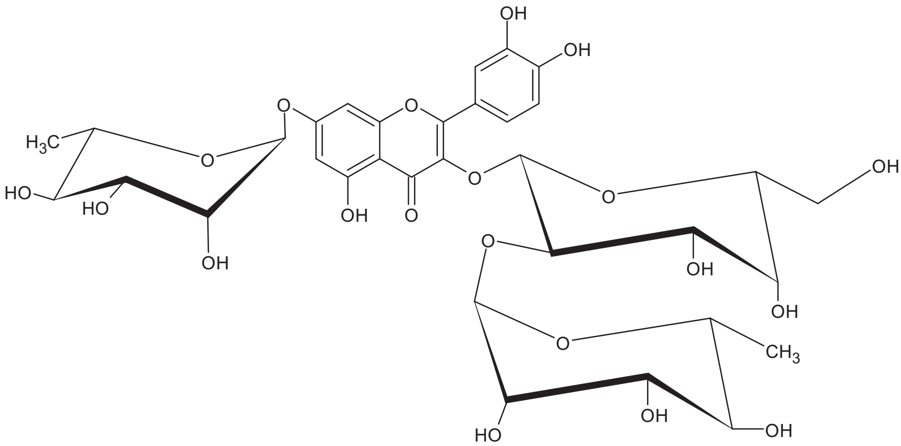


Myricetin

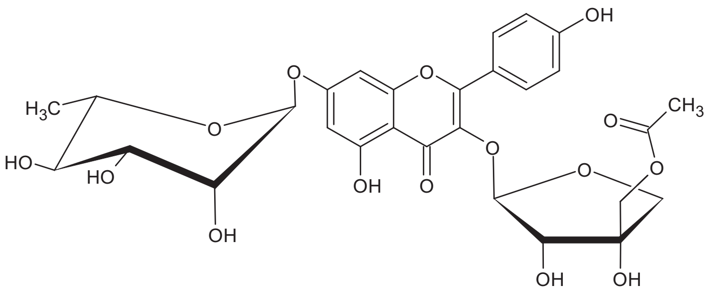


Kumatakenin B

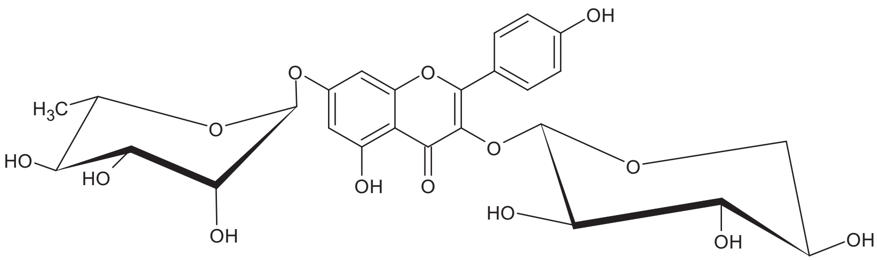
Fig. 6.2 Chemical structures of the major chemical constituents of *Vicia faba* Linn



Quercetin 3-*O*-[α-L-rhamnopyranosyl(1→2)-β-D-galactopyranosyl]-7-*O*-α-L-rhamnopyranoside

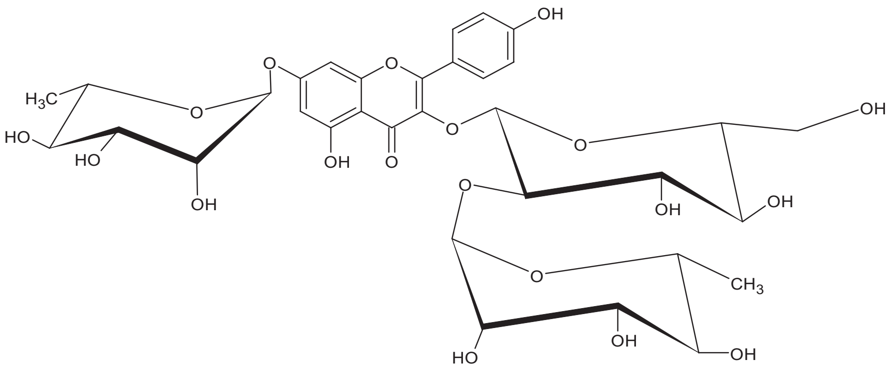


Kaempferol 3-*O*-(5-*O*-acetyl-α-D-apiofuranosyl)-7-*O*-α-L-rhamnopyranoside

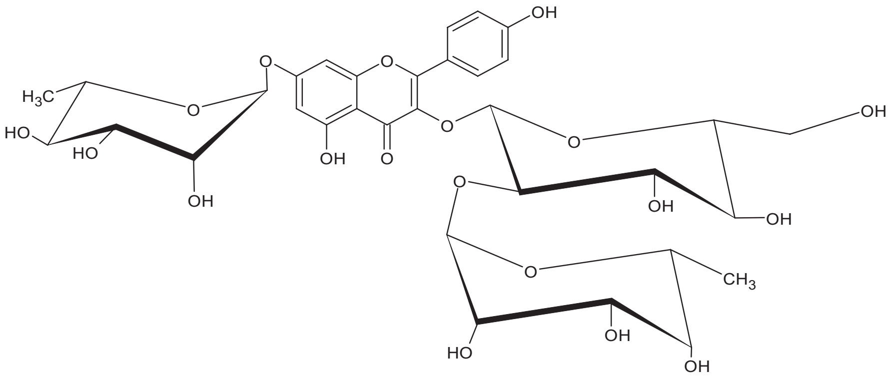


Kaempferol 3-*O*-α-L-arabinopyranosyl-7-*O*-α-L-rhamnopyranoside

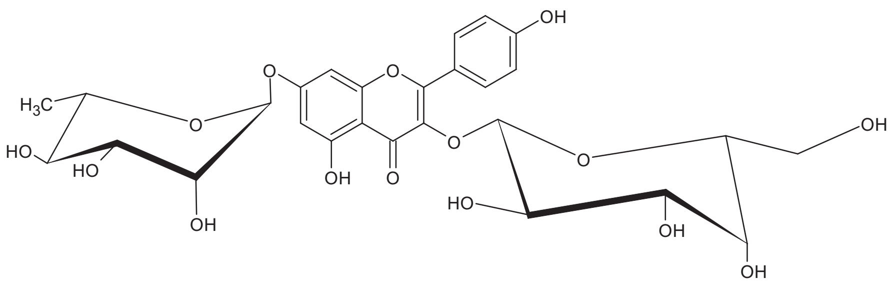
Fig. 6.2 (continued)



Kaempferol 3-*O*-[α-L-rhamnopyranosyl(1→2)-β-D-glucopyranosyl]-7-*O*-α-L-rhamnopyranoside

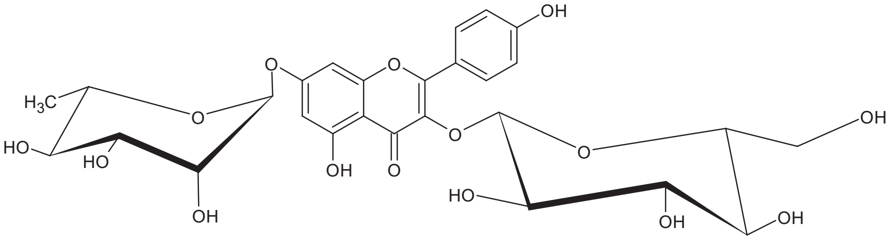


Kaempferol 3-*O*-[α-L-rhamnopyranosyl(1→2)-β-D-galactopyranosyl]-7-*O*-α-L-rhamno pyranoside

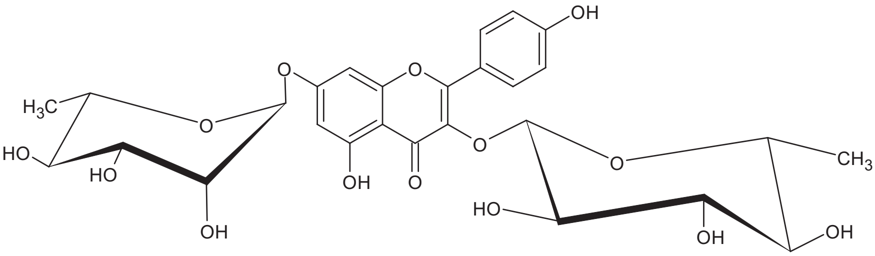


Kaempferol 3-*O*-β-D-galactopyranosyl-7-*O*-α-L-rhamnopyranoside

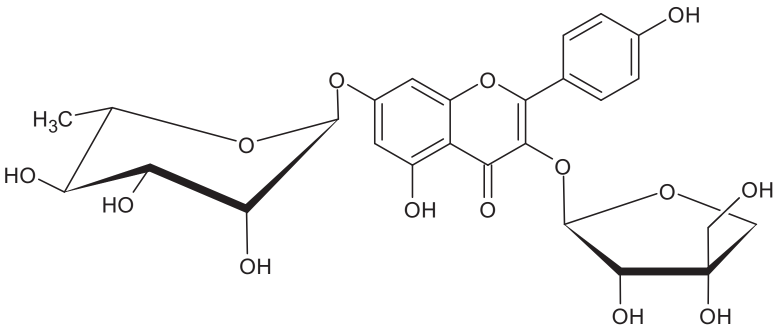
Fig. 6.2 (continued)



Kaempferol 3-*O*-β-D-glucopyranosyl-7-*O*-α-L-rhamnopyranoside

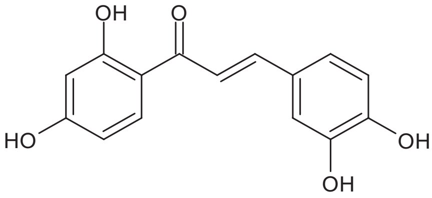


Kaempferol 3-*O*-α-L-rhamnopyranosyl-7-*O*-α-L-rhamnopyranoside

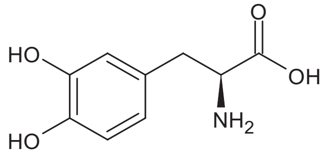


Kaempferol 3-O-β-D-apiofuranosyl-7-O-α-L-rhamnopyranoside

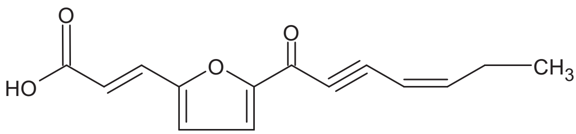
Fig. 6.2 (continued)



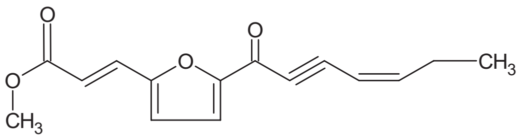
Butein



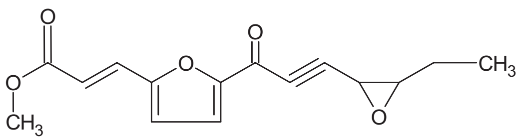
l-dopa (l-3,4-dihydroxyphenylalanine)



Wyerone acid

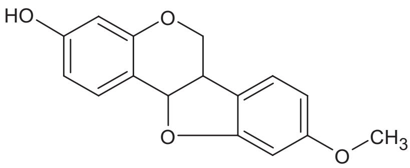


Wyerone

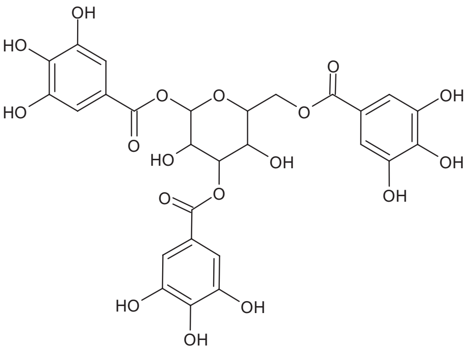


Wyerone epoxide

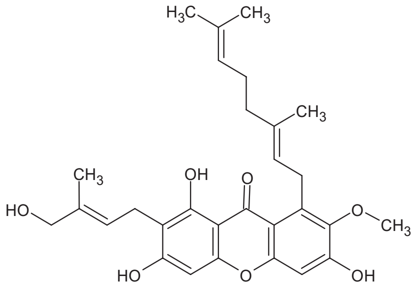
Fig. 6.2 (continued)



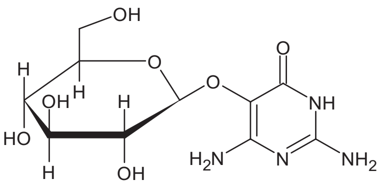
Medicarpin



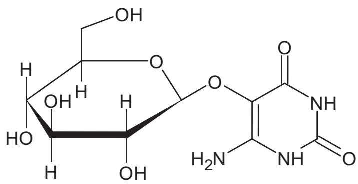
Tannin



Cowanol

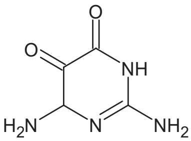


Vicine

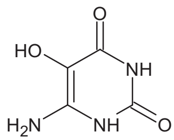


Convicine

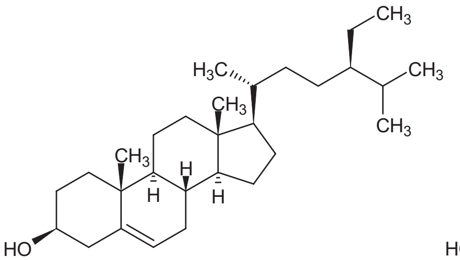
Fig. 6.2 (continued)



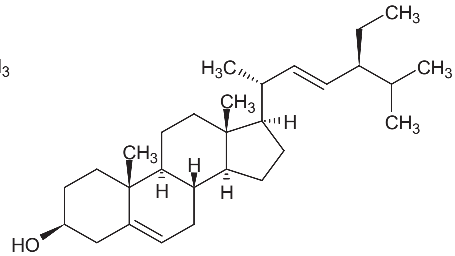
Divicine



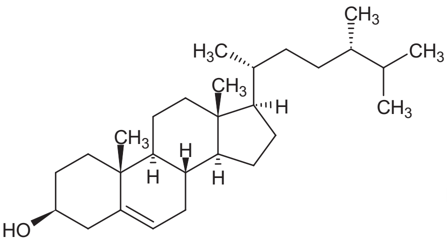
Isouramil



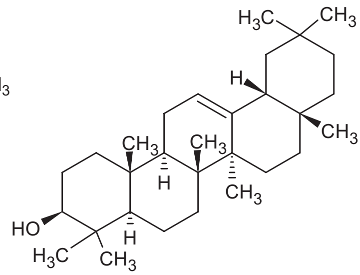
β- sitosterol



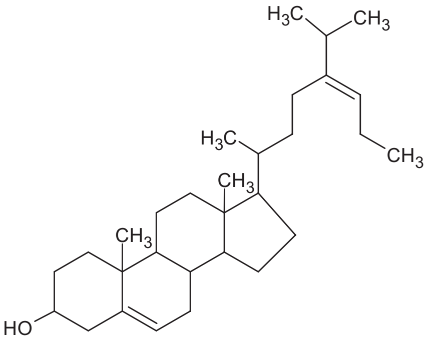
Stigmasterol



Campesterol



β-Amyrin



Cholest-5-en-3-ol, 24-propylidene-, (3.β)-

Fig. 6.2 (continued)

Griffiths, Robertson, Shepherd, and Griffiths et al. (1999) used head-space analysis to identify 27 volatile compounds in the flowers of faba bean. β-ocimene was the most predominant compound (67.59). The number of chemicals found in head-space analysis are given in Table 6.15 (Griffiths et al., 1999)

In the *V. faba* plant, Webster et al. (2008) discovered 16 electro physiologically active chemicals. 15 compounds namely; benzaldehyde, (*E*)-caryophyllene, decanal, (*E*)-β-farnesene, (*S*)-(−)-germacrene D, (*Z*)-3-hexen-1-ol, 1-hexanol, (*E*)-2-hexenal, 6-methyl-5- hepten-2-one, (*Z*)-3-hexen-1-yl acetate, (*R*)-linalool, methyl salicylate, octanal, (*E, E*)-4,8,12- trimethyl-1,3,7,11-tridecatetraene (TMTT), & undecanal were characterized by using coupled GC-MS (Webster et al., 2008)

In 2010, Webster and his colleagues found that faba bean releases several volatile chemicals during the day and found that there was no consistency across time. (Z)-3-hexen-1-ol and (Z)-3-hexen1yl acetate were found to be connected at all four time periods (Webster et al., 2010)

El-Feky et al. (2018) performed GC/MS report of the *V. faba* extract (n-C_6H_{14}) and seventeen volatile components were identified, which represents 85.97 percent of the total lipoidal content. The most prevalent compound was identified to be 5-phenylundecane (23.24 percent), followed by 2 (Benzoyloxy) cycloheptanone (12.74%) (Table 6.16) (El-Feky et al., 2018)

Eleven fatty acids (arachidic, lignoceric, linoleic, linolenic, margaric, Myristic, oleic, palmitic, palmitoleic, pentadecanoic, stearic acid) with unsaturated fatty acids (UFA) were identified by using analytical gas chromatography of the total lipid (Mejri et al., 2018)

GC/MS study of faba extract confirmed the presence of most common fatty acids and other phytochemicals, according to Pasricha, Satpathy, and Gupta (2014). (Table 6.17) (Pasricha et al., 2014) Fig. 6.3.

6.1.6 *Pharmacological Activities of* **Vicia faba** *Linn. Plnt*

Medicinal plants have been a source of drug discovery since ancient time. Therefore, an attention is being focused on the investigation of the efficacy of plant-based drugs primarily used in the traditional medicine. The researchers' experimental pharmacological investigations on the Faba bean are reported in Fig. 6.4. Extracts and individual chemicals compound extracted from various parts of the faba bean plant evidently have distinct biological functions. The plant possesses a number of adaptogenic qualities, including the ability to antioxidant, hypoglycemic and hypolipidemic effects, antihemolytic activity, enzyme inhibition activities, hepatoprotective, anti-Parkinson activity, anticonvulsant activities. In addition to that, phytoconstituents like Vicine and convicine are reported to have significant reproductive effect. The pharmacological activities of the *V. faba* (Linn.) plant studied for the treatment of different ailments and disorders are summarized as follows:

6.1.6.1 Antioxidant Activity
6.1.6.2 Anticoagulant Activity
6.1.6.3 Antidiabetic Activity
6.1.6.4 Antihemolytic Activity
6.1.6.5 Enzyme Inhibition Activity
6.1.6.6 Anticancer Activity
6.1.6.7 Antimicrobial Activity
6.1.6.8 Anti-inflammatory Activity
6.1.6.9 Anti-Parkinson Activity
6.1.6.10 Antidepressant Activity
6.1.6.11 Anticonvulsant Activity
6.1.6.12 Estrogenic Activity
6.1.6.13 Diuretic Activity
6.1.6.14 Antihepatotoxic Activity

Table 6.15 Volatile components of *Vicia faba* (cv Maris Bead) flowers

S. No.	Chemical compounds	RT	Relative concentration (% total area)
1.	α-Thujene	18.5	0.05
2.	α-Pinene	18.9	6.24
3.	Sabinene	20.8	0.12
4.	β-Myrcene	21.0	2.49
5.	(*Z*)-β-Ocimene	22.6	7.83
6.	(*E*)-β-Ocimene	23.3	67.59
7.	Benzaldehyde	23.9	0.25
8.	Linalool	26.7	2.76
9.	*p*-Menthatriene	26.9	0.49
10.	Benzyl alcohol	27.3	0.04
11.	*p*-allyl anisole	30.0	2.31
12.	Nerol	31.3	0.82
13.	Geraniol	32.0	1.62
14.	*p*-Propenyl anisole	33.0	1.78
15.	2-Phenoxyethanol	33.3	0.24
16.	Neryl acetate	33.9	0.26
17.	Geranyl acetate	34.4	0.22
18.	Cinnamyl aldehyde	34.9	0.15
19.	*p*-Propenyl phenol	35.1	0.19
20.	β-Caryophyllene	35.5	0.78
21.	Cinnamyl alcohol	35.8	0.77
22.	Eugenol	36.1	0.66
23.	*O*-Methyl eugenol	36.3	0.29
24.	α-Humulene	36.5	0.10
25.	α-Farnesene	36.6	0.68
26.	Unidentified sesquiterpene	37.2	0.39
27.	Cinnamyl acetate	38.0	0.86
28.	Methyl isoeugenol	38.9	0.02

Table 6.16 Faba bean's n-hexane extract analysis by GC/MS

S. No.	Plant parts used	Chemical compounds	Reference
1.	Pods	n-Decane, nonanal, decanol, dodecanol, 3-methyl pentenyl phenyl ketone, 7-phenyl tridecane, pentadecanol, 5-phenylundecane, 2-(Benzoyloxy) cycloheptanone, n-heptadecane, hexadecanol, 7,7-diphenyl-2,4,6-heptatrienal, methyl palmitate, n-eicosene, methyl linoleate, n-heneicosane, α-carotene 4,4′-dione, hydrocarbons, fatty alcohols, aldehydes, ketones, esters	El-Feky et al. (2018)

Table 6.17 Faba bean's methanol extract analysis by GC/MS

S. No.	Chemical compounds	RT	% Area
1.	Propanal, 2-methyl-3-phenyl-	11.521	0.20
2.	Benzene, 1-methoxy-4-(1-propenyl)-	12.239	5.08
3.	Benzenemethanol, 4-(1-methylethyl)	12.306	0.13
4.	3-Allyl-6-methoxyphenol	13.315	2.83
5.	Caryophyllene	14.269	0.31
6.	2H-Benzopyran-2-one	14.504	0.24
7.	1-(1,5-dimethyl-4-hexenyl)-4-methyl, Benzene	15.031	0.20
8.	1-methyl-4-(5-methyl-1-methylene- 4-hexenyl)-, (*S*)-, Cyclohexene	15.357	0.19
9.	Phenol, 2-methoxy-4-(1-propenyl)-, acetate	15.558	0.57
10.	2-Hydroxy-2-(4-methoxy-phenyl)-N-methyl-acetamide	16.153	0.29
11.	Isopropyl myristate	18.564	0.61
12.	Pentadecane	19.663	0.63
13.	Hexadecanoic acid, methyl ester	19.944	2.68
14.	*n*-Hexadecanoic acid	20.314	3.17
15.	Hexadecanoic acid, ethyl ester	20.605	0.17
16.	9,12-Octadecadienoic acid (*Z, Z*)-, methyl ester	21.603	5.78
17.	9-Octadecenoic acid, methyl ester, (*E*)-	21.648	4.23
18.	Phytol	21.749	0.41
19.	Octadecanoic acid, methyl ester	21.850	0.46
20.	9-Octadecenoic acid, (*E*)-	22.030	11.41
21.	9,12-Octadecadienoic acid (*Z,Z*)-	22.198	1.74
22.	8-Octadecenoic acid, methyl ester (*E*)-	22.243	0.57
23.	Cyclotetracosane	24.934	0.46
24.	Eicosane	24.979	0.32
25.	9-Tricosene, (*Z*)-	26.404	0.28
26.	9-Octadecenoic acid (*Z*)-, 2,3-dihydroxy propyl ester	26.527	4.63
27.	Stigmasterol, 22,23-dihydro-	35.836	24.55
28.	Cholest-5-en-3-ol, 24-propylidene-, (3.β)-	36.127	1.83
29.	β-Amyrin	36.553	3.32
30.	Campesterol	33.694	4.59
31.	γ-Tocopherol	30.520	4.09

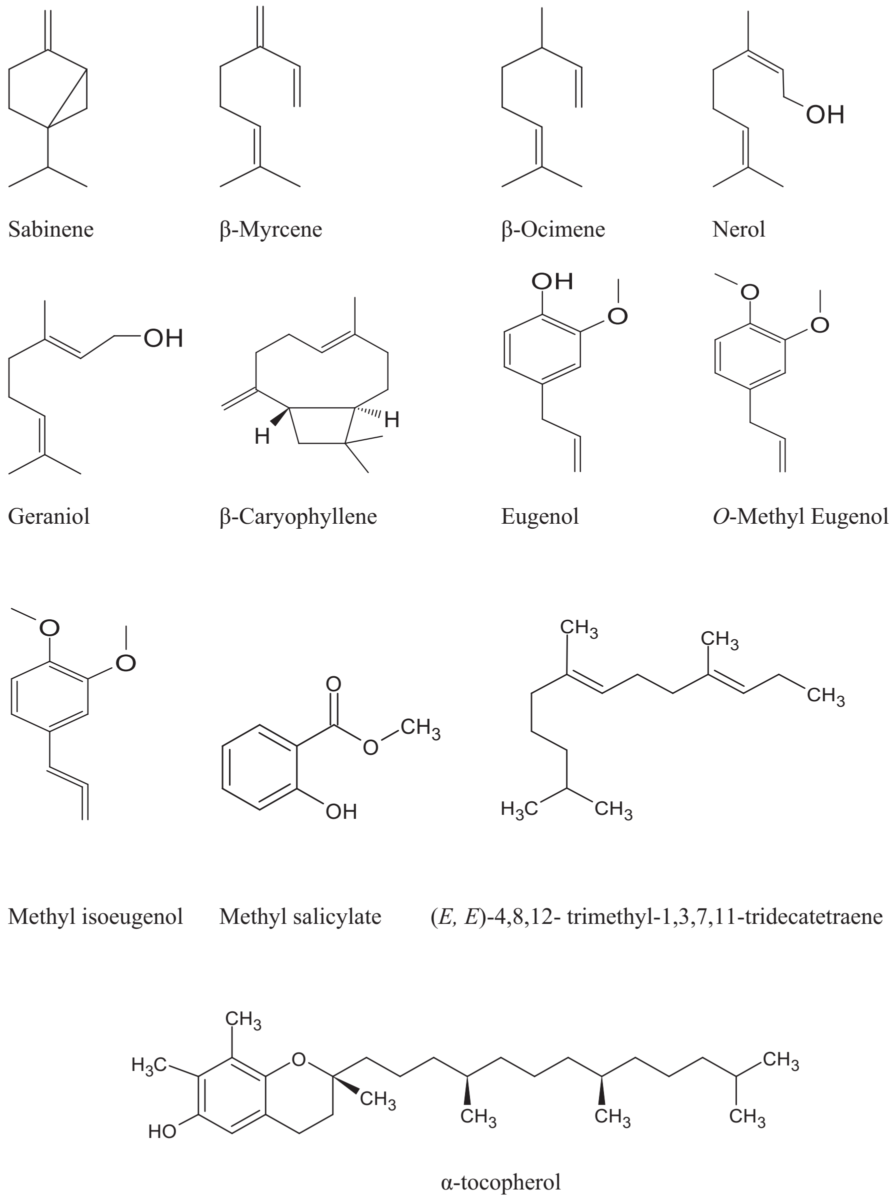
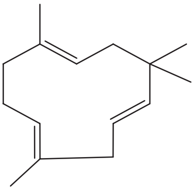
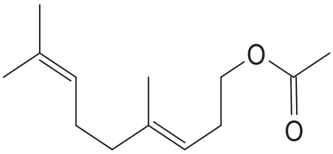


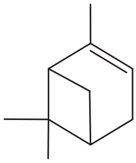
Fig. 6.3 Chemical constituents's structures present in the *Vicia faba* Linn



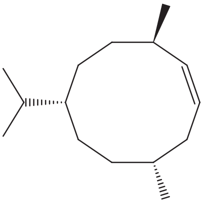
α-Humulene



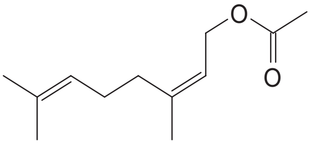
Geranyl acetate



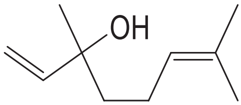
α-pinene



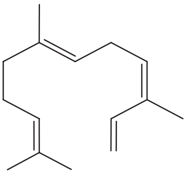
Germacrene D



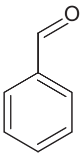
Nerol acetate



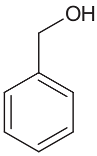
Linalool



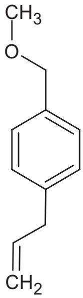
α-Farnesene



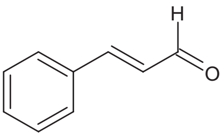
Benzaldehyde



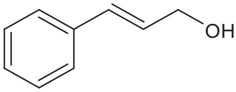
Benzyl alcohol



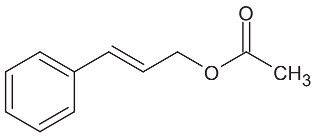
p-Allyl anisole



Cinnamyl aldehyde



Cinnamyl alcohol



Cinnamyl acetate

Fig. 6.3 (continued)

6.1.6.1 Antioxidant Activity

Different parts of *V. faba* plant (flowers, pods and seeds) possesses potent antioxidant activities and it is due to presence of polyphenolic compounds mostly flavonoids and their glycosides (Fig. 6.5).

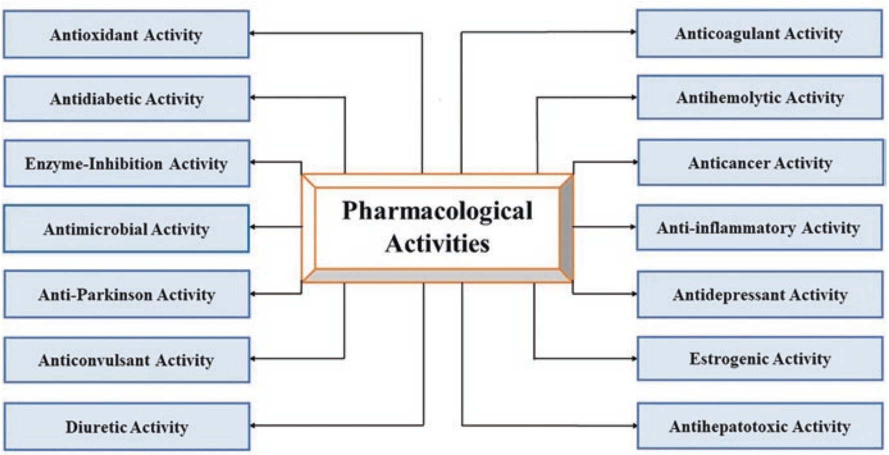


Fig. 6.4 Pharmacological activities of *Vicia faba* Linn. plant

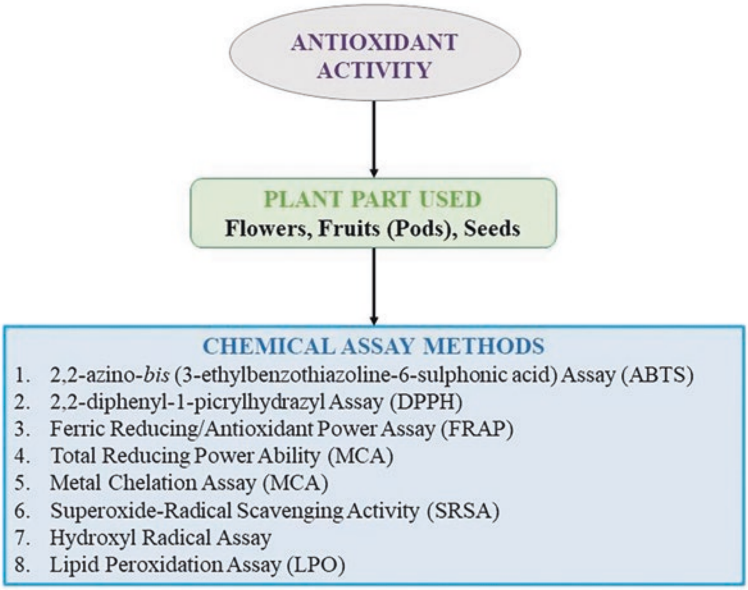


Fig. 6.5 Antioxidant activities of *Vicia faba* Linn. plant

Protein hydrolysate from the seeds of *V. faba* exhibited strong DPPH scavenging (IC_{50} = 0.25–9 mM) activity (Karkouch et al. 2017).

The extract's ABTS radical scavenging activity (percent) was compared to ascorbic acid, and the extract's IC_{50} value was found to be 0.97 mg/ml. The results showed that faba seeds had a lot of antioxidant potential. At a wavelength of

593 nm, the FRAP assay was measured. The activity of the faba seeds sample was found to be 13.95 μg BHT equivalents (BE)/mg (Pasricha et al., 2014).

The IC_{50} values of methanolic extracts of faba seeds were larger than 1000 mg ml^{-1}. *V. faba* fruit rinds had the highest IC_{50} values (>1000 mg ml^{-1}) (Sumitra et al., 2010).

The ABTS radical scavenging activity of *Vicia faba* L. pod ethanol extract (IC_{50} value of 1.5 mg/mL) was equivalent to that of ascorbic acid (IC_{50} value of 1.7 mg/mL) used as a positive control, whereas bean extract, on the other hand, was the most effective in preventing lipid peroxidation (IC_{50} value of 17.6 g/mL after 30 min of incubation) (Loizzo et al., 2021).

According to Chaieb et al. (2011), there is a link between polyphenols and flavonoids content and antioxidant activity. When evaluating different portions or stages of the plant, the antioxidant activity varies for the same genotype. The highest levels of polyphenolic and flavonoids content, as well as antioxidant activity, were seen in different stages of plant development (Chaieb et al., 2011).

El-Feky et al. (2018) tested four extracts (samples) of *P. sativum* and *V. faba* (2 hexanes and 2 ethyl acetate) and found that DPPH scavenging activity was poor in these extracts. The maximal scavenging activity was reported in *P. sativum* ethyl acetate fraction (31.2%) and ethyl acetate fraction of *V. faba* (9.8%) (El-Feky et al., 2018).

Different varieties of faba bean namely; *V. faba* major and *V. faba* minor were studied for their antioxidant activities. The total phenolic content had a connection ($r = 0.753$, $P < 0.01$) with the DPPH scavenging ability, which varied somewhat between the samples (3.1 and 4.73 g TE g^{-1} DW) (Valente et al., 2018).

The antioxidant activity of 70% acetone extracts of raw and processed *V. faba* L. (faba bean) seeds were investigated using various *in vitro* antioxidant assays.

All extracts of processed faba bean seeds showed higher activity in several antioxidant systems, when compared to raw seeds. The DPPH radical scavenging activity of seeds autoclaved with 1% sugar solution was higher (IC_{50}7.4 mg/mL). The extract of dry heated seeds (@ a concentration of 500 μg/mL), inhibited hemolysis better (76.8%) compared to the standard butylated hydroxyl anisole (BHA) (61.8%) as well as α-tocopherol (52.6%) (Yu-Wei et al., 2015).

Antioxidant activity of phenolics extracted from faba bean seed coats and cotyledons of different varieties were analysed and found that because seed coats include more total phenolics, total flavonoids, and condensed tannins, their antioxidant potential was much higher than that of cotyledons (Yue-hong et al., 2018).

Cotyledons and hulls were separated from *V. f* (major) & *V.f* (minor). These plant materials along with whole seeds, were extracted with aqueous acetone (70%) and aqueous ethanol (80%), and the antioxidant activity of these extracts was evaluated in proportion to their phenolic content. The antioxidant activity of aqueous ethanol (80%) extract of lentil hulls was strong (Souhila et al., 2013).

Siah et al. (2012) investigated Australian fava bean genotypes for their antioxidant functions and found that the buff and redcolored fava beans extracts were almost similar. While, the white color had the least amount of polyphenols & least antioxidant/enzyme inhibition action. Roasted one also lowered the polyphenols and antioxidant action in DPPH by 10%–40% (Siah et al., 2012).

Boukhanouf et al. (2016) screened different fractions of *V. faba* bean (coat, cotyledon, seed coat, whole pod, and whole seed pod) were analyzed. The immature raw seed coat and raw pod coat had the maximum values, followed by the whole pod, whole seed, and cotyledon. The immature raw faba bean fractions had a substantially stronger DPPH scavenging effect than the mature raw faba bean fractions ($p < 0.05$). Antiradical activity dropped by 69% in entire seed, 45% in seed coat, and 56% in cotyledons in mature samples (Boukhanouf et al., 2016).

6.1.6.2 Anticoagulant Activity

Diosmin, (5,7,3′-trihydroxy-4′-methoxy flavone rhamnoglucoside) is an active compound for the drugs used for the treatment of hemorrhoid, pre-ulcer state and phlebitis. According to Ivashev and his colleagues (1995), found that *Vicia* plant (Asian vetch) contained diosmin in large quantity. Diosmin increases coagulation time and reduces fibrinolysis at small dosages (2 & 10 mg/kg) (Ivashev et al., 1995).

6.1.6.3 Antidiabetic Activity

Beans from *V. faba* had a promising inhibitory actions against α-glucosidase, with a concentration of 38.31 μg/mL as the IC_{50}, although pods were more active against α-amylase (IC_{50} value of 38.31 μg/mL). With IC_{50} values of 129.21 and 134.05 g/mL for beans and pods, respectively, no statistically significant differences were found against lipase. However, all the reported values are greater than those reported for positive controls (Loizzo et al., 2021).

Diabetes was induced in mice by alloxan and these mice were used by Mejri et al. (2018). the methanolic extract of faba bean pods was examined and found that oral administration of methanol extract at a dose of 500 mg/kg bw, for fourteen days (two weeks), mice showed a normal lipid profile and were able to reduce the oxidative stress associated with diabetic condition. These activities could be attributed to flavan-3-ols like catechin and epicatechin, as well as flavonols (glycosides of quercetin and rutin) (Mejri et al., 2018).

Lasheras et al. (1980) investigated the effects of *V. faba* and *V. ervilia*-rich legumes on sugar levels in the small intestine of chicks. The action of sugars (maltase & sucrose) were measured in animals from 1 day to 2 months, since their activities differed according on their age. In 60 day-old chicks, sucrose activity increased, while maltase activity remained unaffected (Lasheras et al., 1980).

Mejri et al. (2018) used a single intra-peritoneal injection of 160 mg/kg bw of alloxan monohydrate to produce hyperglycemia and acute diabetes for 5 days. Furthermore, in alloxan-induced diabetic mice, the serum levels of alanine aminotransferase (ALA), aspartate aminotransferase (AST), and alkaline phosphatase

(ALKP), as well as urea, uric acid, and creatinine, were reduced after oral administration of a 500 mg/kg body weight dosage of *V. faba* pods methanol extract.

It reduced the severity of oxidative stress-induced histopathological lesions in the pancreas, liver, kidneys, and testes by normalizing lipid profiles, oxidative stress. As a result, broad bean pods were suggested as a useful functional diet for diabetes management and its consequences (Mejri et al., 2018).

In 2016, Choudhary and Mishra investigated the effects of *V. faba* seed extract on hypoglycemia and oxidative stress in *S. cerevisiae in vitro* recently and found that at a glucose concentration of 25 mM, acetone extract had a considerable impact on sugar absorptivity (77.28 2.42%) in yeast cells. In comparison, chloroform seed extract revealed a minimum glucose absorption rate of 52.36 2.06%. Furthermore, the authors suggested that polyphenols including phenolics, flavonoids compounds found in seed extract of faba bean or their synergistic action may be responsible for hypoglycemia potential and oxidative stress (Choudhary & Mishra, 2016).

Alloxan-induced diabetic mice were given a methanolic extract (500 mg per kg bw) by orally for treatment. The results show the reduction of blood alanine aminotransferase (ALA), aspartate aminotransferase (AST), and alkaline phosphatase activity, as well as urea, uric acid, and creatinine levels (Mejri et al., 2018)

6.1.6.4 Antihemolytic Activity

Erythrocytes, the most common cells in the human body with excellent physiological and morphological properties, are heavily used in administration of medication (Hamidi & Tajerzadeh, 2003).

Djeridane et al. (2006) performed a biological test in cow blood that involved free radical-induced erythrocyte lysis. The antihemolytic activity of raw and processed Faba bean seed extracts, as well as standards, at 500 μg/ mL were studied. The findings show that raw and processed seed extracts were significantly effective in inhibiting erythrocyte hemolysis. When compared to the standards BHA and α-tocopherol, extract of the dry heated seeds (76.8%) had the strongest potential to suppress hemolysis by H_2O_2 induced membrane damage in cow blood erythrocytes (Djeridane et al., 2006).

According to Chaudhuri et al. (2007), flavonoid attachment to red blood cell membranes greatly prevents lipid peroxidation while also enhancing their integrity against lysis (Chaudhuri et al., 2007).

6.1.6.5 Enzyme Inhibition Activity

Peptides P4 from the seeds of *V. faba* showed effective tyrosinase inhibitory activition with IC_{50} values of 1 and 0.14 mM,

The phenolic extract from immature faba bean seed coats and cotyledons was found to be an efficient source of α-glucosidase and lipase inhibitors by Yue-hong et al. (2018). As a result, fresh faba bean seed could be utilized as a dietary supplement to help regulate blood glucose and obesity (Yue-hong et al., 2018).

The inhibitory effect of crude seed extracts of faba bean on the activities of α-amylase was investigated by Choudhary and Mishra (2018). The acetone & methanol extracts of faba bean seeds had the most anti-α-amylase activity, with IC_{50} values of 2.94 & 5.27 mg/mL, respectively. Nonetheless, *in-silico* research revealed that the polyphenolic components found in the faba bean formed hydrogen bonds and hydrophobic interactions with the α-amylase enzyme's catalytic residues (Choudhary & Mishra, 2018).

According to Orhan et al. (2004), $CHCl_3$:H_2O extract (1 mg/mL) of the whole fresh fava bean plant demonstrated identical acetylcholinesterase inhibitory activity as the standard galantamine (45.23 & 48.8% for fava bean and galantamine, respectively) (Orhan et al., 2004).

Anti-AChE activity was found in Methanol, Ethanol, Butanol, and Ethyl acetate extracts at the dose tested (100 μg/mL) in various degrees (18.8–30.94%). The ethyl acetate extract had the most inhibitory efficacy against AChE, while the methanol extract had the least (Mejri et al., 2018).

6.1.6.6 Anticancer Activity

The antiproliferative efficacy of hexane & ethyl acetate extracts of *V. faba* was tested at 100 ppm with the help of two different human cancer cell lines [(MCF-7) human breast carcinoma and (HCT-116) human colon carcinoma]. *n*-hexane of *V. faba* extract gave 40.2 and 6.7, while ethyl acetate extract 32.3, 22.1 over human breast carcinoma and human colon carcinoma, respectively (El-Feky et al., 2018).

Apigenin from the peels of fruits of *V. faba* is a potent phytochemical works on (MCF- & 7) and having no carcinogenic effects on cells of humans (El-Feky et al., 2018).

Broad bean extracts suppressed the development of human cancer cells (AGS, BL13, Hep G2, & HT-29), which showed cellular tolerance from H_2O_2-induced DNA damage (as measured by RAW264.7 cells). Furthermore, broad bean extracts had no effect on non-transformed human cells (CCD-18Co). In HL-60 cells, broad bean extracts effectively induced apoptosis (acute promyelocytic leukaemia), according to flow cytometric analysis (Siah et al., 2012).

6.1.6.7 Antimicrobial Activity

5 μg of vicine showed significant fungistatic effect for fungi *Fusarium culmorum* and *Alternaria alternate* while 500 ng of vicine showed significant fungistatic effect for *Cladosporium herbarum* and *Botrytis cinerea* (Pavlík et al., 2002).

In 1997, research on peptides of *V. faba* as an antibacterial agent began. Two novel antimicrobial peptides, called "fabatins," were discovered in *V. faba* seeds. These peptides were found to be effective against *E. coli*, *Enterococcus hirae*, and

Pseudomonas aeruginosa but not against *C. albicans* or *S. cerevisiae* yeasts (Zhang & Lewis, 1997).

Antifungal effects against *Mycosphaerella arachidicola* & *Physalospora piricola* was discovered in a novel trypsin-chymotrypsin inhibitor with an N-terminal sequence isolated from *V. faba* and HIV-1 reverse transcriptase activity was suppressed (IC_{50} = 32 μM) (Ye & Ng, 2002).

Antifungal effects against *Botrytis cinerea, Fusarium oxysporum*, & *Mycosphaerella arachidicola* was discovered in a novel trypsin-chymotrypsin inhibitor with an N-terminal sequence isolated from *V. faba* and HIV-1 reverse transcriptase activity was also suppressed (Ye et al., 2001).

VFTI-E_{1-} a new Bowman-Birk type trypsin inhibitor with an N-terminal sequence was extracted from faba bean and screened for its antifungal activity toward the *Valsa mali* –a filamentous fungus (IC_{50} = 20 μM) (Fang et al., 2010).

Wang et al. (2012) isolated a novel chitinase from the seeds of *V. faba*. This novel chitinase was found to be effective against a number of species of fungi, namely; *Alternaria alternate, Botrytis cinerea, Fusarium oxysporum* f. sp. *Melonis, Fusarium solani, Physalospora piricola,* and *Pythium aphanidermatum* (Wang et al., 2012).

Viruses and several bacteria e.g. *Bacillus subtilis, Proteus mirabilis, Staphylococcus aureus,* and *Staphylococcus epidermidis* were used to test the antibacterial activity of the seeds of dried faba. The inhibiting concentrations employed for the sample were 80 mg/ml and 500 mg/ml, respectively. In any of the four strains, there was no zone of inhibition and concluded that he dried seeds were the least effective at inhibiting any of the strains (Pasricha et al., 2014).

The extracts of the seeds and fruit rinds in hexane and ethyl acetate, as well as the methanolic and aqueous extracts of the fruit rinds of *V. faba* plants, exhibited action against *K. aerogenes*. *B. subtilis, B. megaterium, C. rubrum*, and *P. pictoruim* were all inhibited by an ethyl acetate extract of the fruit rind of *V. faba*. Antibacterial activity of *V. faba* was stronger against Gram positive bacteria than against Gram negative bacteria (Sumitra et al., 2010).

The antibiofilm activity of peptides P1, P5, P6, and P7 against *Pseudomonas aeruginosa* PA14 was particularly interesting, with $MBIC_{50}$ values ranging from 12 to 35 μM. It was suggested that the hydrolysate of *V. faba* seed proteins could be applied as a source of natural bioactive peptides for cosmetic and medicinal purposes (Karkouch et al., 2017).

6.1.6.8 Anti-Inflammatory Activity

Cotyledons & hulls of *Vicia faba major* and *minor* were segregated from the plant. These plant materials along with whole seeds, were extracted with aqueous acetone (70%) and aqueous ethanol (80%), and the anti-inflammatory activity of these extracts was tested. Except for V. minor, hull extracts inhibited 15-LOX at different concentrations, with inhibition rising considerably ($P < 0.001$) with concentration. The extracts' inhibitory efficacy at 30–242 μg/ml differed considerably ($P < 0.001$) between samples. The extract of *V. major* has a higher inhibitory effect than the extract of *V. minor* (Souhila et al., 2013).

Vicine and its aglycone divicine possessed a strong anti-inflammatory action. After 3 h of administration of Vicine and its aglycone-divicine (150 mg/kg) produced anti-inflammatory effects in a dose-dependent manner against fresh egg albumin-induced edema in rats, with inhibition percentages of 59.6 and 45.6%, respectively, in comparison to the conventional drug diclofenac sodium (100 mg/kg) with 100% inhibition (Siah et al., 2012).

6.1.6.9 Anti-Parkinson Activity

V. faba are considered to be a good alternative to synthetic L-dopa-dihydroxyphenylalanine, which is the main source of dopamine (Polanowska et al., 2019; Vered et al., 1994). Parkinson's disease develops in those who are not able to produce dopamine. The usage of broad beans for the treatment of PD has inspired a wave of interest.

Apaydin et al. (2000) used cooked fava bean (250 g) on their patients at least two times in a single day without altering their eating patterns. The patients were instructed to keep track of the timings and lengths of their "on" and "off" phases, and also their sleeping time, on a daily basis. The average values of "on" and "off" periods, and sleeping time, for all patient were collected during the course of 5–7 days of starting time evaluation and intake of fava bean for 1–3 months. The findings demonstrated that *V. faba* has a favorable effect in Parkinson's patients, as evidenced by a longer "on" time and a shorter "off" duration (Apaydin et al., 2000).

V. faba's processed extract, E-PodoFavalin-15,999 (Atremorine), with dihydroxyphenylalanine concentration (2%, w/w), is recommended as dopaminergic neuroprotectant and donor of L-dopa (Cacabelos et al., 2016; Cacabelos et al., 2019).

Atremorine is a potent catecholamine stimulant in the plasma with time- and genotype-dependent effects in Parkinson Diseases. A single oral dose (5 g/day) of Atremorine were given to all patients and a genetically-dependent response was found in treatment-patients. The high concentration of natural L-DOPA (average concentration 20 mg/g) in Atremorine's composition is responsible for its pro-dopaminergic activity (Cacabelos et al., 2016).

Atremorine has neuroprotective effects on dopaminergic neurons and works as a natural L-DOPA donor in Parkinson's disease (PD). In this study, scientists show the action of a single dose of Atremorine (5 g, p. o.) on plasma dopamine (DA) response and brain function in PD ($n = 183$) (Cacabelos et al., 2019).

Subcutaneous injections (s.c.) of small amounts of rotenone (1 mg/kg per 48 h) were administered to male Swiss albino mice to induce Parkinsonism. Three doses (200, 400, and 600 mg/kg) of 80% methanol extracts of seeds or sprouts of the *V. faba* were given to rotenone–Parkinsonian mice. The fava sprout extract (600 mg/kg dose) had the most favorable effect (Abdel-Sattar et al., 2021).

6.1.6.10 Antidepressant Activity

In male Swiss albino mice, antidepressant effects of methanolic extract of *V. faba* hull and *Vicia sojakii* Chrtkova aerial parts were assessed using the modified forced swimming test (FST) and tail suspension tests (TST). In both models (FST and TST), extract shortened remarkably the immobility period and exhibited a dose dependent activity ($p < 0.001$) (Alam et al., 2016).

6.1.6.11 Anticonvulsant Activity

Anticonvulsant effects of faba bean extract on strychnine-sensitive glycine receptors and γ-aminobutyric acid A (GABAA) receptors was investigated by Salih and Mustafa (2008) and discovered that it prevented strychnine-induced convulsions and mortality in mice. When extract of faba bean (0.01 mL/g) was given with diazepam (20 mg/kg, i.p.) 20 minutes before strychnine (0.112 mg/kg, i.p.), the survival rate improved from 66.7 to 100% (Salih & Mustafa, 2008).

6.1.6.12 Estrogenic Activity

The estrogenic activities of methanol extracts of *Proteus vulgaris* and *V. faba* were examined by Tsiapara et al. (2008). At concentrations of 1–100 µg/mL, all methanol extracts had a substantial estrogenic action and markedly suppressed E2-stimulated luciferase gene in MCF-7 cells co-transfected with a luciferase reporter gene regulated by an estrogen response element (Tsiapara et al., 2008).

6.1.6.13 Diuretic Activity

Intake of 40 g freshly crushed fava bean with 120–130 mg L-dopa resulted in a rise in plasma L-dopa as well as sodium and dopamine excretion in the urine. In comparison to the dopamine/creatinine ratio after a normal diet (1.8 µg/g), the dopamine/creatinine ratio after *V. faba* (fava bean) ingestion reached a highest peak (280 µg/g) 60 minutes later. In comparison with the normal diet (1.4 mmol/g), the sodium/creatinine ratio achieved its highest peak (2.85 mmol/g) 90 min after intake of fava bean. These data suggested that fava bean-rich meal could be beneficial in treatment of heart failure, hypertension, liver cirrhosis, & kidney failure (Vered et al., 1997).

All renal values tended to return to normal after consumption of fava bean pods extract, indicating that fava bean possessed protective action against alloxan-induced kidney damage. The lowering of FFAs and their peroxide could help to restore urea, uric acid, and creatinine levels (Mejri et al., 2018).

6.1.6.14 Antihepatotoxic Activity

All of the parameters related to liver tended to return to normal after administration of *V. faba* pods extract, indicating that fava bean possessed protective action against alloxan-induced liver damage. The lowering of FFAs and their peroxide, as well as suppression of oxidation, phosphorylation, and inflammation, could help restore ALA, AST, and alkaline phosphatase (Mejri et al., 2018).

6.1.7 Conclusion

It is perceptible that *Vicia faba* Linn. is a valuable medicinal resource encompassing phytoconstituents of diverse chemical classes with wide spectrum of pharmacological uses. The plant is traditionally considered as a safe herbal medicine. Its fruits (pods) are rich in proteins and widely consumed by the people in all over the world. *V. faba* plant has been extensively studied in terms of phytochemical and pharmacological activity of its major chemical compounds, and the results revealed potent antioxidant, anticoagulant, antidiabetic, antihemolytic, antimicrobial, enzyme inhibition, anticancer, anti-inflammatory, and anti-Parkinson activities.

It is evident that *V. faba* possesses potent antioxidant activities and it is due to presence of polyphenolic compounds mostly flavonoids and their glycosides. It also possesses broad spectrum antimicrobial property and this might be helpful in the management of the new life-threatening diseases including COVID-19. Isolation of bio active molecules from *V. faba* might act as a good lead that can be employed in novel therapeutic formulation based on an increasing attention towards green chemistry and transitional medicinal plants in recent years. Fava bean is a well-known resource of natural L-3, 4-dihydroxyphenylalanine (L-dopa), which is a dopamine precursor. Parkinson's disease develops in those who are unable to produce dopamine. The usage of *Vicia faba* in the treatment of Parkinson's disease (PD) has inspired a wave of interest.

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Chapter 7
Effect of Processing on the Nutrients and Anti-nutrients Composition of Faba-Bean

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7.1 Introduction

Globally, legumes are known to be sustainable sources of nutrients including carbohydrates, proteins, and phytochemicals. Faba bean, a typical legume is considered an important crop due to its nutritional, ecological and economic benefits (Dhull et al., 2021). Notable among the nutrients are dietary fiber, lysine-rich protein, complex carbohydrates, minerals, l-3,4-dihydroxyphenylalanine (L-DOPA) and bioactive compounds including antioxidants, phenols (Singh et al., 2013; Dhull et al., 2021). In addition, Faba bean is known to contain compounds that are not nutritionally important and negatively influence the bioavailability of its nutrients. These compounds including condensed tannins, favism-inducing factors (vicine and convicine), lectins (haemagglutinins), phytic acid, saponins, and trypsin inhibitor limits its utilization as they reduce its biological value (Labba et al., 2021). Oligosaccharides including raffinose, stachyose and verbascose present in Faba bean also contribute to its limited utilization (Toklu et al., 2021). These compounds are capable of causing flatulence through fermentation in the gut, causing discomfort (Dhull et al., 2021). As a result, Faba bean is usually subjected to different processing methods to reduce/eliminate the anti-nutrient and increase the bioavailability of nutrients. The method of processing can either be physical or biological which are either used singly or combined (Fig. 7.1). This chapter therefore, reviews various processing

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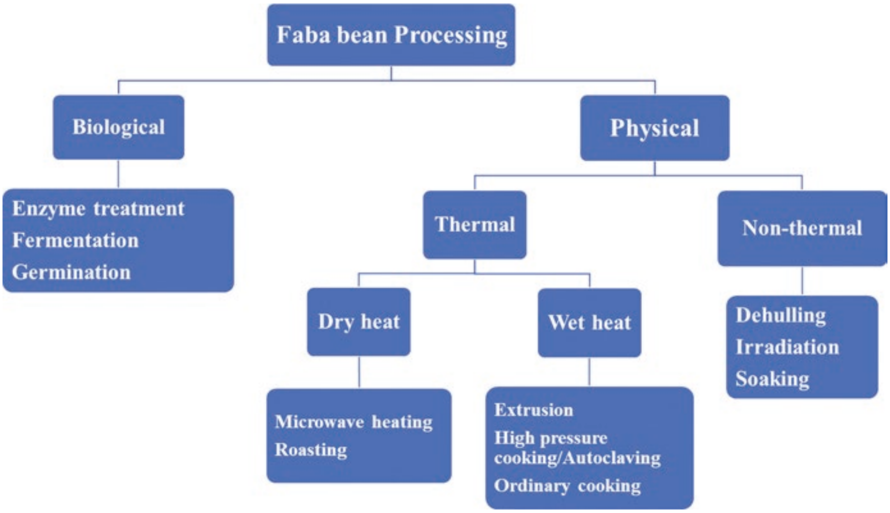

Fig. 7.1 Faba bean processing methods

technologies that have been used in the reduction of anti-nutrients in Faba bean and the effect of these techniques on the nutrient and anti-nutritional composition of Faba bean.

7.2 Effect of Processing on Faba Bean Nutrients and Anti-nutrients Composition

Processing of foods is important majorly to transform food commodities into edible forms and to also ensure safety and quality. Processing techniques are generally often considered to hurt food nutrients by reducing the nutritional value of foods (Van Boekel et al., 2010). However, these techniques enhance food safety and quality through the release of bioactive and beneficial components and the destruction of anti-nutrients. Foods are processed for various reasons. For example, processing makes food edible, provides convenience, and creates variety and diversity and these processes can be achieved at both room and elevated temperatures. Food processing induces biological, chemical and physical changes leading to textural, sensory and nutritional alterations (Van Boekel et al., 2010). In legumes such as Faba bean, the processing is more positive than negative as it enhances its palatability and improves nutrient bioavailability. Generally, domestic processing and cooking methods such as autoclaving, cooking, soaking and dehulling are employed in Faba bean processing to improve its nutritional quality, shelf life and utilization (Espinosa et al., 2020; Dhull et al., 2021). These simple techniques have been found to improve nutrient quality and bioavailability. For instance, hydrothermal processing has been reported to reduce or eliminate anti-nutrients in Faba bean thereby increasing its biological value (Espinosa et al., 2020). Other processing methods have also been employed both domestically and commercially and these are further discussed in the succeeding sections.

7.2.1 Blanching

Blanching is a processing technique in which foods are scalded in boiling water or steam for a short time. It is usually a pre-treatment to other processing techniques such as freezing and canning. Blanched foods are usually cooled immediately after blanching to halt the blanching process. The main reason for blanching is to soften the tissues of the food material and inactivate enzymes, especially peroxidase (Rahate et al., 2021). Blanching at 100 °C for a period between 90–120 s at water-to-bean ratio of 1:3 for Faba bean is optimum for the inactivation of peroxidase activity (Petzold et al., 2014). The lipoxygenase activity of Faba bean was eliminated after blanching for 10 min in boiling water (Al-Nouri & Siddiqi, 1982). Blanching also results in gelatinization of starch and leaching of Ca^{2+} ions and about 50% reduction was observed in the folate content of blanched Faba bean (Hefni et al., 2015). Similarly, a significant reduction in ascorbic acid and mineral content after blanching has been previously reported for Faba bean (Kmiecik et al., 2000; Rahate et al., 2021). Although their seems to be a dearth of information on the impact of blanching on the anti-nutrients of Faba bean, previous research on other legume types reported that blanching contributed to the increase in *in vitro* protein digestibility of blanched-dehulled African yam bean (Ene-Obong & Obizoba, 1996). Also, Manzoor et al. (2019) reported a significant reduction in ash content and no effect on protein, fat and fiber content of blanched dried green bean. Future studies on the impact of blanching on Faba bean anti-nutrient profile are thus required, to fill this knowledge gap.

7.2.2 Soaking

Soaking is a preliminary operation to other unit operations such as cooking, hulling, milling, and germination, employed in food processing to achieve the aim of hydrating grains (Revilla, 2015; Drulyte & Orlien, 2019). It is also a process that enhances the removal of soluble antinutritional compounds (Vidal-Valverde et al., 1998; Dhull et al., 2021) and shortens cooking time (Revilla, 2015). The soaking media usually vary depending on the intended end use of the grains. For instance, Huma et al. (2008) soaked some legumes in 2% acetic acid, sodium bicarbonate and sodium chloride before further processing. Lower levels of phytate were reported for Faba bean soaked in the different solutions compared to those soaked in water. Vidal-Valverde et al. (1998) also reported the use of citric acid and sodium bicarbonate in soaking Faba bean. The neutral detergent fiber content of Faba bean was found to decrease after soaking except for soaking in 0.07% sodium bicarbonate solution where an increase was observed. The increase was associated with the increase in cellulose after soaking (Vidal-Valverde et al., 1998). Soaking in sodium bicarbonate solution was found to result in a higher loss of raffinose in the Faba bean. This was probably due to the ability of sodium bicarbonate to enhance the extraction of oligosaccharides by tenderizing the seed coat and the cotyledon (Revilla, 2015). Soaking for 9 h irrespective of the soaking solution resulted in up to 16% reduction in the starch content of Faba bean (Vidal-Valverde et al., 1998).

Furthermore, about 61% reduction in minerals was also reported by Luo and Xie (2012) after soaking hammer-milled Faba bean flour in 0.1 N acetic/sodium hydroxide buffer (pH 5.5) at 37 °C for 60 min. In the study, the soaking solution was discarded, and this treatment was found to result in a greater loss than previously described methods such as germination and cooking where whole grains of the legumes were treated (Luo & Xie, 2012). The increased surface area obtained through milling (before soaking) may have been responsible for this. In addition to this, a 39% reduction in iron content was also observed in the study (Luo & Xie, 2012). However, the addition of phytase to the soaking solution retained more iron (10% loss) when compared to ordinary soaking. The acidic and buffering soaking medium may have encouraged the leaching of inorganic iron into the soaking medium. Also, the loss of phytic acid (about 54%) which has a strong ability to complex with minerals may have contributed to the loss of iron. Revilla (2015), also reported a significant reduction in phytic acid, tannins, and polyphenols content of Faba bean after soaking. The extent of tannin reduction was associated with the soaking period. A longer soaking period further reduced the tannin content of the Faba bean. Reduction in phytic acid during soaking may have resulted from the activation of endogenous phytase during soaking which converts phytic acid to Myo-inositol and free orthophosphate ion via hydrolysis (Luo et al., 2009; Revilla, 2015). Furthermore, gradient concentration during soaking could favor the leaching of phytic acid into the soaking medium. Also, the presence of sodium bicarbonate was found to lead to a higher reduction in phytate content than the other compounds. Additionally, trypsin inhibitor activity significantly decreased after soaking (Abd & Habiba, 2003). Trypsin inhibitors are water-soluble substances, hence the reduction during soaking.

About 4% and 7% loss of calcium was observed for Faba beans previously soaked in acidic medium and water respectively, while no significant changes were found in those soaked in basic medium (Vidal-Valverde et al., 1998). Expectedly, the thiamine content of the Faba bean decreased after soaking in water and sodium bicarbonate solution. However, no significant decrease was observed in the thiamine content of Faba bean soaked in citric acid solution (Revilla, 2015). A higher reduction in thiamine content in basic medium was associated with a higher rate of thiamine decomposition in the basic medium than acidic medium (Prodanov et al., 1997). Hefni et al. (2015) also reported a significant loss in folate content of Faba bean after soaking with more loss reported at higher soaking temperatures.

The influence of Faba bean variety on the effect of soaking has also been documented in the literature (Luo & Xie, 2013). For instance, soaking had no significant effect on white Faba bean variety irrespective of the duration of soaking, however, a significant increase in trypsin inhibitor activity was observed in the green variety after soaking for 36 h (Luo & Xie, 2013). Contrarily, Anderson et al. (1994), reported a substantial decrease in trypsin inhibitor activity after soaking overnight. Alonso et al. (2000), also reported a significant reduction in tannins, polyphenols, phytic acid, trypsin, chymotrypsin and α-amylase inhibitors anti-nutrients after soaking for 12 h at 30 °C. Reduction in phytic acid content during fermentation, germination and soaking may be linked to the activation of endogenous phytase during these processes as the reduced pH favors the activity of the enzyme (Rosa-Sibakov et al., 2018). On the contrary, a significant increase of about 6% and 7% in phytic acid was observed in soaked green and white Faba bean respectively, the phytic acid level increased with increasing soaking time (Luo & Xie, 2013). Although tannins are known to be water-soluble, the hydrolysis of polymers into simpler units during soaking was reported to be responsible for the significantly higher tannin content observed in the soaked grains (Luo & Xie, 2013). Protein digestibility was not only influenced by the presence of anti-nutrients as an increase in phytic acid and trypsin inhibitor did not decrease protein digestibility. Cell wall rigidity and fiber content were also proposed to impact protein digestibility (Acton et al., 1982; Luo & Xie, 2013).

Soaking for 12–16 h in water reduced the protein content of Faba beans (Alonso et al., 2000; Abd & Habiba, 2003; Revilla, 2015). This was reported to have resulted from the leaching of water-soluble proteins during the soaking period. During soaking, the soluble carbohydrate content of Faba bean is affected due to certain metabolic reactions and as a result, glucose which was originally absent in raw Faba bean was reported to be present in the soaked grains (Vidal-Valverde et al., 1998). The levels of individual minerals including Na, K, Cu, Mn, and Mg of the Faba bean reduced after soaking. This again was attributed to the leaching of nutrients during soaking. No significant change was observed in the calcium and lectin content of Faba beans after soaking (Alonso et al., 2000; Luo & Xie, 2013). However, Sharma and Sehgal (1992) reported a slight reduction in the lectin content of soaked Faba bean as the lectin remaining after soaking was found to be sufficient to agglutinate rabbit red blood cells.

7.2.3 Dehulling

Dehulling is a mechanical process of hull removal usually applied to legumes as a pretreatment (Rahate et al., 2021). Legume hulls or coats are rich sources of antioxidants and polyphenolics (Boudjou et al., 2013). Removal of their hulls has been identified as an effective means of reducing the antinutritional content of legumes thereby increasing their nutritional value (Nalle et al., 2010). However, the extent of anti-nutrient reduction is dependent on the specific anti-nutrient of concern, the method used in dehulling the grains and possibly the percentage level of hulls removed. Lectins, phytic acid and trypsin inhibitors are concentrated in the kernels and not removed by hulling while tannins are known to be concentrated in the hulls of legumes and removal of the hull are effective in reducing its level in Faba bean (Nalle et al., 2010; Luo & Xie, 2013). Alonso et al. (2000), observed about 9% increase in the phytic acid content of Faba bean after dehulling but no significant difference was observed in haemagglutinating activity. Luo & Xie, 2013 in their study on green and white Faba bean also found about 10% and 12% (respectively) increase in the phytic acid content of manually dehulled grains. In addition, this study (Luo & Xie, 2013) observed approximately 59% and 67% decrease in tannin content of green and white Faba bean varieties respectively (Table 7.1). Furthermore, a substantial increase of about 18% and 28% trypsin inhibitor activity was observed in white and green Faba bean, respectively (Luo and Xie 2013). Phytates and trypsin inhibitors are concentrated in the cotyledon of grains and the removal of the hull which contributes greatly to the weight of Faba bean could have resulted in the increase. Contrarily, Sharma and Sehgal (1992) observed an approximately 4% reduction in the phytic acid content of Faba bean after dehulling. The variation in the outcome of these two studies may be attributed to differences in the soaking conditions. Alonso et al. (2000) soaked at grain to water ratio of 1:5 (w/v) and a soaking temperature of 30 °C while Sharma and Sehgal (1992) had a ratio of 1:10 and soaking temperature of 37 °C.

Dehulling was reported to have increased protein content while fat, soluble, and insoluble non-starch polysaccharides decreased (Alonso et al., 2000). About 15% increase in protein content was reported for manually dehulled Faba bean while condensed tannins and polyphenol content of the samples were reduced. An improvement in *in vitro* starch digestibility after dehulling has also been reported for Faba bean and has been linked to the decreased condensed tannins and polyphenol as these anti-nutrients inhibit α-amylase activity (Alonso et al., 2000). Although phytic acid, trypsin, chymotrypsin, and α-amylase inhibitor levels increased in the dehulled Faba bean, a significant increase in *in vitro* starch and protein digestibility was observed. This confirms the significant role of condensed tannins in the inhibition of digestive enzymes (Alonso et al., 2000). Saponins on the other hand were reduced up to 29% after soaking for 12 h at seed-to-water ratio of 1:10 (w/v) and subsequent dehulling of two Faba bean varieties (Sharma & Sehgal, 1992). The solubility of saponins in water may have caused its leaching during soaking.

7.2.4 Cooking

The traditional method of cooking legumes involves boiling in water for a varied length of time at atmospheric or increased pressure. It alters the physical, biological, and chemical properties of the legumes, thus resulting in changes in their textural attributes, nutritional composition, and sensory properties (Oyeyinka et al., 2019). Reactions including deamidation, cleavage of covalent bonds, hydrolysis of peptide bonds, and destruction of disulphide bonds result in the different degradation that occurs in thermally processed foods (Rahate et al., 2021). Also,

Table 7.1 Anti-nutrient composition of processed faba bean

Anti-nutrients	Bl	Co	Ge	So	Au	De & Co	Ex	De	So & De	So & Co	So, De & Co	So, De & Au	So & Au	Ir	Ir & Co	En	Fe	Mi	Ro	Reference
Phytic acid (g/kg)	–	2.7–9.1	1.8–10.1	9.5–14.6	8.9–9.3	–	15.9	23.8	8.4–9.4	6.1–9.2	6.4–10.3	5.9–9.6	5.1–9.2	–	–	0.9–8.2	23.4	–	5.4	Sharma and Sehgal (1992), Khalil and Mansour (1995), Vidal-Valverde et al. (1998), Alonso et al. (2000), Luo and Xie (2012), Rosa-Sibakov et al. (2018)
Condensed tannins g eq cat k/t	–	–	0.8–0.9	1.0	–	–	0.9	0.2	–	–	–	–	–	–	–	–	–	–	–	Alonso et al. (2000)
Trypsin inhibitor (IU/mg)	–	0.9–2.3	3.3–5.5	0–4.3	0.5–1.3	–	0.1	4.9	2.6–3.4	1.2–2.0	1.6–2.1	0.9–1.9	0.7–1.9	–	–	–	2.4	0.7–4.8	8.1–10.8	Anderson et al. (1994), Khalil and Mansour (1995), Alonso et al. (2000), Abd and Habiba (2003), Luo and Xie (2012), Pysz et al. (2012), Coda et al. (2015)
Chymotrypsin inhibitor	–	–	3.1–3.3	3.4	–	–	1.7	3.7	–	–	–	–	–	–	–	–	–	–	–	Alonso et al. (2000)

(continued)

Table 7.1 (continued)

Anti-nutrients	Bl	Co	Ge	So	Au	De & Co	Ex	De	So & De	So & Co	So, De & Co	So, De & Au	So & Au	Ir	Ir & Co	En	Fe	Mi	Ro	Reference
Haemagglutinin (Hu/mg)	–	0.0	49.3	49.3	0.0	–	0.2	49.3	–	–	–	–	–	–	–	–	–	–	–	Khalil and Mansour (1995), Alonso et al. (2000)
Saponin (mg/100 g)	–	–	308–949	1047–1059	–	–	–	–	964–978	860–892	852–853	666–705	494–540	–	–	–	–	–	–	Sharma and Sehgal (1992)
Tannin (mg/g)	–	4.8–6.5	10.3	3.6–4.9	4.7–6.5	–	–	–	1.8–7.8	2.6–4.2	2.4–4.8	2.2–4.8	2.2–4.0	–	–	–	–	–	4.8–14.4	Anderson et al. (1994), Khalil and Mansour (1995), Abd and Habiba (2003), Luo and Xie (2012)
Vicine (mg/g)	–	2.8–6.8	4.9	–	4.1	–	–	–	–	–	–	–	–	–	–	–	7.8	–	2.75–5.40	Khalil and Mansour (1995), Cardador-Martínez et al. (2012), Coda et al. (2015)
Convicine (mg/g)	–	0.2–1.8	1.9	–	1.6	–	–	–	–	–	–	–	–	–	–	–	3.6	–	0.5–1.5	Khalil and Mansour (1995), Cardador-Martínez et al. (2012), Coda et al. (2015)

Bl blanching, *Co* cooking, *Ge* germination, *So* soaking, *Au* autoclaving, *De* dehulling, *En* enzyme treatment, *Ex* extrusion, *Fe* fermentation, *Ir* irradiation, *Mi* microwave, *Ro* roasting gelatinization of starch during hydrothermal processing enhances the susceptibility of the starch to enzyme hydrolysis thus improving overall starch digestibility (Alonso et al., 2000). High pressure cooking/autoclaving shortens cooking time compared to open pan cooking at atmospheric pressure. However, cooking at atmospheric pressure has been found to result in more reduction in anti-nutrients than pressure cooking (Nergiz & Gökgöz, 2007) while more carbohydrates and proteins were better retained during atmospheric cooking than in high pressure cooking (Güzel & Sayar, 2012). Other wet cooking methods employed in Faba bean processing include microwave wet cooking and blanching.

Generally, the cooking of legumes has been reported to result in the loss of greater amounts of sugars than proteins and minerals. Cooking is usually preceded by soaking to shorten the cooking time. Loss of soluble solids during cooking impacts both the nutritional and economic value of a product and is used as a measure of quality in cooked legumes (Güzel & Sayar, 2012). High pressure cooking was found to result in the loss of more solids (mostly carbohydrates and proteins) than atmospheric pressure cooking. Loss of sugars during cooking has been associated with the soluble characteristics of sugars in water which is enhanced by the separation of grain cells and the resulting release of cell components to the environment (Huma et al., 2008). The solubility of carbohydrates has been reported to be temperature-dependent, increasing with increasing temperature (Güzel & Sayar, 2012). Cooking also resulted in about a four-fold increase in rapidly digestible starch fractions of Faba bean. This increase was associated with the increased susceptibility of starch to the action of digestive enzymes (Güzel & Sayar, 2012). On the other hand, Giczewska and Borowska (2004) reported a decrease in starch digestibility of hydrothermally processed Faba bean. Hydrothermal processing was found to cause starch retrogradation, changes in amylase fraction and formation of β-type conformational structure with high resistance to amylolytic enzymes (Giczewska & Borowska, 2004). Pressure cooked Faba bean had more fraction of resistant starch and lower slowly digestible starch than grains cooked at atmospheric pressure. Also, high pressure cooking have been reported to result in slightly lower protein than ordinary cooking with the latter having more essential amino acids (histidine, leucine, threonine, and tyrosine) (Khalil & Mansour, 1995).

Additionally, high pressure cooking seems to have a greater ability to reduce the anti-nutrients present in Faba bean. Higher reductions in convicine, phytic acid, tannin, trypsin inhibitor and vicine content of Faba bean were reported in high pressure cooked samples than in samples cooked at atmospheric pressure. Also, a similar trend was observed by Sharma and Sehgal (1992) for phytic acid and saponin, a longer period of high pressure cooking resulted in higher reductions in the levels of these anti-nutrients and a corresponding increase in protein digestibility (10–12%) (Tables 7.1 and 7.2). Conversely, atmospheric pressure cooking (47%) resulted in a higher reduction in flatulence causing oligosaccharide, stachyose than in high pressure cooked samples (38%) (Khalil & Mansour, 1995).

Luo and Xie (2013) also reported a higher reduction in trypsin inhibitor levels in Faba bean subjected to ordinary cooking and high pressure cooking than those that were wet cooked using microwave heating. High pressure and ordinary cooking

Table 7.2 Nutrient composition and enzyme activity of processed faba bean

Nutrients	Bl	Co	Ge	So	Au	De & Co	Ex	De	So & De	So & Co	So, De & Co	So, De & Au	So & Au	Ir	Ir & Co	En	Fe	Mi	Ro	Reference
Folate (μg/100 g)	44.0	–	38.0	43.0–47.0	21.0–27.0	–	–	–	–	–	–	–	–	–	–	–	–	–	–	Hefni et al. (2015)
Ash (g/100 g)	3.9–4.3	–	–	2.9–3.1	–	2.91–3.32	–	–	–	–	–	–	–	3.7–3.9	3.5–4.3	–	–	–	3.6–3.9	Anderson et al. (1994), Kmiecik et al. (2000), Abd and Habiba (2003), Osman et al. (2014), Coda et al. (2015)
Protein (g/100 g)	–	–	27.2–27.6	26.9–29.6	–	–	27.1	31.3–32.2	–	–	–	–	–	32.2–36.3	30.8–37.7	–	–	–	29.2–31.8	Anderson et al. (1994), Alonso et al. (2000), Abd and Habiba (2003), Nalle et al. (2010), Osman et al. (2014)
Polyphenols (g/kg)	–	–	3.1–3.6	3.7	–	–	2.8	0.7	–	–	–	–	–	–	–	–	–	–	1.2–8.3	Alonso et al. (2000), Siah et al. (2014)

Nutrients	Bl	Co	Ge	So	Au	De & Co	Ex	De	So & De	So & Co	So, De & Co	So, De & Au	So & Au	Ir	Ir & Co	En	Fe	Mi	Ro	Reference
In vitro protein digestibility (%)	–	–	73–78.1	71.3–80.4	–	–	87.4	72.5	–	–	–	–	–	–	–	–	–	53.2–81.2	–	Vidal-Valverde et al. (1998), Alonso et al. (2000), Abd and Habiba (2003), Pysz et al. (2012)
α-Amylase (IU/g)	–	–	11.9–13.9	16.1	–	–	0.0	20.7	–	–	–	–	–	–	–	–	–	–	–	Alonso et al. (2000)
In vitro Starch digestibility	–	–	187.0–222.0	167.0	–	–	290.0	174.0	–	–	–	–	–	–	–	–	–	–	–	Alonso et al. (2000)
Fat (g/100 g)	–	–	–	–	–	–	–	–	–	–	–	–	–	1.4–2.8	1.3–2.8	–	1.53	–	2.2–2.7	Anderson et al. (1994), Osman et al. (2014), Coda et al. (2015)
Crude fiber (g/100 g)	–	–	–	–	–	–	–	–	--	–	–	–	–	5.6–8.5	7.7–11.8	–	7.2	–	–	Osman et al. (2014), Coda et al. (2015)
Carbohydrate (g/100 g)	–	–	–	–	–	–	–	–	–	–	–	–	–	49.6–58.4	43.8–53.6	–	–	–	61.4–64.0	Anderson et al. (1994), Osman et al. (2014)

Bl blanching, *Co* cooking, *Ge* germination, *So* soaking, *Au* autoclaving, *De* dehulling, *En* enzyme treatment, *Ex* extrusion, *Fe* fermentation, *Ir* irradiation, *Mi* microwave, *Ro* roasting significantly increased phytic acid and the increase resulted from the heat stable nature of phytic acid (Luo & Xie, 2013). Contrarily, microwave heating, ordinary cooking and autoclaving reduced the haemagglutinin content of the Faba bean. Breakdown of haemagglutinin into subunits during high temperature treatment may account for the loss of this compound (Luo & Xie, 2013). Similarly, haemagglutinin was completely destroyed by high pressure cooking and ordinary cooking (Khalil & Mansour, 1995).

Protein denaturation, destruction of trypsin inhibitor and reduction in anti-nutrients such as tannins and phytic acid were found to be responsible for the improvement. High temperature treatment have also been reported to be effective in the destruction of lectins in Faba beans (Dhull et al., 2021). Convicine and vicine levels of Faba bean were also significantly reduced by boiling and l-3,4-dihydroxyphenylalanine (L-DOPA) was completely removed (Cardador-Martínez et al., 2012). The convicine and vicine content vary with variety and the extent of reduction in these anti-nutrients also depended on the variety of the Faba bean. For instance, a variety (Col-288) had a 39% reduction in vicine while the ZAC variety had 0.90% and boiling lead to a higher decrease than roasting for both convicine and vicine (Cardador-Martínez et al., 2012). The partial solubility of these anti-nutrients in water during boiling could make them more susceptible to heat.

The effect of high temperature treatment on Faba bean was dependent on the pre-treatment the Faba bean was subjected to before the high temperature. Cooking in combination with a preliminary process of soaking was found to cause a significant reduction in phytic acid and tannin content of the legumes (cowpea, white gram, red and white kidney beans) (Huma et al., 2008). Soaking in citric acid followed by cooking reduced the phytic acid content of Faba bean by 35% (Vidal-Valverde et al., 1998). This reduction may be due to the solubility of phytic acid in an acidic medium. Khalil and Mansour (1995) in the study on processed Faba bean observed an insignificant difference in the protein content of raw and high pressure cooked (previously soaked) Faba bean but non-protein nitrogen significantly decreased with the processing. On the other, a slight but insignificant decrease in protein content was reported by Anderson et al. (1994) after soaking in water (1:3 w/v) overnight. The different preliminary processes before cooking in these studies may have accounted for the different outcomes. Anderson et al. (1994) cooked the Faba bean directly without any pretreatment while Khalil and Mansour (1995) soaked the beans in distilled water for 12 h before cooking.

Boiling of dehulled Faba bean cotyledon for 20 min at 121 °C reduced the vicine levels of Faba bean to different degrees (0.90–39.86%), however, the convicine level of some of the Faba bean varieties increased after boiling. Boiling was found to be more effective in reducing the glycosides than roasting and this could be due to the solubility of these compounds in water increasing their susceptibility to heat (Cardador-Martínez et al., 2012). L-3,4-dihydroxyphenylalanine(L-DOPA), an important phenolic amino acid known to be a precursor of dopamine in healthy neurons was found to have been eliminated in all the processed Faba bean varieties except for the ZAC variety (Cardador-Martínez et al., 2012; Coda et al., 2015).

A combination of processing methods including soaking, dehulling and high pressure cooking was found to be more effective in improving the *in vitro* protein digestibility of Faba bean (Luo & Xie, 2013). This improvement could be attributed to the reduction or elimination of different anti-nutrients as interactions between the anti-nutrients and proteins could increase the extent of cross-linking thus decreasing the solubility of proteins by forming protein complexes. These complexes can impair proteolytic enzyme access to peptide bonds. Further to this, increased chain flexibility and accessibility to proteases arise from enhanced changes in the structure of proteins like globulin resulting from thermal treatment (Luo & Xie, 2013).

A combination of soaking and dehulling followed by cooking significantly reduced saponin levels by 37% which is more than the reduction observed in just soaking and dehulling. Autoclaving of Faba bean for 15 min without any prior treatment resulted in up to 44% reduction in saponins while autoclaving (15 min) of previously soaked and dehulled grains resulted in up to 50% reduction. A longer autoclaving period of 25 min resulted in higher levels of reduction (up to 84%) (Sharma & Sehgal, 1992). The further reduction after cooking could be due to the heat- labile characteristic of saponins (Sharma & Sehgal, 1992). Additionally, the formation of complex compounds between saponins and amino acids or sugars with low extractability may have caused the further reduction.

A significant reduction in mineral content after blanching (Kmiecik et al., 2000) and cooking (Anderson et al., 1994) have been previously reported for Faba bean. Soaking in alkaline and neutral solutions before cooking is found to result in higher losses of vitamins as this processing methods favor the leaching of nutrients (Prodanov et al., 2004). Also, vitamins especially B-vitamins are known to be susceptible to high temperature treatment, heat treatment reduced the B-vitamins of Faba bean although high pressure cooking retained more B-vitamins than ordinary cooking (Khalil & Mansour, 1995).

7.2.5 Roasting

Roasting is a domestic processing technique applied to different food products and is usually used as a preliminary process in Faba bean utilization (Dhull et al., 2021). High temperature roasting resulted in higher protein content compared to low protein heating and depolymerization of high molecular weight proteins to smaller units was also reported after roasting. Dry heat treatment at 120 °C for 15 min reduced calcium, dietary fiber, starch content, soluble sugars and anti-nutrients including α-galactosides and phytic acid (Vidal-Valverde et al., 1998). The reduction in phytic acid content was attributed to the formation of phytin complexes with minerals during the high temperature treatment (Dhull et al., 2021).

Roasting temperature and time had a significant effect on the proximate and anti-nutrient composition of Faba bean. Roasting at 150 °C for 60 min was found to significantly reduce the total phenol and flavonoid content of Faba bean and a longer roasting time further reduced the total flavonoid and phenol content (Siah et al., 2014). Also, the antioxidant activity of Faba bean using the 2,2-diphenyl-1-picrylhydrazyl radical scavenging and Trolox equivalent antioxidant capacity assays reduced significantly after roasting while for the ferric reducing antioxidant power assay, roasting for up to 120 min increased the antioxidant activity.

Furthermore, roasting at 149 °C for 20 min significantly reduced protein and insoluble dietary fiber content while compared to other roasting regimens at higher temperatures (177–232 °C) and shorter time (12–18 min), that did not significantly affect the protein and insoluble dietary fiber content (Anderson et al., 1994). Trypsin inhibitor activity was also found to be most reduced at higher temperature and short time.

Cardador-Martínez et al. (2012) in their study on 10 varieties of Faba bean observed varied effects of roasting at 120 °C for 10 min on the vicine and convicine levels of the dehulled Faba bean varieties. For instance, no changes were observed in the vicine levels in one of the cultivars after roasting while convicine levels increased whereas in the other cultivars, convicine levels remained unchanged after roasting. Roasting significantly reduced the convicine and vicine levels of the other Faba bean varieties.

7.2.6 Germination

Germination is a common domestic process that enhances the flavor and bioavailability of nutrients in food products (Patil & Khan, 2011; Chinma et al., 2021). It softens the cotyledons of the grains, reduces cooking time, reduces anti-nutrients and thus enhances nutrient composition (Vidal-Valverde et al., 1998). It involves the sprouting of the grain embryo under suitable environmental conditions. Usually, the grains are hydrated by soaking in water and kept moist and warm to ensure sprouting. During germination, hydrolytic enzymes are activated (Luo & Xie, 2013) and macromolecules such as protein and starch are broken down into smaller molecules which increase their *in vitro* digestibility (Torres et al., 2007). Conversely, secondary metabolites are utilized as a nutrient source and thus result in the reduction of some components of the germinated grains (Vidal-Valverde et al., 1998). Germination has been considered to be an effective biological process for the reduction of flatulence factors in legumes and specifically effective in producing nutrient-rich Faba bean flour (Dhull et al., 2021). About 80% reduction was observed in the hemagglutinin content of Faba bean after germination (Khalil & Mansour, 1995).

Germination was found to result in the breakdown of polysaccharides to yield monomers such as glucose thus increasing the starch *in vitro* digestibility (Vidal-Valverde et al., 1998). It also reduced levels of α-galactosides by approximately 94% (Vidal-Valverde et al., 1998) and caused an insignificant increase in crude protein (4.5%), non-protein nitrogen (12.5%) and protein efficiency ratio (Khalil & Mansour, 1995). The observed increase during germination was associated with the metabolic activities during germination that led to a depletion of components and breakdown of protein into smaller units (Khalil & Mansour, 1995). The utilization of carbohydrate as an energy source during germination was also found to be responsible for the higher protein levels observed in germinated Faba bean (Alonso et al., 2000). Also, a longer germination period (72 h) resulted in higher protein content and lower levels of condensed tannins, phytic acid and polyphenols (Sharma & Sehgal, 1992). The activity of endogenous phytase enzymes during germination coupled with the leaching of phytic acid during the hydration stage was reported to be responsible for the reduced phytic acid content (Alonso et al., 2000). Similarly, a 24 h germination of Faba bean grains reduced saponin content by 30%, while a longer germination period (48 h) further reduced saponin by 77%. This decrease was associated with the degradation by enzymes during germination.

About 6% increase in calcium was reported for germinated Faba bean due to a decrease in hemicellulose content (Vidal-Valverde et al., 1998). A positive correlation has been established between reduced hemicellulose content and increased calcium bioavailability (Urbano et al., 1999). Likewise, higher calcium content was attributed to reduced phytic acid content in another study (Vidal-Valverde et al., 1998). Zinc and iron were also found to increase after germination (Dhull et al., 2021).

Compared to ordinary soaking and cooking, germination resulted in a higher reduction of phytic acid (Table 7.1). Furthermore, higher phosphorus content was also observed after germination, with this being attributed to the breakdown of phytic acid by phytase enzyme (Vidal-Valverde et al., 1998). Hefni et al. (2015) also observed high retention of B-vitamins especially folate (40%) in germinated Faba bean than in heat treated ones. This is expected as B-vitamins are known to be heat sensitive. In addition to this, flatulence-causing oligosaccharides (stachyose) were reduced by the cooking treatments and completely removed by germination (Khalil & Mansour, 1995). Vicine which is one of the major anti-nutrients of concern in Faba bean was significantly reduced with these processing techniques. However, lectins were also found to be present in germinated Faba beans at levels sufficient to agglutinate rabbit red blood cells.

7.2.7 Fermentation

Fermentation is a metabolic process where foods undergo changes in the chemical composition resulting from the activities of microorganisms and their enzymes (Van Boekel et al., 2010). The microorganisms use up food components to fuel their metabolic activities. For instance, carbohydrates such as lactose (milk sugar) are converted to lactic acid during the production of fermented milk products. Furthermore, glucose is converted to alcohol and carbon dioxide by the action of yeast during bread production (Van Boekel et al., 2010). Fermentation can be spontaneous or controlled and the process preserves foods, enhance nutrient composition, increase digestibility, provide value-added products, and reduce anti-nutrients. In a study by Coda et al. (2015), fermenting Faba bean with *Lactobacillus plantarum* VTT E 133328 significantly reduced anti-nutrients and eliminated favism-causing compounds. The activity of β-glycosidase by the *L. plantarum* was found to be responsible for the significant decrease (90%) in the vicine and convicine levels in the fermented Faba bean. Verni et al. (2017) also reported a similar trend for anti-nutrient reduction in fermented Faba bean. Additionally, the starch and protein digestibility, free amino acids and γ-aminobutyric acid of the fermented Faba bean were enhanced. Fermenting Faba bean flour with *L. plantarum* for 24 h was also found to have a slight impact (9%) on the elimination of phytic acid (Rosa-Sibakov et al., 2018). Also, the release and solubilization of proteins during *in vitro* digestibility were enhanced with fermentation with release observed during the gastric phase. In addition to the reduction of anti-nutrients, the higher *in vitro* protein digestibility may also be associated with increased proteolytic activity which enhanced free amino acids and γ-aminobutyric acid (Coda et al., 2015). Fermentation has also been reported to produce partial or total elimination of α-galactosides, tannins, phytic acid and trypsin inhibitor activity (Granito & Alvarez, 2006).

7.2.8 Enzyme Treatment

Bioprocesses such as enzyme treatment are known to influence the composition of legumes including Faba bean. Enzyme treatment has the advantage of reducing/eliminating targeted components of the substrate thus having little or no effect on the other components of the food material (Nyyssölä et al., 2021). Different studies have reported the use of exogenous enzymes such as phytase in food processing to achieve different objectives. For instance, phytases have been used in hydrolyzing phytates in legumes (Frias et al., 2003). Luo and Xie (2012), in their study, observed a significant reduction (61.7%) in the phytic acid content of Faba bean flour treated with phytase enzyme. Also, Rosa-Sibakov et al. (2018) observed an 80% reduction in phytic acid content after incubating for 1 h at 55 °C at the highest phytase dosage of 20 U activity in the study. Furthermore, about 95% reduction in phytic acid content was reported by Luo et al. (2010) for Faba bean incubated with exogenous phytase for 3 h. The extent of phytic acid reduction varied with the duration of exposure and the quantity of phytase enzyme added. Longer exposure time and more enzymes resulted in higher levels of reduction of phytic acid in the Faba bean (Rosa-Sibakov et al., 2018). The phytase enzyme hydrolyses phytic acid into inositol and Myo-inositol and this reaction is favored at pH of about 5.1 (Rahate et al., 2021). Hence, the pH at which the experiments were conducted in the different studies may explain the variation in the extent of reduction in anti-nutrient composition reported in the different studies.

Nyyssölä et al. (2021) also reported the use of α-galactosidases in reducing the galactooligosaccharide content of Faba bean to reduce flatulence associated with the consumption of Faba bean. Further studies on the sustainable use of enzymes in Faba bean processing are thus recommended.

7.2.9 Extrusion Cooking

Extrusion cooking technology is used largely in food processing to provide convenient and aesthetically appealing ready-to-eat food products (Pasqualone et al., 2020; Dhull et al., 2021). It is a high temperature short time processing technique used in processing cereal-based foods due to their expansion ability (Dogan et al., 2013). In recent times, legumes have been incorporated into extruded products to increase the nutritional profile of the products (Pasqualone et al., 2020). Extrusion can improve the nutritional quality of legumes at a lower cost due to more efficient use of energy and it is thus categorized as a versatile technology with low overhead cost, high productivity and short cooking time (Abd & Habiba, 2003). The process line usually involves a grinder, preconditioner, extruder, dryer and cooler (Dhull et al., 2021). The properly ground and conditioned raw materials are extruded at high pressure and temperature conditions of up to 20 MPa and 200 °C, respectively (Dogan et al., 2013; Pasqualone et al., 2020). These series of unit operations depending on the quantity of steam and water, pressure, mechanical shear, temperature, die dimension, etc. results in a variety of alterations in the physicochemical properties of the extruded products (Dhull et al., 2021). For instance, the extent of starch gelatinization during extrusion decreases at high screw speed due to the low residence time of the extruded product. On the other hand, low screw speed was found to result in the degradation of starch to dextrin due to excess mechanical energy (Dogan et al., 2013). Additionally, increasing extrusion temperature resulted in a higher reduction in lysine (Pasqualone et al., 2020). Abd and Habiba (2003) reported that changes in barrel temperature led to a significant difference in protein content of extruded Faba bean.

Generally, starch gelatinization resulting from the high temperature treatment during extrusion cooking improves digestibility. Cleavage of amylose chains following shear force produces small and more digestible fragments including dextrin and reducing sugars (Dogan et al., 2013). In addition, an increase in starch composition was observed in extruded Faba bean and this was linked to the influence of the process on resistant starch, making them more susceptible to hydrolysis (Adamidou et al., 2011; Dhull et al., 2021). The change in starch composition found by these authors could result from the breakdown of resistant starch thus, enhancing hydrolytic breakdown by endogenous amylase enzyme (Adamidou et al., 2011). At high temperatures (typical of extrusion process), starch granules undergo disruption and rupturing making them susceptible to hydrolyzing enzymes (Alonso et al., 2000). Furthermore, the extrusion process reduced the total non-starch polysaccharides in all extruded Faba bean, although the preconditioning process had more impact on the insoluble non-starch polysaccharide than the drying process. Changes observed in the fraction of soluble and insoluble non-starch polysaccharides may result from the depolymerization or incomplete solubilization of hemicellulose and insoluble pectic substances (Vidal-Valverde et al., 1998; Adamidou et al., 2011). In summary, regulation of extrusion process parameters can be useful in altering the digestibility of extruded products to suit the intended consumers (Pasqualone et al., 2020).

Alonso et al. (2000), found extrusion to be more effective in lowering the α-amylase (Table 7.2), chymotrypsin, and trypsin inhibitor activity of Faba bean than other methods such as soaking, dehulling, germination and extrusion. The alterations in the characteristics of the proteins and starch of the extruded product improve their *in vitro* digestibility and positively impact the nutritional potential of extruded products. Trypsin inhibitors are known to prevent protein proteolysis in the digestive tract thus, resulting in hypertrophy of the pancreas which reduces protein digestibility (Khatoon & Prakash, 2004). Also, this technology has been found effective in the reduction of inherent anti-nutrients in leguminous foods (Adamidou et al., 2011; Patil et al., 2016; Pasqualone et al., 2020).

Extrusion cooking has been reported to be effective in improving protein digestibility (Table 7.2) of extruded products majorly by reducing trypsin inhibitors. Protein denaturation resulting from high temperature and friction together with shear and increased surface area may probably enhance access to sensitive proteolytic sites (Pasqualone et al., 2020). Contrarily, protein digestibility can be impaired by the formation of protein aggregates through hydrophobic interactions, hydrogen and disulphide bonds which reduce protein solubility (Arribas et al., 2019).

Generally, the extrusion process reduced phytic acid and total tannin level in the Faba bean, however, the temperature of preconditioning was found to have a greater influence on the physicochemical parameters of the Faba bean than the temperature of the dryer (Adamidou et al., 2011). For instance, the extruder drying process had more effect on the tannins and phytic acid content of the extruded Faba bean while the trypsin inhibitor content of the extruded Faba bean was more influenced by the precondition-extruder processing. Similarly, the feed moisture and extrusion temperature were also reported to significantly influence phytic acid levels of extruded Faba bean. Higher feed moisture (22%) and temperature (180 °C) resulted in a higher reduction in phytic acid levels (Abd & Habiba, 2003). Soaking of the legume grains in distilled water and drying (50 °C) before the extrusion process was found to further reduce the level of anti-nutrients present in the extruded product (Abd & Habiba, 2003). The extrusion process led to the hydrolysis of inositol hexaphosphate to the tri-, tetra- and pentaphosphate derivatives which resulted in a significant reduction (29%) in the phytic acid content of Faba bean (Alonso et al., 2000). However, conditions for the extrusion process determined the extent of reduction in the phytic acid content of extruded Faba bean as reported by Adamidou et al. (2011). A significant reduction of about 92% was observed for both tannins and polyphenols extruded at 150 °C (Alonso et al., 2000). Reduction of tannins and polyphenols have also been associated with thermal degradation and changes in chemical reactivity of these anti-nutrients following the high temperature involved during extrusion cooking (Alonso et al., 2000). Adamidou et al. (2011) and Abd and Habiba (2003) also, observed a decrease in the tannin content of extruded Faba bean. The differences in the extent of reduction of these anti-nutrients could result from the variations in the temperature used. Heat treatment has been suggested to increase the polymerization of tannins thus reducing their extractability during analysis (Van der Poel et al., 1991). Additionally, a significant reduction in heamaglutinin activity was observed after extrusion (Alonso et al., 2000). The reduction in anti-nutrients including phytic acid, polyphenols and tannins which lower protein digestibility by reducing their susceptibility to proteolysis may also be accountable for the increased protein digestibility observed by Pasqualone et al. (2020). Abd and Habiba (2003) also reported an increase in *in vitro* protein digestibility after extrusion with pre-soaked samples having higher digestibility. About 44% reduction in trypsin inhibitor activity was found in extruded Faba bean and this was linked to the susceptibility of this anti-nutrient to high temperatures (Adamidou et al., 2011) while no trypsin inhibitor was observed by Abd and Habiba (2003). The variation in the outcome of the two studies may be associated with the discrepancies in their extrusion process.

7.2.10 Irradiation

Irradiation of foods is a processing operation that involves the use of specific ionizing radiations to enhance microbiological safety and shelf stability (Farkas & Mohácsi-Farkas, 2011). Foods are exposed to ionizing energy by gamma photons emitted through ^{60}Co radioisotopes, accelerated electrons of max 10 MeV or machine-generated X-rays with max 5 MeV kinetic energy. These energy sources do not induce radioactivity in foods but rather perform other functions including enhancing microbial safety and stability of foods (Farkas & Mohácsi-Farkas, 2011). There are speculations about the effect of irradiation on the nutrient composition of foods especially, vitamins. However, Food Standard Australia New Zealand reviewed the effect of irradiation on homegrown produce and concluded that there was no significant effect on sensitive vitamins at the maximum permissible dosage (1 kGy) (Roberts, 2014). This novel processing technique has been found effective in the reduction of anti-nutrients in cereals and legumes (Osman et al., 2014). These authors observed no significant difference in the proximate composition of Faba bean except for a slight increase in the fat and protein contents after irradiation treatments (0.5 & 1.0 kGy). This same trend was also observed in cashew nuts irradiated with 0.25, 0.5, 0.75 and 1.0 kGy (Bhattacharjee et al., 2003).

Minimal changes were observed in the ash content of gamma-irradiated Faba bean. Treatments below 2 kGy have been reported to have an insignificant ($P \geq 0.05$) effect on the major and trace minerals naturally present in legumes and cereals (Hassan et al., 2009). However, higher doses caused a significant reduction in calcium, sodium and potassium contents of liquorice root flour (Al-Bachir & Lahham, 2002).

Gamma irradiation had a varied effect on the anti-nutrient composition of Faba bean, especially phytic acid and tannins. Osman et al. (2014) observed a reduction in the tannin content of the irradiated Faba bean (0.5 and 1.0 kGy) with a further reduction in the tannin levels after cooking. A similar trend was also observed for irradiated (6 kGy) cooked beans by Brigide and Canniatti-Brazaca (2006). On the other hand, for phytic acid, Osman et al. (2014) observed different trends at the two irradiation dosages used and among Faba bean cultivars. For instance, irradiation at 0.5 and 1.0 kGy significantly reduced the phytic acid content of SH-S2 cultivars while for the BB7- S1 cultivar, irradiation at 0.5 kGy reduced the phytic acid levels but higher irradiation dosage (1.0 kGy) caused a significant increase in phytic acid content. Cooking of 0.5 kGy irradiated samples led to a slight increase in the phytic acid levels of the beans while at 1.0 kGy irradiation dosage, cooking reduced the phytic acids levels for both cultivars (Osman et al., 2014). The reduced phytic acid levels were linked to chemical breakdown triggered by free radicals produced through radiation changing phytate to its counterpart inositol and inositol phosphates (Lima et al., 2019). Also, phytate ring cleavage during irradiation was found to be a probable way to explain the reduction in phytic acid content (Osman et al., 2014).

Irradiation with subsequent cooking of Faba bean has also been found to be effective in improving *in vitro* protein digestibility of Faba bean (Osman et al., 2014). This was said to result from the inactivation of antinutritional factors such as protein inhibitors. The disruption of bonds such as disulphide and hydrogen bonds that stabilize protein structure by irradiation could also increase protein digestibility. This disruption of bonds can lead to the unfolding of the protein bonds thus, exposing additional peptide bonds for proteolysis (Koppelman et al., 2005).

7.2.11 Microwave Heating

In recent times, heating technologies used in the food industry are aimed at reducing energy expenditure through the decreased heating period and thus reducing processing costs (Pysz et al., 2012). In microwave heating, food materials absorb electromagnetic energy and achieve self-heating rapidly. Energy dosage can be specified thus allowing for maximum energy which affects the nutritional value of foods positively (Hardy et al., 1999). Although microwave heating may cause non-uniform heating in the samples, the penetration of microwaves is dependent on frequency as better penetration is favored by the lower frequency. Furthermore, product characteristics such as the shape of the product, salt and water content, and specific density influence microwave penetration (Pysz et al., 2012).

Pysz et al. (2012) comparing microwave heating with high pressure cooking found the latter to be more efficient in improving protein digestibility than microwave heating. However, microwave heating was found to be more efficient in improving starch digestibility (Espinosa et al., 2020). Resistance of proteins to hydrolytic breakdown by enzymes, protein aggregation and crosslinking are some of the factors that could reduce protein digestibility (Espinosa et al., 2020). Contrarily, Khatoon and Prakash (2004) found a higher protein and starch digestibility in pressure cooked Faba bean than in microwaved samples. The variations may arise from the differences in the processing conditions of these two authors. The longer period of heating in food processing has been found to result in loss of amino acids and reduced digestibility, causing loss of nutritional value (Khatoon & Prakash, 2004).

Considering the influence of varietal difference on the effect of processing on Faba bean nutrients and anti-nutrients, Espinosa et al. (2020) in their study on low and normal tannin Faba bean observed higher "moderately degradable" and "indigestible" protein fractions in normal tannin Faba bean than their low tannin counterpart after heat treatments. Pysz et al. (2012) soaked three varieties of Faba beans in water for 4 h followed by microwave heating at energy doses ranging between 500 and 2000 J/g. A general significant decrease in trypsin inhibitor activity was observed after microwave treatment. This was however dependent on the variety as the lowest energy dose (500 J/g) caused a 20% reduction of trypsin inhibitor in the Windsor and Basta varieties while a 50% decrease was observed in the Bacchus variety. Higher energy doses further reduced the trypsin inhibitor content of all the varieties. Additionally, microwave heating decreased the solubility of protein in the samples and subsequently, denaturation of protein. The authors proposed an exposure of hydrophobic groups which were initially in the spatial protein structure moving the polar groups into the interior of the molecule. The treatment however increased protein digestibility of all the varieties with lower improvement found in the Windsor White variety with highest trypsin inhibitor content. Also, the formation of insoluble phytins during dry heating of Faba bean was reported to be responsible for the 36% reduction in the phytic acid content of Faba bean subjected to dry heat (Vidal-Valverde et al., 1998).

7.3 Conclusion

Faba bean is a promising legume with great potential for use in food applications. However, its antinutritional property is a major setback to its utilization. Different processing techniques such as cooking, dehulling, enzyme treatment, extrusion, fermentation, and germination have been employed domestically and industrially to reduce/eliminate these anti-nutrients. These processing techniques have been used individually and combined to reduce anti-nutrients in Faba bean. A combination of different processing techniques has been found to result in significantly higher reductions than when they are used singly. The reduction of these anti-nutrients increases the bioavailability and *in vitro* digestibility of nutrients in Faba bean. However, loss of nutrient during Faba bean processing have also been reported. Hence, the need for optimization of these processing conditions to maximize the reduction in anti-nutrients and minimize nutrient loss is required and thus further improve the utilization of this leguminous crop. Further studies are equally required to explore processed Faba bean flours in various food applications.

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Chapter 8
Effect of Storage on Quality and Cooking Attributes of Faba Bean

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8.1 Introduction

Plants offer about 60% of the world's protein supply for human nutrition, with grain legumes of the *Fabaceae* family contributing for one-third (Smýkal et al., 2015; Henchion et al., 2017). Legume crops are one of the important foods in the human nutrition, and they are widely grown all over the globe as a long-term supply of high-protein food (Collado et al., 2019a; Sanju et al., 2021). Calcium, potassium, iron, zinc and magnesium, as well as polyunsaturated fatty acids, are abundant in them. Several studies have revealed that consuming a lot of beans helps protect the body from illnesses including cancer, diabetes, osteoporosis, and cardiovascular disease (Annor et al., 2014).

The faba bean (*Vicia faba* L.), also known as fava bean, wide bean, field bean, or horse bean (Duc, 1997; Mínguez & Rubiales, 2021). It is named after the large and flat grains it produce. Grain size and shape vary, but they are usually virtually spherical and white, green, buff, purple, brown or black (Altuntaş & Yýldýz, 2007). It is one of the world's oldest bean crops, dating back to the 10th millennium BC (Cubero, 1974; Tanno & Willcox, 2006; Chillo et al., 2008). In terms of total output, the faba bean ranks fourth among cool-season pulse crops (Rebaa et al., 2017; Sallam et al., 2017). Ecologically, nutritionally, and economically, the faba bean is a valuable crop (Xiao et al., 2021). It is primarily planted for human use of the edible seeds. Despite slight changes across varieties, faba beans are high in protein, carbohydrate, crude fiber, vitamin and mineral (Giménez et al., 2013; Multari et al., 2015;

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Collado et al., 2019a; FAO, 2019; USDA, 2021). They are also high in bioactive substances including phenolic compounds (primarily flavonoids), which are anti-oxidants, anti-diabetic, and anti-inflammatory (Siah et al., 2014; Turco et al., 2016; Valente et al., 2018).

Faba bean is taken in three forms: fresh, dry, and conservative (Altuntaş & Yýldýz, 2007). Fresh bean is classed as a non-climacteric commodity since it is a highly perishable immature commodity with an extraordinarily high respiration rate. Browning, flavor degradation, and dehydration are the major indicators of fresh faba bean quality loss, resulting in a limited postharvest life (Collado et al., 2019a). The method of keeping beans in storehouses, bags, heaps and bulks in such manner that both seedling and food values are preserved under specified conditions such as ventilation, fumigation, and optimal temperature and humidity is known as storage (Befikadu, 2014). However, legume seeds are often stored dry at room temperature (Strauta & Muižniece-Brasava, 2016). Unfavorable storage conditions can degrade their quality and lead to longer cooking time, in which the beans stay hard due to poor water uptake and softening of the cotyledon tissue, resulting in color, texture, and nutritional content loss (Yousif & Deeth, 2003). After being stored in storage, dried faba bean seed commonly respires or "sweats," resulting in moisture build-up or degradation inside the bin. Poor quality beans have a poor texture and mouthfeel, and their nutritional value suffers as a result of processing. The focus of this chapter therefore is on the factors that influence the quality and cooking characteristics of faba beans during postharvest storage, as well as ways for preserving their quality.

8.2 Postharvest Conditions During Storage

It is all too easy to lose sight of what is needed to keep the beans in good condition once the final grain has been stored and the hatches have been closed. However, if not properly handled, that grain can swiftly rot and become a useless heap (David & David, 1998). As a result, monitoring grain quality while it is being kept is crucial. Storage temperature and duration as well as moisture content of the seeds all have an impact on bean quality and should be taken into account during bean storage (Mills & Woods, 1994).

8.2.1 Temperature

The temperature within a store is influenced by the sun, the cooling impact of store radiation, outside air temperatures, heat created by grain respiration, and any insects present (Tilahun, 2007). Dark grey walls absorb more heat from the sun than light grey ones. Smaller silos (less than 30 t) and field bins will have a higher proportion of grain exposed to these surface temperature changes, resulting in faster grain quality loss (PBA, 2013). Whether the seeds are stored for a short time or for a long time, it is critical to keep grain temperatures under control by flowing air through the grain mass. Aeration is required to avoid heat and mold growth since both grain and mold respire and generate heat. Grain that has been aerated can be stored for up to four times as long as grain that has not been aerated. Aeration is also required to maintain the proper temperature of the grain mass and to keep temperatures equalized, even if the grain is dry when placed in storage. Convection currents arise when grain temperatures differ, transferring and concentrating moisture in the storage‘s top chamber. As the ambient air temperature rises, moisture movement, also known as moisture migration, becomes more evident. The first sign of a problem is usually the creation of a crust, which is followed by wet or sticky kernels on the grain surface (Befikadu, 2014).

8.2.2 Bean Moisture Content and Relative Humidity of the Store

The best aeration equipment and monitoring management will not prevent a bean from deteriorating if the moisture level is too high; it will just postpone the inevitable. Mold, like other microorganisms, need water to survive and reproduce. Microorganisms will be unable to proliferate if the moisture content of the beans entering the store is too low, as long as the relative humidity in the store is also kept low. The safe moisture content is the moisture level below which bacteria cannot survive (Tilahun, 2007). During storage, the aggregate moisture content of bean seed is the most critical factor. Due to physical susceptibility to mechanical forces and microbiological degradation from mold, seeds with moisture content greater than 18% are susceptible to substantial damage during storage and processing. Seeds with less than 15% moisture content, on the other hand, are more susceptible to impact damage. The seed coat and cotyledon break down when beans are stored in tin cans at low moisture levels, producing clumping and splitting, whereas excessive initial moisture promotes discoloration, off-flavor development, water absorption loss, and mold growth (Uebersax & Siddiq, 2013). The safe moisture content is proportional to the storage period to some extent. Moisture levels beyond the allowable moisture content can be tolerated for a brief period of time. Going into storage with the right amount of moisture in the beans does not mean it will stay that way. Due to high relative humidity caused by storage roof or sidewall leaks, grain may be rewet. Bucket elevator downspouts and uncovered hatches are potential entry points for moisture. Localized increases in bean moisture content can also be caused by condensation. Condensation is prevalent when warm grain is cooled in cold weather or when hot grain from a dryer is refrigerated in a storage (David & David, 1998).

8.2.3 Time and Light

When beans are first brought into storage, their quality is at its peak, but it can quickly decline if the storage environment is not properly controlled. Maintaining grain quality and conquering numerous insect issues connected with storage necessitates a mix of proper farm hygiene, storage selection, and aeration cooling. When grain enters storage, it must be monitored on a regular basis so that any bug or grain-quality issues may be addressed quickly. Farmers who plan to store faba beans for a long time should bear in mind that the grains continue to mature after harvest, and their quality will deteriorate in the sun and over time. High seed moisture content, high relative humidity, high temperatures, poor seed condition at harvest, and sunshine accelerate seed coat darkening (grain color degeneration) (PBA, 2013). Changes that occur can go unnoticed and so be difficult to analyze (Bressani, 1989); but, as the storage time lengthens, such changes can be identified. Long-term storage (months or years) or short-term storage (less than six months) under insufficient circumstances causes the grain's quality to deteriorate, lowering its economic worth.

8.2.4 Insect Pests in Storage

With stored faba beans, insect infestation is not a major issue. When faba beans are stored in storages with residues of cereal grain infested with pest insects like grain borers and flour beetles, infection might occur. They have the ability to proliferate and disseminate in faba beans. By combining proper cleaning habits with aeration cooling, this can be avoided. The only management alternatives for bug infestation in stored faba beans are phosphorus fumigation, any other alternative fumigant, or controlled atmospheres such as carbon dioxide or nitrogen (PBA, 2013).

8.3 Overview of Postharvest Storage of Dried Faba Bean

It is critical to have adequate storage facilities/structures to provide a year-round supply of high-quality faba bean seeds. The storage structures for faba bean seeds are chosen based on the degree of production, cultural practices, and climatic circumstances. Table 8.1 lists the benefits and drawbacks of storage strategies for faba bean seeds. The following are some of the structures (Fig. 8.1) utilized for faba bean storage.

Table 8.1 Benefits and drawbacks of faba bean seeds storage structures

Storage Types	Benefits	Drawbacks
Gas-tight sealed silo	Insect infestation can be controlled via use of phosphine and controlled atmosphere options since it is gas tight and sealable. Aeration can easily be achieved with use of fans Can last for ≥25 years. Commodity can easily be loaded and off loaded Good hygiene practices can easily be carried out	Capital intensive Seals must be maintained regularly
Non-sealed silo	It is simple to aerate with fans 7–10% less expensive than a sealed silo Can last for ≥25 years	Effective fumigation cannot be carried out
Grain storage bags	Cheaper Easily operated	Used for short term storage (≤ 3 months). Control of insect is limited as fumigation can only be done under specific protocols Requires regular inspection and maintenance Aeration of grain is difficult Can easily be attacked by rodents, birds etc
Plastic bags	Can give effective hermetic storage environment if properly used It is reusable Low cost. Imperviousness to water	Control of insect is limited as fumigation can only be done under specific protocols. Inspection and repair are required on a regular basis Aeration of grain is difficult
Tin cans	Excellent physical protection and barrier properties Can be sealed hermetically	May react with the bean seeds during long term storage if not coated which may result in corrosion, pitting, perforation, product deterioration and discoloration
Makamer	Effective against insect infestation, fire and mites Low construction and operational costs	Mold damage, lower commodity quality, and reduced viability and nutritional value could all result from increased moisture content over time
Glass jars	Tough, durable, chemically inert material Has no permeability to gas, water vapor and liquids	Can easily break Aeration of grain is difficult
Aluminum foil bags	Excellent barrier to light, gas, moisture and micro-organisms	Pinholes and strip breaks could occur when using very light aluminum foil bags

Adapted from Ahmed et al. (1988), Nasar-Abbas et al. (2008), Omobowale et al. (2015), Helmy et al. (2020), Piotrowicz-Ciéslak et al. (2020)

Fig. 8.1 Storage structures for faba beans

8.3.1 Silos

Most nations store food grains, rice, and legumes in silos because they are robust and give some amount of insect and pest resistance. Metal, mud, concrete, and plastic have all been used to make silos, but none of these materials have shown to be the most effective (Mijinyawa, 1999; Adejumo, 2013). Faba beans may be preserved in silos for 6 months to several years, with seeds ranging from 0.5 to several millions of metric tons depending on the size of the silo (Omobowale et al., 2015). Loading and unloading of large silos is done with the assistance of elevators and conveyors. The silo is normally built on a base of loose coarse gravel, which also serves to insulate the silo from moisture (Barbari et al., 2014). There are two types of silos: sealable and non-sealable.

8.3.1.1 Sealable Silos

It is advisable that gas-tight, sealable silos are used for the storage of faba beans as appropriate fumigation can be carried out in cases of insect infestation.

8.3.1.2 Non-Sealable Silos

Non sealable silos are also used for storing of faba beans. Although they are cheaper than the gas-tight, sealable silos, complete fumigation cannot be achieved as the gases will escape through available holes, hence, elimination of insect infestation is not guaranteed.

8.3.2 Grain Bags

Faba beans are also stored in grain bags, otherwise called silo bags, harvest bags or sausage bags. They are only used to store faba beans temporarily. They have the problem of imparting unpleasant odors and taints to the bean seeds. To avoid water penetration when storing faba bean seeds in grain bags, they must be packed at the good moisture level and the bag must remain shut during the storage time.

8.3.3 Plastic Bags

Polyethylene or polypropylene bags had been used to store faba beans (Helmy et al., 2020). The use of polyethylene bags for storage can provide a very effective, hermetic storage environment. Placing polyethylene bags inside regular storage bags to make multi-layer polyethylene storage bags can provide additional layers of protection to provide water resistance and entirely airtight storage conditions (Ng'ang'a et al., 2016).

8.3.4 Tin Cans

Tin cans can also be used to store faba beans (Ahmed et al., 1988). Tin cans are airtight, rodent-proof, insect-proof, and water-resistant. To prevent the seeds from being caked due to change in moisture and heating, the tin cans must be maintained away from direct sunlight and other heat sources. In properly sealed tin cans, seeds can be kept for up to a year.

8.3.5 Storage in Makamer

Traditionally, faba bean seed is stored in *makamer* in some countries (Ahmed et al., 1988). *Makamer* is a popular storage method in some countries, especially Egypt. It entails storing seeds in dry pots in pits dug under the ground. Air entry is minimized by completely filling the pits with seeds. This method of storage is said to help prevent seed discoloration and infestation by insects and is also referred to as the *kamre* process.

8.3.6 Glass Jars

Storage of faba beans in air-tightly closed glass jars have also been reported (Piotrowicz-Ciéslak et al., 2020). Glass is an amorphous, transparent material which does not have free and mobile electrons that absorb light energy. It does not react with chemicals and does not corrode. It has no permeability to gas, water vapor, odor and liquids.

8.3.7 Aluminum Foil Bags

It has also been claimed that faba bean seeds may be preserved for a year in polyethylene packed aluminum foil bags sealed with an impulse heat sealer (Nasar-Abbas et al., 2008).

8.4 Influence of Postharvest Storage Conditions on Physical Properties of Faba Bean

Physical properties, including color, hydration, swelling coefficient, electric conductivity, and solute leaching, are reported to be quality factors that influence the cooking quality (hardness defect) and consumer acceptability of beans stored at high temperatures for an extended period (Granito et al., 2008; Nasar-Abbas et al., 2008; Pirhayati et al., 2011; Ferreira et al., 2017). As a result, information on physical qualities is critical since they are good indications of correct faba-bean handling, storage, and processing (Altuntaş & Yýldýz, 2007; Nasar-Abbas et al., 2008; Siah et al., 2014). These characteristics can have an impact on the faba bean‘s postharvest quality.

8.4.1 Seed Testa Color

Freshness and quality can be indicated by color. The color of the seed testa (coat) is important in faba bean marketing for human consumption. Although the seed testa color can range from white to purple depending on the faba bean variety, the ideal color has been described as buff, beige, or light tan (AGWEST, 1998). The most frequent seed coat color in faba bean during harvest is light brown or beige, while this color is not uniform and darkens during storage (Robertson & El-Sherbeeny, 1991). The seed testa color may transform to medium brown, dark brown, or even chocolate brown depending on storage conditions and time. Consumers always equate a dark tint with an older seed (Hughes & Sandsted, 1975). After harvest, the faba bean‘s color darkens, lowering its value and popularity among consumers. In many species of beans, conditions at storage have a significant impact on the durability of postharvest seed color. Temperature, seed moisture content, relative humidity, and light are the key elements that impact seed color stability during storage in legumes, according to previous findings (Hughes & Sandsted, 1975; Park & Maga, 1999). The researchers also identified seed moisture content as a significant determinant in faba bean color darkening. Seeds with a greater moisture content discolored more quickly than seeds with a lower moisture level. It was discovered that faba bean moisture level of 14–15% increases postharvest color deterioration significantly during storage.

Nasar-Abbas et al. (2009) discovered that the storage temperature (5–60 °C) and duration (0.5–12 months) of an Australian faba bean testa color packaged in transparent polyvinyl chloride and polyethylene coated aluminium foil bags altered the color. The initial color (beige) of seeds stored at temperatures below 25 °C evolved to medium brown after 12 months, but faba beans stored at temperatures above 37 °C evolved to dark reddish-brown and nearly black after 12 months, according to their findings, as shown in Fig. 8.2. During storage at 37 °C, darkening was detected not only in the testa, but also in the kernel of faba beans. The storage temperature has a substantial impact on the testa color of the two Poland faba bean seed cultivars after 30 years of storage at −14 and +20 °C (Nadwslánski and Dino) (Piotrowicz-Ciéslak et al., 2020). Seeds kept at normal temperature (+20 °C) were black, whereas those kept at −14 °C were light brown (Fig. 8.3). Faba bean color was also shown to be significantly affected by light during storage. Testa darkening in the presence of light for 1 month was shown to be equivalent to darkening in the absence of light for 12 months at the same temperature (20 °C). Under light storage conditions, faba bean seed coat darkening increased with rising temperature at storage. Even at moderate temperatures, long-term storage induced color fading. Faba bean color darkening is accelerated by high oxygen levels during long-term storage, but color darkening is slowed by low nitrogen levels (Nasar-Abbas et al., 2008). The oxidation of leucoanthocyanidins in faba beans, which is catalyzed by air and light, might be the cause of faba bean color deterioration during storage (Stanley, 1992).

8.4.2 Hydration Coefficient (Imbibition Value)

The hydration coefficient measures the ability of faba bean seeds to absorb water in an acceptable amount of time after soaking. Soboka et al. (2021) found that hydration potential differed from genotype to genotype. The Authors observed highest values of hydration coefficient in all the new released Ethiopian faba bean genotypes evaluated. This rise shows that each grain of faba bean may absorb twice its initial weight, indicating that the seeds are capable of efficiently imbibing water after soaking, and it is a valuable quality characteristic for a consumer which correlates positively with cookability. This implies that the test genotypes will generate a high amount of flour. When faba beans are stored at high temperatures after

Fig. 8.2 Testa color of an Australian faba beans after 12 months at different storage temperatures (Nasar-Abbas et al., 2009)

Fig. 8.3 Seed testa colors of cultivar Nadwíslánski stored at −14 °C (**a**) and +20 °C (**b**), and cultivar Dino Poland faba bean stored at −14 °C (**c**) and +20 °C (**d**) (Piotrowicz-Ciéslak et al., 2020)

harvest, they lose moisture and have a larger incidence of hard beans, which affects seed cookability over time. Nasar-Abbas et al. (2008) discovered that storing faba beans at lower temperatures (5–25 °C) had no effect, but that temperatures above

37 °C reduced the hydration coefficients as presented in Table 8.2. El-Refai et al. (1988) found similar effects in Egyptian faba beans stored in *makamer* (underground pits) for 9 months or in tin cans at room temperature.

8.4.3 Swelling Coefficient

The quantity of water absorbed determines the swelling coefficients. As seen in Table 8.2, the swelling coefficient reacted similarly to the hydration coefficient. The ability of faba beans to swell reduced as storage temperature increases. Seeds stored at 5 °C were compared to seeds stored at higher temperatures, and it was observed that seeds stored at 25 °C had a 3% decrease in swelling coefficients, while seeds stored at 37 °C had a 7–19% decrease in swelling coefficients, according to Nasar-Abbas et al. (2008). El-Refai et al. (1988) discovered that after storing faba beans in tin cans for a long time, the swelling coefficient steadily decreased. The testa becomes tougher and less permeable to water after storage at high temperatures, acting as a barrier and preventing water from reaching the cotyledons (Liu et al., 1992). Furthermore, these cotyledon modifications may cause the seeds to absorb less water, resulting in a slower cooking rate (Hincks & Stanley, 1987; Berrios et al., 1998).

8.4.4 Electric Conductivity

The level of ions released from the grains to the hydration water is measured by electric conductivity, commonly known as electrolyte leakage (Hentges et al., 1991). The breakdown of phytate in the bean produces these ions (mostly divalent cations). Many factors impact electric conductivity, including the original moisture level, the existence of physical defects, and storage conditions, among others. According to Nasar-Abbas et al. (2008), electric conductivity increased with increased storage temperature. The authors found that a drop in the hydration coefficient induced partial electrolyte leakage from cotyledons during imbibition,

Table 8.2 Some physical properties of faba bean at different storage temperatures

	Storage temperatures (°C)					
Properties	5	15	25	37	45	50
Hydration	193.00	191.00	188.00	174.00	170.00	158.00
Swelling coefficient	215.00	210.00	209.00	201.00	189.00	175.00
Electric conductivity (μS/cm)	827.00	905.00	1115.00	2523.00	3216.00	3467.00
Solute leaching (mg/g)	3.80	6.60	7.40	18.10	24.80	36.10

Means of three determinations
Adapted from Nasar-Abbas et al. (2008)

especially in those held at higher temperature (37 °C). The rise in electric conductivity, on the other hand, came as a result of a cell disruption phenomenon, which indicates that the higher the bean's cell disruption, the higher the conductivity (Berrios et al., 1999). The rise in electric conductivity of stored beans was ascribed by Freitas et al. (2011) to increased moisture content, which resulted in a high incidence of fungus they detected during the storage period.

8.4.5 Solute Leaching

The electric conductivity of the soaking water was linked to solute leaching (leakage) (Nasar-Abbas et al., 2008). Table 8.2 shows that faba bean seeds stored at 37 °C lost 18–36 mg/g of solute, but seeds stored at 25 °C only leaked 4–7 mg/g. Phytase hydrolysis, according to Maria et al. (2007), led in the release of cations such as Na^+, K^+, Mg^{2+}, and Ca^{2+} from the bean cell wall structure, resulting in solute leaching. Part of these ions may combine with pectic acids to generate insoluble pectates, which prevent the bean from absorbing water and cause separation of the cell during cooking (Njoroge et al., 2014). High moisture concentration affects the bean cell membrane, allowing for fungus growth. Fungi cause metabolic changes that cause cell membranes damage, resulting in greater solute leaching and, as a result, higher electrical conductivity of the solution (Perez et al., 2007).

8.5 Influence of Storage Conditions on Chemical Composition of Faba Bean

8.5.1 Nutritional Composition of Faba Bean

The nutritional content of faba beans has been observed to change depending on storage conditions as presented in Table 8.3.

8.5.1.1 Protein

The protein content of faba beans ranges from 18–32% (Helmy et al., 2020). The percentage of protein in faba beans is inversely related to the amount of time they have been stored (Abeer et al., 2013). The protein content of faba beans is also affected by the methods of storage (Ahmed et al., 1988; Gezer et al., 2003). Faba beans stored for 9 months in cans at ambient temperature have been reported to have a detectable reduction in the level of protein from 29.2% to 19.8% (El-Refai et al., 1988). However, Nasar-Abbas et al. (2008) found no significant changes in faba beans stored at different temperatures. According to Ahmed et al. (1988), the

Table 8.3 Some chemical properties of faba bean seeds stored in *Makamer* and tin cans over a period of 9 months

Chemical properties	Unstored	Storage method and period (month)								
		In *Makamer*			In tin cans					
					After heating			Without heating		
		3	6	9	3	6	9	3	6	9
Moisture (%)	10.3	10.2	10.9	9.7	8.3	8.3	8.1	10.0	10.7	9.6
Crude protein (%)	29.2	27.3	25.4	23.4	26.8	24.5	22.2	26.3	24.5	19.8
Total sugars (%)	4.5	4.7	5.3	5.5	4.9	5.4	5.5	4.8	5.4	5.8
Reducing sugars (%)	0.5	1.1	1.7	2.4	0.9	1.3	2.4	1.3	3.4	3.3
Non-reducing sugars (%)	4.0	3.6	3.6	3.1	4.0	3.9	3.1	3.5	3.0	2.6
Pectin (%)	2.0	1.9	1.9	1.6	2.0	1.8	1.6	1.9	1.6	1.3
Ash (%)	3.6	2.8	2.6	2.0	2.9	2.8	2.1	3.0	3.0	2.0
Phosphorus (mg/100 g)	691	691	691	691	687	691	689	686	690	689
Iron (mg/100 g)	15.1	15.0	15.0	15.0	14.8	14.8	15.0	14.9	15.0	14.8
Calcium (mg/100 g)	72.0	72.0	71.4	71.8	72.0	71.7	71.8	72.0	71.9	71.1
Magnesium (mg/100 g)	8.0	8.0	8.0	7.9	8.0	7.9	8.0	8.0	7.9	7.9

Means of three determinations
Adapted from Ahmed et al. (1988)

protein content of beans decreased from 29.2% to 26.8%, and 26.3% after 3 months of storage in cans after heating and without heating, respectively, while the protein content gradually decreased from 6 to 9 months of storage to 22.2% and 19.8%, respectively. Enzymes (proteolytic) may be responsible for the steady decrease in crude protein content of faba beans.

8.5.1.2 Moisture

The moisture content of faba bean reduces as the storage time lengthens (Helmy et al., 2020). After heating faba beans in cans for 2 h at 70 °C, the moisture content reduced from 10.5% before heating and storage to 8.3% after 3 months, and then to 8.1% after 9 months (Ahmed et al., 1988). Heat may have dehydrated the bean seeds, resulting in a drop in moisture level. However, the moisture content of faba beans is unaffected by the storage duration (Ahmed et al., 1988).

8.5.1.3 Fat

Regardless of storage conditions, the fat content of faba beans increases as the storage duration increases (Helmy et al., 2020). This might be related to biochemical reactions occurring in seed mass.

8.5.1.4 Fiber

The amount of crude fiber in faba beans is inversely related to the amount of time they have been stored. The crude fiber content of faba bean appears to decrease as storage time rises (Helmy et al., 2020).

8.5.1.5 Ash

Ash content of faba beans increases with an increase in the storage period. This may be due to the metabolic activity of seeds and associated micro-organisms which tend to consume the organic matter during storage (Stefanello et al., 2015). Over a 9-month storage period, there is no discernible change on the iron, phosphorus, calcium and magnesium concentrations of faba beans (Ahmed et al., 1988).

8.5.1.6 Carbohydrate

The carbohydrate content of faba beans increases as the storage time lengthens (Helmy et al., 2020). During storage, the carbohydrate, protein, and lipid components of faba beans have an inverse relationship (Stefanello et al., 2015). According to Boghdady et al. (2017), faba beans have a carbohydrate content of 55–63%. Sugars found in faba beans are mostly sucrose and fructose (Collado et al., 2019a). During the preservation of faba beans, the sucrose content decreases while the fructose content increases (this may be due to the hydrolysis of sucrose to fructose leading to an increase in the fructose level). The sugar content of newly harvested faba beans ranges from 68–83% (dry weight basis). The overall sugar content of faba beans is unaffected by storage method, however storage duration has a minor impact on the levels of these nutrients (Ahmed et al., 1988). The total sugars in faba beans gradually rise as they are stored. This might be related to the conversion of starch to sugars that occurs during storage.

The reducing sugar content of faba beans is affected by storage techniques as well as storage time. The faba beans kept for 9 months under varied storage conditions showed significant increase in sugar content (Ahmed et al., 1988). This increase might be due to the hydrolysis of starch to monosaccharides during storage. Under varied storage duration and temperatures, the non-reducing sugar content of faba beans reduces after 3, 6, and 9 months (Ahmed et al., 1988). This might be because non-reducing sugars are converted to reducing sugars. Collado et al. (2019b) found that freshly harvested faba bean had a raffinose level of 6.64 g/Kg. After 3 and 6 days of storage, this quantity increases by 15–30% and 30–40%, respectively. With an increase in storage duration, only minor alterations are seen. The raffinose content of faba beans is unaffected by microwave heating during storage (Collado et al., 2019b). The starch content of dehulled faba beans is changed greatly by both storage technique and storage duration, and decreases progressively after 3, 6, and 9 months of storage under various storage methods (Ahmed et al., 1988).

8.5.1.7 Vitamin C

The total vitamin C content of faba beans reduced during storage, according to Collado et al. (2019a), with initial values ranging from 154.6 to 163.78 mg/kg and a 24–41% fall in vitamin C level after 10 days.

8.5.2 Bioactive Compounds of Faba Bean

8.5.2.1 Total Phenolic Content

The phenolic content of freshly harvested faba beans as shown in Fig. 8.4 ranges from 2.04 to 2.13 g/kg (Collado et al., 2019b). This remains rather steady for the first four days of storage, after which it gradually decreases by around 20% over the next six days (Collado et al., 2019b). When faba beans are stored at ≥37 °C, total phenolics are continuously reduced. The lesser the total free phenolics, total tannins, and proanthocyanidins in faba beans during storage, the darker the testa and cotyledons (Nasar-Abbas et al., 2009). Microwaving also reduces the overall phenolic content of faba beans by around 30% (Collado et al., 2019b). This might be owing to the effect of high temperatures on polyphenols and/or the creation of new compounds as a result of cooking (Xu & Chang, 2008).

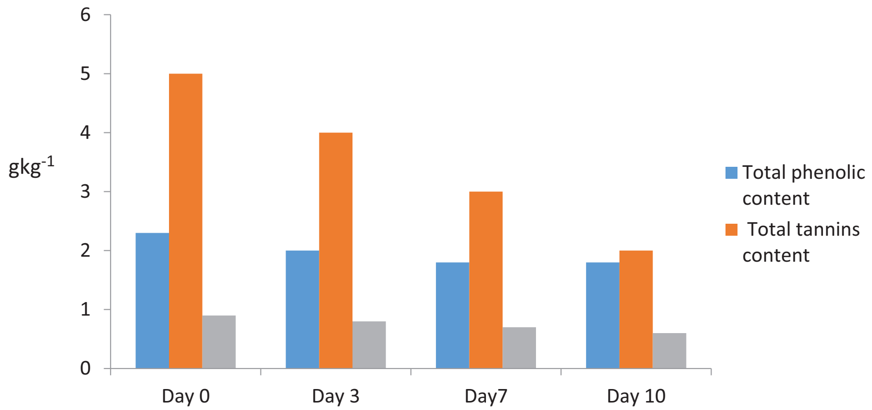

Fig. 8.4 Changes in total phenolic content, total tannins content and phytic acid content of faba bean seeds stored over a period of 10 days. (Adapted from Collado et al. (2019a, b))

8.5.2.2 Total Tannin Content

The total tannin content of faba beans after 10 days of storage decreases significantly (Collado et al., 2019a). The concentration of faba bean tannins reduces as the temperature rises. This decrease in tannin concentration is accompanied by an increase in the cotyledon's hardness (Nasar-Abbas et al., 2008). This decrease in phenolic content of faba beans at high storage temperatures might be due to oxidative degradation, which typically increases as temperature rises. Microwaving also reduces the tannin level of faba beans that have been kept for 10 days by 30–60%. (Collado et al., 2019b). Microwaving is said to be the most effective way to lower the tannin level of beans (Revilla, 2015; Klug et al., 2018). The total condensed tannins content of freshly harvested faba bean is estimated to be 2.20 gCaE/Kg (Collado et al., 2019b). The seed coats contain the majority of the condensed tannins (Revilla, 2015), and removing the seed coats reduces the overall condensed tannins content of faba beans by 92% (Alonso et al., 2000). After three days of storage, the tannin content of faba beans drops by around 40% and then remain unchanged (Collado et al., 2019b). The complex formation between the pectin released from the cell walls and tannins may be the cause of the reduction in tannin concentration in faba beans (Taira et al., 1997). The tannin level of faba beans is reduced by around 30% when cooked in the microwave (Collado et al., 2019b). This reduction might be due to heat degradation or interactions with other seed components, such as proteins, resulting in the formation of insoluble complexes (Nithya et al., 2007).

8.5.2.3 Phytic Acid Content

The phytic acid level of faba bean reduces by 30% after a 10-day storage period (Collado et al., 2019b) and continues to decrease with storage duration. This might be because phytic acid is the principal supply of phosphorus for the many metabolic activities that faba beans go through after harvest (Collado et al., 2019b). Phosphorus is mostly stored as phytic acid in legumes, grains, oil seeds, and nuts (Vats & Banerjee, 2004). The storage conditions, temperature, humidity, and fermentation duration all have an impact on the phytate concentration in faba bean seeds (Hussien, 1982). At 3, 6, and 10 days of storage, microwaving lowers the phytic acid level of faba beans by 25–30%, 15–6%, and 7–9%, respectively (Collado et al., 2019b). Thermal deterioration of faba beans, in addition to changes in chemical reactivity or the production of insoluble complexes, may result in a decrease in phytic acid content (Alonso et al., 2000).

8.5.2.4 Total Alkaloid Content

Collado et al. (2019b) found that the total alkaloid content of newly harvested faba beans ranged from 1.98–2.36 g/Kg. The alkaloid content of faba beans decreases by 20–30%, 75–80%, and 80–85% after 3, 7, and 10 days of storage, respectively

(Collado et al., 2019b). This decline might be the result of antioxidant chemicals (phenolic compounds, vitamin C, etc.) degrading during storage (Ansah et al., 2018). The researchers also found out that when faba beans are microwaved, the total alkaloid content increases by 0.9 and 1.2–1.7 g/Kg after 3 and 7–10 days, respectively. This is due to an increase in the antioxidant compounds' extractability.

8.5.2.5 Pectic Substances

With an increase in storage time, the amount of pectic substances in faba beans gradually decreases. After 9 months of storage, this decline ranges from 19–31% of the initial value (Ahmed et al., 1988).

8.6 Influence of Storage Conditions on Faba Bean Cookability

When faba beans are stored at high temperatures, the cotyledon becomes hard and difficult to cook, resulting in longer cooking times, changes in color and texture, a loss in nutritional content, and more energy used on preparation (Martin-Cabrejas et al., 1997; Yousif et al., 2003). Important quality parameters such as soluble solids, water absorption and electrolyte leaching can be used to detect a decrease in faba bean quality at storage (Berrios et al., 1999).

The hard-to-cook condition of faba bean is supposed to increase as storage temperature (37 °C) and time increase (Nasar-Abbas et al., 2008). High storage temperatures accelerate the processes that cause the cotyledon of faba beans to harden. This lowers the hydration (inhibition) and swelling coefficients, as well as the cookability of the seeds. The hard-to-cook phenomena of faba beans is unaffected by storage temperatures ranging from 5–25 °C (Nasar-Abbas et al., 2008). High-temperature storage of faba beans can cause structural and chemical changes in the testa, resulting in an increase in the testa's hardness. When the bean is cooked, the increased hardness acts as a barrier, preventing water from reaching the cotyledon (Aguilera & Rivera, 1990; Liu et al., 1992; Berrios et al., 1998). The involvement of phenolic compounds and phenol metabolism during storage is thought to be the source of bean cotyledon hardness (Hincks & Stanley, 1986; Liu, 1995; Garcia et al., 1998; Maurer et al., 2004). It might possibly be due to a significant rise in acid detergent fiber and lignin content, which indicates an increase in the testa and cell wall fraction (Yousif & Deeth, 2003). An increase in lignification during storage will make faba beans more difficult to cook.

8.7 Conclusion

Under ideal storage conditions, faba beans may be preserved for a long period while maintaining their quality. In general, difficulties with stored faba beans present themselves over time as the hardness of the bean cotyledon, leads to a protracted cooking duration. Furthermore, there is evidence of off-colored products, loss of nutritional values, and bioactive components as a result of seed quality during harvest, as well as storage exposure to unfavorable temperature, light, and humidity. However, when combined with moderate low temperatures, appropriate storage structures, and a nitrogen environment that delays seed darkening, the application of breeding programs with better grain yield, and disease resistance for storage have proven to be beneficial.

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Chapter 9
Faba Bean Starch: Structure, Physicochemical Properties, Modification, and Potential Industrial Applications

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9.1 Introduction

Starch continues to be of utmost importance in nutrition, functionality, and industrial applications. These roles are driven by the two alpha-glucans, amylose and amylopectin, which represent approximately 98–99% of the dry weight of starch (Wani et al., 2016). Minor constituents may include lipids, proteins, and phosphates (Sofi et al., 2013). In terms of supply, cereals, roots and tubers have been the common sources of starch, particularly for industrial applications. However, due to industry searching for novel functionality, as well as health and technological advantages, interests are growing remarkably towards non-conventional sources,

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and this justifies the current recognition being received by legumes (Punia et al., 2019; Oyeyinka et al., 2021a).

Legumes are a group of crops belonging to the family *leguminosae*, with 16,000–19,000 known species (Wani et al., 2016). Ranked fifth in terms of annual grain production after wheat, rice, corn, and barley, they are cultivated over an area of 78 million hectares in the world. Primarily, the cotyledonous seeds of many legumes are valuable as food, with the highest global consumption coming from India (Aggarwal et al., 2004). The popular use of legumes as foods is unconnected with them being a rich protein source (20–50%) (Oyeyinka et al. 2021b). However, legumes are classified into oil seeds, forage and pulses, based on their oil content and dry matter. So other than their protein content, some pulses have been discovered to be rich sources of starch, notable among which are Bambara groundnut, cowpea, and Faba bean.

Among the most widely grown winter season legumes, Faba bean was ranked fourth (Punia et al., 2019). In addition to its cultivation for dietary purposes in cultures such as Middle East and North Africa (Multari et al., 2015), the pulse is currently receiving notable research attention in the wake of increasing global need for environmental preservation and sustainable future proteins. Notably, the starch content of Faba bean, which can vary between 22% and 45% (Punia et al., 2019) is currently being explored to unlock even more industry-related prospects. This chapter focuses on the composition, structure, physicochemical properties, as well as modifications of Faba bean starch, with insights into its future industrial potentials.

9.2 Yield and Starch Isolation

The recoverable starch yield from any starch-rich material is an important factor to consider when deciding among available options. This, coupled with achievable level of purity, can be greatly influenced by the starch extraction method (Wani et al., 2016; Oyeyinka & Oyeyinka, 2018). Generally, there are two main methods of starch extraction from legumes, i.e., dry and wet-milling processes (Wani et al., 2016). While dry-milling finds a wider adoption at the industrial scale, wet milling is common in the laboratory, and is synonymous to a higher starch purity due to the limitation of the former to efficiently separate starch-protein matrices (Meuser et al., 1995). As a way to enhance the purity of starch obtained through dry-milling, subsequent washing of air-classified legume starch with water may be considered (Reichert & Youngs, 1978; Hoover & Sosulski, 1986). It is also worthy of mention that wet-milling may further be classified as either flour- or grain-based (Oyeyinka & Oyeyinka, 2018). This means starch can be extracted from the legume in question after being milled into flour or just after dehulling without prior flour production. Reviewing the literature suggests that Faba bean starch has been predominantly extracted using the wet milling method. This method commonly involves steeping of grains or flour in water, with added sodium metabisulfite (Ambigaipalan et al., 2011), sodium hydrogen sulphite (Zhang et al., 2019), or sodium hydroxide (Haase & Shi, 1991; Morad et al., 1980a). The diverse composition of the solvent suggests modification of the seed softening operation to suit experimental peculiarities or objectives. In fact, Dong and Vasanthan (2020) used a combination of alcohol and aqueous extraction as described by Gao et al. (2009). Sodium hydroxide, for example, is believed to aid protein solubilisation. Following the soaking operation is draining in the case of grains, and centrifugation in the case of flour. Though other factors such as variety matter, the varying yields (32.94–84.70%) (Table 9.1) reported for Faba bean starch may be partly explained by the diverse extraction methods and other varying parameters.

Table 9.1 Yield, composition, crystallinity pattern and granule morphology of Faba bean starch

Faba bean source	Yield (%)	Amylose content (%)	Protein (%)	Ash (%)	Lipid (%)	XRD pattern	Granule shape	Reference
Canada	32.94–36.34	31.63–31.86	0.31	0.03	0.05	Type C	Oval, round and irregular	[a]Ambigaipalan et al. (2011)
Canada	NR	39.90	0.20	0.01	NR	NR	Oval, kidney and irregular shape	Li et al. (2019)
NR	NR	31.30	0.52	NR	0.08	NR	Oval or irregularly shaped	Lorenz (1979)
NR	–	33.69	5.73	0.82	NR	NR	Round or ellipsoidal	Morad et al. (1980a)
China	NR	33.55	0.30	0.07	0.38	Type C	Oval, spherical, kidney, and elliptical shape	Zhang et al. (2019)
India	NR	51.69	NR	NR	NR	Type C	Round, elliptical, irregular, and oval shape	Sofi et al. (2013)
Canada	41.10–47.50	28.80–30.00	NR	NR	NR	NR	NR	Hood-Niefer et al. (2012)
Canada	NR	32.00	0.45	0.90	0.08	Type C	NR	Hoover and Sosulski (1986)
Canada	NR	NR	NR	NR	NR	NR	Oval, round	Dong and Vasanthan (2020)

[a]Authors reported as percentage nitrogen and the value was converted by multiplying with 6.25; NR: Not Reported

9.3 Starch Composition and Structure

Starch is generally composed of two main biopolymers called amylose and amylopectin (Fig. 9.1). These two polymers are made up of repeating units of glucose molecule joined by glycosidic linkages and account for approximately 98–99% of starch (dry weight) (Tester et al., 2004). The presence of amylose and amylopectin in starch molecules as well as other minor starch components such as ash, fibre, lipids, and proteins are well-known to significantly influence the functional and physicochemical properties of starch (Oyeyinka & Oyeyinka, 2018; Srichuwong & Jane, 2007). The ratio of amylose to amylopectin and the minor starch components has been found to vary with botanical origin and variety of legumes (Oyeyinka & Oyeyinka, 2018). Besides the ratio of amylose to amylopectin in starch, their structural conformation and arrangement in starch molecules is thought to dominate the physicochemical properties of starch. For example, Jane et al. (1999) reported that the pasting and gelatinisation properties of starch from different botanical origins

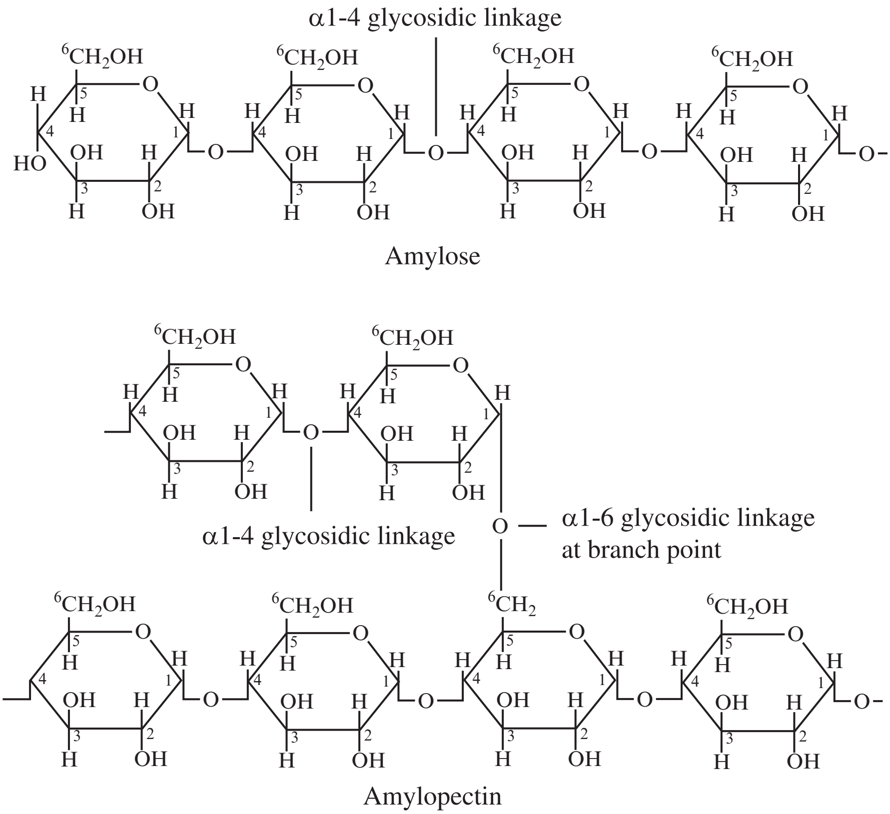

Fig. 9.1 Structure of amylose and amylopectin in starch

were influenced mainly by the structure of amylose and amylopectin branch chain length. Although the minor starch components are usually found in very small quantities, they are frequently used to assess starch purity (Piecyk et al., 2013; Maaran et al., 2014) and can also greatly influence the pasting and thermal properties of starch (Tester & Morrison, 1990). The possibility of amylose forming inclusion complexes with endogenous lipids or added lipids have been reported to reduce swelling power and pasting properties in cereal (Tester & Morrison, 1990) and legume starches (Oyeyinka et al., 2021b). The composition including amylose, amylopectin and minor starch components as well as the structure (morphology and crystallinity pattern) of native Faba bean starch is discussed below.

9.3.1 Amylose, Amylopectin and Minor Starch Component

The composition of Faba bean starch with regards to amylose and minor starch components are presented in Table 9.1. None of the studies that characterised native Faba bean starch reported its amylopectin component (Sofi et al., 2013; Ambigaipalan et al., 2011; Zhang et al., 2019; Morad et al., 1980a; Lorenz, 1979; Hood-Niefer et al., 2012; Li et al., 2019). Meanwhile, some authors have determined the amylopectin component of starches by subtracting the amylose content from 100 (Aina et al., 2009; Falade & Okafor, 2013), although other studies determined the amylopectin by iodine complex formation (Bates et al., 1943) or by subtracting the amylose content from the starch (Deng et al., 2021). Future studies on Faba bean starch should document its amylopectin content as subtraction of amylose from 100 may not accurately represent the true amylopectin content of these starches. Significant variation in the amylose contents (17.00–51.69%) have been observed in starches extracted from Faba bean grains (Sofi et al., 2013; Ambigaipalan et al., 2011; Zhang et al., 2019; Haase & Shi, 1991; Morad et al., 1980a; Lorenz, 1979; Hood-Niefer et al., 2012; Li et al., 2019; Gunasekera et al., 1999; Morrison & Laignelet, 1983). Hood-Niefer et al. (2012) studied the impact of growth location and genotype on the starch, amylose and protein contents of legume starches, including Faba bean starch, and found significant variations among the studied genotypes. According to the authors, genotypic differences did not significantly influence the amylose content of the starches, but growth location did. Although the locations received similar rain fall when the grains were planted in 2006 and 2007, the timing of the rainfall varied, as more rain reportedly fell in July and August 2006 than in 2007 (Hood-Niefer et al., 2012). Previous studies similarly found that genotypic differences and environmental growth conditions may influence crop yield and grain composition (Jing et al., 2010). The amylose content of Faba bean starches is generally high and within the range of values (11.60–88.00%) reported for pulse starches (Hoover et al., 2010). The relatively high amylose content of pulse starches, which makes these starches highly resistant to digestive enzymes positions pulse starches (Hoover et al., 2010) as a functional ingredient for various industrial uses (Oyeyinka & Oyeyinka, 2018). The molecular weight (M_w) of amylose and amylopectin of pulse starches such as cowpea (Kim et al., 2018), pigeon pea (Kaur & Sandhu, 2010), mung bean (Kim et al., 2018; Kaur et al., 2011) and pea (Ratnayake et al., 2001) as well as the chain length distribution of amylopectin has been reported in the literature (Kim et al., 2018; Ratnayake et al., 2001; Huang et al., 2007) and those of Faba bean starch are also required in future studies.

9.3.2 Crystallinity

The crystal packing arrangements inside starch granules studied using an X-ray diffractometer can show three main types of pattern, A-type, B-type and C-type (Hizukuri et al., 1983), which are generally found in cereal, root and tuber starches as well as high amylose cereal starches and pulse starches, respectively (Hoover et al., 2010). The A- and B-types are mainly differentiated by the amount of intrahelical water content and the packing arrangement of double helices within the amylopectin structure (Imberty & Perez, 1988). While the A-type is closely packed and less hydrated, the B-type is more hydrated with a loose packing arrangement (Imberty & Perez, 1988; Cheetham & Tao, 1998). The C-type pattern, which is mostly found in pulse starches, is a mixture of the A- and B-types (Pérez et al., 2011). So far, only a few studies reported the crystallinity pattern (C-type) for Faba bean starch (Sofi et al., 2013; Ambigaipalan et al., 2011; Zhang et al., 2019). Although the C-type pattern is generally found in pulse starches, some authors have reported the A- or B-type for some pulse starches like those extracted from Bambara groundnut (Oyeyinka et al., 2017; Sirivongpaisal, 2008), mung bean (Ohwada et al., 2003; Hoover et al., 1997) and yam bean (Forsyth et al., 2002). Hence, it is important to characterise the crystalline patterns of Faba bean starches in future studies as well as investigate the impact of variety, genotypes and growing conditions on the crystallinity pattern.

9.3.3 Granule Morphology

The morphology of starch from pulses including those from Faba bean has been largely studied using a scanning electron microscope (SEM) (Sofi et al., 2013; Ambigaipalan et al., 2011; Zhang et al., 2019; Morad et al., 1980a; Lorenz, 1979), though some authors have also used a confocal laser scanning microscope (CLSM) (Zhang et al., 2019; Li et al., 2019), light microscope (LM) and polarised light microscope (PLM) (Zhang et al., 2019). Most of the granules of Faba bean starches are reportedly oval, round, irregular, kidney and ellipsoidal in shape (Table 9.1), smooth with no evidence of fissures or pin holes and have sizes ranging between 6.8 and 30 μm (Sofi et al., 2013; Ambigaipalan et al., 2011; Li et al., 2019). Zhang et al. (2019) studied the morphology of different pulse starches using SEM, LM, PLM and CLSM and found differences in SEM, LM and PLM micrographs (Fig. 9.1).

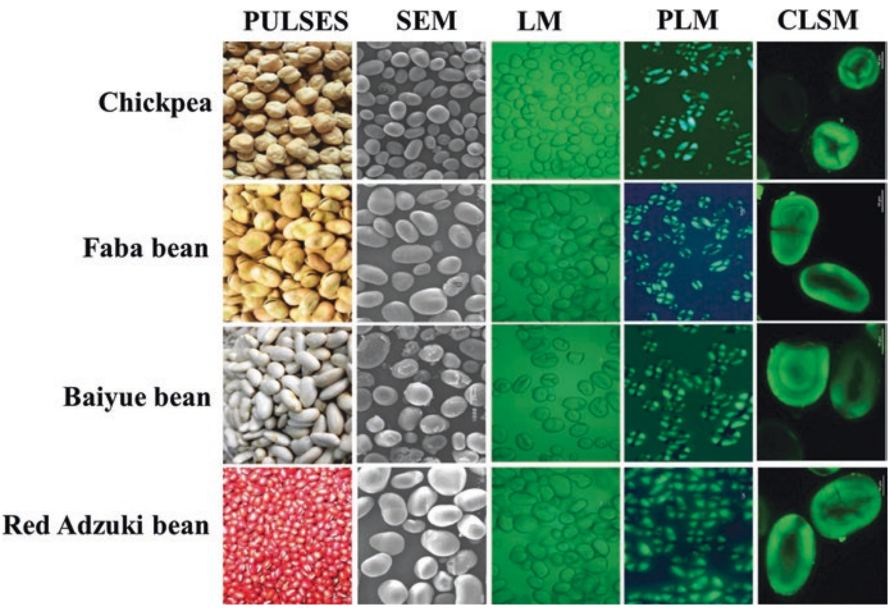

Fig. 9.2 Morphology of legume bean starches studied using SEM (**a**), LM (**b**), PLM (**c**) and CLSM (**d**) (Zhang et al., 2019)

However the fluorescence intensity as revealed by the CLSM images were similar among the starches, indicating similar amylose molecular content in the starches (Zhang et al., 2019). Future studies on starch from Faba bean and other lesser-known pulses should use these microscopic techniques (SEM, LM, PLM and CLSM) for characterisation and better understanding of the morphological structures (Fig. 9.2).

9.4 Physical and Physicochemical Properties of Faba Bean Starch

9.4.1 Colour and Light Transmittance

Colour is an important parameter when assessing starch quality (Sit et al., 2013). Since an L^* value greater than 90 has been noted as satisfactory for starch lightness (Wang et al., 2000), it is noteworthy to state that Faba bean starch may exhibit a remarkable level of whiteness, which would enhance its potential competitiveness with some more common starch sources. For instance, the L^* value reported by Sofi et al. (2013) for Faba bean starch (96.67) (Table 9.2) is comparable to those recorded for some cereal sources, e.g., rice (96.79) (Kim et al., 2015), wheat (96.46) (Zhu et al., 2009) and corn (94.15) (Pietrzyk et al., 2015). Again, relative to root and tuber

Table 9.2 Physical and physicochemical properties of Faba bean starch

Property	Values	References
Colour		
L^{*a}	96.67	Sofi et al. (2013)
a^{*a}	0.65	Sofi et al. (2013)
b^{*a}	6.02	Sofi et al. (2013)
Leaching temperature (°C)	70–75	Ambigaipalan et al. (2011)
pH	7.23	Sofi et al. (2013)
Solubility at 60–90 °C (%)	2.29–9.92	Zhang et al. (2019)
Swelling power at 60–90 °C (g/g)	1.09–12.67	Zhang et al. (2019)
Water absorption (g/kg)	1680	Sofi et al. (2013)
Oil absorption capacity (g/kg)	1790	Sofi et al. (2013)
Bulk density (g/L)	0.95	Sofi et al. (2013)
Peak viscosity (cP)	3524	Zhang et al. (2019)
Breakdown viscosity (cP)	1247	Zhang et al. (2019)
Trough viscosity (cP)	2277	Zhang et al. (2019)
Final viscosity (cP)	4814	Zhang et al. (2019)
Setback (cP)	2536	Zhang et al. (2019)
Pasting temperature (°C)	63.0–73.0 °C	Zhang et al. (2019), Doublier (1987), Hood-Niefer et al. (2012)
Pasting time (min)	4.2	Zhang et al. (2019)
Gel strength (g)	47.2[a]	Zhang et al. (2019)
	47.2–627.6[b]	Song and Liu (2013)
Gel hardness (g)	113.916–1993.353[b]	Song and Liu (2013)
Gel gumminess (g)	109.351–1744.267[b]	Song and Liu (2013)
Gel chewiness (g)	102.234–1718.657[b]	Song and Liu (2013)

[a]After 2 ½ h of storage
[b]Starch concentration of 6–14%

sources, the lightness implied by Sofi et al. (2013) is similar to what was noted for potato starch (96.70) and slightly lower than that of cassava (99.28) (Mbougueng et al., 2012). Sofi et al. (2013) also reported a^* and b^* values of 0.65 and 6.02 (Table 9.2), respectively, for Faba bean starch. Future investigations into the physical attributes of Faba bean starch may consider the determination of the colour characteristics as there are currently limited data in this regard.

Some insights about the light transmittance of Faba bean starch paste during storage are available (Sofi et al., 2013; Ambigaipalan et al., 2013; Sharma et al., 2020). Sofi et al. (2013) observed the transmittance of freshly prepared Faba bean starch to be 6.93%, but decreased to 0.505% after 5 days of refrigerated (4 °C) storage (Table 9.3). Likewise, Sharma et al. (2020) reported the transmittance of

Table 9.3 Light transmittance of Faba bean starch paste

Storage parameters		Value (%)	References
Temperature (°C)	Storage period (day)		
4	First day	6.93	Sofi et al. (2013)
25	After 5 days	0.505	Sofi et al. (2013)
6	First day	18.80	Sharma et al. (2020)
6	After 6 days	<5	Sharma et al. (2020)

18.80%, but after 6 days of storage at 6 °C, this was below 5%. The difference in transmittance values and extents of decrease reported in the studies described above may be due to varietal and analytical differences. For example, Sofi et al. (2013) employed a heating time of 30 min while Sharma et al. (2020) adopted double that time. This may underly the need to have a standardized analytical procedure for easy comparison of data.

A similarly reduced light transmittance was reported by Ambigaipalan et al. (2013) but with some more insightful detail. The authors noted that the rate at which light transmittance dropped was more rapid during the first 24 h (at 4 °C) than the rest (24 days at 25 °C) of the storage period. The initially high falling rate was attributed to the interaction between leached amylose molecules while intra- and intermolecular association of amylose and amylopectin may explain the lower extent of decline during the remaining storage period. It is however unclear why the authors did not discuss the potential role that storage temperature might have played in the varied rates of reducing transmittance, since the first day of storage was at 4 °C while the rest was at 25 °C. Compared to black and pinto bean, Faba bean starch paste demonstrated lower extent of decreasing transmittance during storage, presumably due to a lower degree of amylopectin-amylopectin interaction vis-à-vis higher amylose leaching. It was explained that the higher amylose leaching from Faba bean starch might have resulted in a much more viscous environment, such that it restricted the mobility of amylopectin molecules to interact, but facilitated their entrapment within the amylose network (Ambigaipalan et al., 2013). From this explanation, it is deducible that a higher amylose leaching does not reliably translate to a higher decline in light transmittance. Generally, factors responsible for the reduction of starch light transmittance may include amylose leaching, chain lengths of amylose and amylopectin, binding forces, as well as granule swelling and remnants (Craig, 1989).

9.4.2 Amylose Leaching

According to Ambigaipalan et al. (2011), the temperature range (70–75 °C) (Table 9.2) within which amylose leaching was detected in Faba bean starch was low, when compared to those of black bean and pinto bean starches (>80 °C). However, Faba bean starch exhibited a higher extent of amylose leaching. The authors attributed the higher extent of amylose leaching to a weaker interaction between starch components (amylose and amylopectin) at temperatures below 80 °C. Another likely factor was the presence of cracked granules in Faba bean starch, relative to those of the other starches. Apparently, information on the amylose leaching of Faba bean starch is currently limited, so more studies in this area are encouraged. Amylose leaching has been implied to influence the pasting temperature of starch. Starches which readily leach out their amylose are more likely to attain their peak viscosities at a relatively low temperature range (Nuwamanya et al., 2011). This is because amylose inhibits the expansion of starch paste during heating, hence a high pasting temperature will be encountered.

9.4.3 Swelling and Solubility

Zhang et al. (2019) reported the swelling power of Faba bean starch to be 1.09–12.67 g/g at temperatures of 50–90 °C (Table 9.2). Sharma et al. (2020) also showed that an increase in temperature within the range of 60–90 °C resulted in a steady increase of the swelling power of Faba bean starch. The steady increase of swelling power as temperature increased was related to possible disruption and melting that might have taken place within the amorphous and crystalline regions of the starch as proposed by Ratnayake et al. (2001). An earlier study showed that the swelling power of Faba bean starch was higher than that of field pea but lower than that of lentil, throughout the temperature range of 50–85 °C. In another comparative report, swelling factor was higher in Faba bean starch than black bean and pinto bean starches, when determined within the temperature range of 60–85 °C (Ambigaipalan et al., 2011). According to Ambigaipalan et al. (2011), an interplay between cracked granules, weakly ordered amylopectin crystallites, and fragile links between starch components could be responsible for the high swelling observed. Interestingly, the swelling factor decreased at temperatures beyond 85 °C, suggesting probable weaker starch integrity due to the presence of cracks and/or poor orderliness of amylopectin crystallites (Ambigaipalan et al., 2011). This is somewhat in contrast with the findings of Zhang et al. (2019) and Sharma et al. (2020) who showed that swelling power of Faba bean starch increased as temperature rose within the range of 50–90 °C and 60–90 °C. This presumable inconsistency with regards to the swelling behavior of Faba bean starch above 85 °C may be associated with some varietal, maturity or experimental differences, which may be ascertained in future research.

Solubility is an important physicochemical property as it indicates the degree of dispersibility of solid starch in an aqueous solution. While comparing the starches from red adzuki bean, chickpea, Faba bean, and baiyue bean, it was found that Faba bean starch had the lowest solubility (9.92%) at 90 °C (Table 9.2) and this was attributed to its starch integrity (Zhang et al., 2019). It can thus be suggested that binding of starch molecules was stronger in Faba bean than in the other starches. This is plausible since swelling capacity is a function of starch binding forces.

Meanwhile, all the pulses demonstrated a rapid increase in starch solubility as temperature was increased beyond 70 °C, probably due to higher disorganisation of starch granules. Similarly, solubility increased with increase in temperature (60–90 °C) according to Sharma et al. (2020). Generally, legumes have been reported to exhibit type C X-ray pattern which is synonymous with limited solubility, restricted swelling and stability of swollen granules against mechanical shearing (Punia et al., 2019). Sofi et al. (2013) reported a C-type pattern with substantial reflections at 5.6°, 7.1°, 9.1°, 15.0°, 17.0°, 19.6° and 22.4° for Faba bean starch. An earlier study had also indicated that legume-starches are characterized with limited swelling and low final solubility, but higher solubility than cereal starches at the intermediate temperature range of 60–90 °C (Doublier, 1987). Albeit seldom, other physicochemical/functional properties that have been reported for Faba bean starch are pH (7.23), water absorption capacity (1680 g/kg), oil absorption capacity (1790 g/kg), and bulk density (0.95 g/L) (Sofi et al., 2013).

9.4.4 Rheological and Pasting Properties

The significance of rheological information about legume-based starches was emphasised by Doublier (1987). Firstly, this was on the backdrop of their poor gel textural properties. Secondly, it was noted that swelling-solubility patterns may be unreliable as the basis for the functionality potentials of starches. The author concluded that the hot paste viscosity of Faba bean starch was lower than that of maize but higher than those of wheat and pea starches. Zhang et al. (2019) associated the low breakdown viscosity (1247 cP) of Faba bean starch in their study to restricted swelling and ability to withstand shear stress and heat while its high final viscosity (4814 cP) following cooling was linked to possible recrystallisation of leached amylose (Table 9.2). However, according to Ambigaipalan et al. (2011), it was very unlikely that leached amylose significantly contributed to elevated viscosity during the heating cycle of Faba bean starch. The authors explained that both breakdown and peak viscosities were largely influenced by phosphate content, since the two parameters showed a steady progress with increasing levels of phosphate in Faba bean varieties. Weaker amylopectin structure due to repulsion of ionized phosphate groups would result in an increased susceptibility to shear and higher amylopectin solvation leading to increased breakdown and peak viscosities, respectively (Ambigaipalan et al., 2011). Furthermore, contrary to the finding of Zhang et al. (2019), Ambigaipalan et al. (2011) summarized that the Faba bean starch varieties in their study demonstrated poor thermal stability, predicting how this might hinder their suitability in the preparation of foods that require rigorous thermal processing, high shear, as well as freezing and thawing cycles. It was on this basis that starch modification of the Faba bean cultivars in question was recommended.

Doublier (1987) noted the pasting temperature of Faba bean starch to be 71.2 °C and 63 °C, according to Brabendar Viscograph and Ottawa Starch Viscometer methods, respectively (Table 9.2). These were lower when compared with those of maize, wheat, and pea starches. Although the author cautioned that the use of the Brabendar Viscograph method might not be reliable, particularly when comparing the rheology of maize and legume starches, a more recent study recorded a similar pasting temperature of 70.2 °C for Faba bean using a Rapid Visco Analyser (Zhang et al., 2019). Again, the pasting temperature was significantly lower than those of red adzuki bean, chickpea and baiyue bean starches. Furthermore, the pasting temperature of 11 varieties of Faba bean have been shown to vary between 71.9 and 73.0 °C (Hood-Niefer et al., 2012). Faba bean starch also pasted relatively faster (4.2 min) when compared to the starches of red adzuki bean, chickpea and baiyue bean starches (4.37–4.6 min) (Zhang et al., 2019).

Li et al. (2019) provided some insight about the strength of gel prepared from Faba bean starch (8% db, 28.0 g total weight) using a Rapid Visco Analyser and stored for a period of 2½ h. The gel strength of Faba bean starch was found to be 727.4 g, and higher than those of pea, lentil, roquette, normal maize, waxy maize, and tapioca starches. It was implied that the well-maintained integrity of swollen granules during heating, as well as strong network formation during cooling and storage contributed to the development of a strong gel. This hypothesis could be supported with the typically low breakdown viscosity, high setback and high final viscosities of pulse starches (Li et al., 2019; Ai et al., 2013; Ring, 1985). The ability of Faba bean starch to form a strong gel presents it as a suitable material in the preparation of foods that require a strong firm gel, including jello-type dessert and glass noodles (Li et al., 2019; Wang et al., 2014).

The effect of some processing factors on the Faba bean starch gel strength and textural properties were investigated by Song and Liu (2013). It was found that an increase in Faba bean starch concentration from 6% to 14% led to a corresponding rise in gel strength (47.2–627.6 g), hardness (113.916–1993.353 g), gumminess (109.351–1744.267 g), and chewiness (102.234–1718.657 g). By a heating time of 40 min, Faba bean gel strength, hardness, cohesiveness, gumminess, and resilience had reached their maximum values, though it took 10 min less of heating for elasticity, adhesion, and chewiness, to peak. Increasing the NaCl concentration in the range of 0.001–0.05 mol/L was also shown to enhance hardness and gumminess of the gel, while gel strength was highest at pH 5.

9.5 Thermal Properties

In the course of heating, there is a transformation of starch from an ordered to a disordered phase, a process referred to as gelatinisation (Punia et al., 2019). On the other hand, retrogradation may result from reformation of double helices by amylopectin chains and resultant partial restoration of crystalline structure (Ambigaipalan et al., 2013). Using a Differential Scanning Calorimeter (DSC), these processes can be assessed on the bases of transition temperatures (i.e., onset – T_o, midpoint – T_p, and conclusion – T_c) and enthalpy (ΔH).

9.5.1 Gelatinisation and Retrogradation Temperatures

Li et al. (2019) found that Faba bean starch exhibited lower onset (58.9 °C) and peak (62.4 °C) gelatinisation temperatures than maize and tapioca starches (Table 9.4). This was in spite of possessing amylopectin with relatively larger proportions of branch chains with degree of polymerization (DP) >12, which should supposedly enhance the formation of more thermally stable crystallites. This was attributed to the loose packing of B polymorphs of the starches which are located at the centre, where gelatinisation of pulses normally begins. Zhang et al. (2019) recorded the values of 61.96 °C, 66.38 °C, and 76.03 °C as the $T_{o,}$ T_P and T_c of Faba bean starch, respectively, while noting the gelatinisation temperature range (ΔT_r) of 11.09 °C. Meanwhile, the report of Li et al. (2019) showed T_o, T_p, T_c, and ΔH of 58.9 °C, 64.2 °C, 72.1 °C, and 12.4 J/g, respectively, for Faba bean starch. The perfectness of starch crystallites is reflected by their gelatinisation temperatures, while ΔT_r is indicative of the non-uniformity of starch granule size and distribution of amylose and amylopectin, which lead to the formation of a semi-crystalline arrangement (Zhang et al., 2019). It is thus presumed that ΔT_r holds much significance and implication, albeit less commonly discussed as a thermal property of starches. In a more comprehensive study, $T_{o,}$ T_P, $T_{c,}$ and ΔT_r of starches from eleven Faba bean genotypes were in the ranges of 59.5–61.7 °C, 65.8–67.6 °C, 86.6–87.5 °C, and 25.1–27.1 °C, respectively (Hood-Niefer et al., 2012). Hood-Niefer et al. (2012) observed that genotypic differences resulted in significant variation with respect to $T_{o,}$ and T_P while other gelatinisation parameters were comparable. In the same study, an interaction between genotype and location was revealed to affect the T_o of Faba bean starch.

Effect of storage (25 °C) on the retrogradation properties of Faba bean starch gels has also been investigated. It was discovered that onset, peak, and completion of retrogradation transition temperatures did not manifest until after 2 days, and were generally much lower when compared to gelatinisation transition temperatures (Ambigaipalan et al., 2013). The lower values were suspected to have resulted from

Table 9.4 Thermal properties of Faba bean starch

Gelatinisation temperature (°C)				Gelatinisation enthalpy	Reference
Onset (T_o)	Peak (T_p)	Final (T_c)	Range (T_r)	ΔH (J/g)	
58.9	64.2	72.1		12.4	Li et al. (2019)
61.96	66.38	73.06	11.09	6.68	Zhang et al. (2019)
59.5–61.7	65.8–67.6	86.6–87.5	25.1–27.1	16.7–18.0	Hood-Niefer et al. (2012)
62.7	68.4	73.3		9.47	Sharma et al. (2020)
Retrogradation temperature (°C)				Retrogradation enthalpy	
Onset (T_o)	Peak (T_p)	Final (T_c)	Range (T_r)	ΔH (J/g)	
45.8	58.5	73.8		6.5	Li et al. (2019)
46.54–50.12	59.59–61.65	76.54–78.21	28.09–30.35		Zhang et al. (2019)

improper alignment of starch chains in the course of association. In addition, due to the variance in size, stability and perfection of crystallites as retrogradation progressed, ΔT_r was remarkably broader. A similar observation was made by Li et al. (2019) who investigated the melting temperatures of Faba bean paste stored at 4 °C for 7 days. These authors confirmed that there was a reformation of double helices by amylopectin chains resulting in partial restoration of crystalline structure.

9.5.2 Gelatinisation and Retrogradation Enthalpies

The relatively high crystallinity of Faba bean starch suggests that it would require more energy during gelatinisation (Punia et al., 2019; Zhang et al., 2019). However, Faba bean starch was reported to have a lower ΔH of 12.4 J/g, relative to those of tapioca and maize starches. This was probably as a result of the higher amylose content being situated in the amorphous region of the starch granules, and normally playing no role in the formation of double helical crystalline structures (Li et al., 2019). Ambigaipalan et al. (2013) also showed that the mean ΔH (8.61 J/g) of starches from five Faba bean cultivars was lower when compared with those of their black bean (13.76 J/g) and pinto bean (14.51 J/g) counterparts. Ruling out factors such as amylopectin chain length distribution, amylose/amylopectin ratio, crystallinity, B-polymorphic content, and phosphate contents, Ambigaipalan et al. (2013) explained how the lower level of organization of amylopectin crystallites in Faba bean starch might have contributed to its lower gelatinisation properties. It is noteworthy that Zhang et al. (2019) recorded a much lower value of ΔH (6.68 J/g) for Faba bean starch. An interaction between genotype and location has been found to significantly affect the ΔH of Faba bean starch (16.7–18.0 J/g) (Hood-Niefer et al., 2012).

Enthalpy of retrogradation (ΔH_r) which represents the thermal energy associated with crystalline melting and dissociation, as well as unravelling of starch double helices, were found to be generally lower than that of gelatinisation enthalpy (Ambigaipalan et al., 2011; Ambigaipalan et al., 2013). A mean increase of 1.6 J/g was however observed after 25 days of storage. When compared to those of black and pinto bean, a higher increase of ΔH_r was observed in Faba bean starch paste at the initial stage of storage, presumably due to higher amylose leaching, hence a more enhanced amylose-amylopectin interaction (Ambigaipalan et al., 2013). Corroborating this finding, Li et al. (2019) who stored Faba bean paste starch at 4 °C for seven days also reported lower retrogradation (6.5 J/g) than gelatinisation (12.4 J/g) enthalpy.

9.6 In-Vitro Starch Digestibility

Resistant starch (RS), slowly digestible starch (SDS), rapidly digestible starch (RDS), hydrolysis index (HI) and expected glycaemic index (eGI) have been determined to monitor the kinetics and extent of enzymatic digestion of Faba bean starch.

Generally, while both SDS and RDS are digested and absorbed in the small intestine, postprandial plasma glucose is higher with the latter than the former. On the other hand, RS represents the sum of starch and starch derivatives that are not absorbed in the small intestine of healthy individuals but get to the large intestine where they may be fermented. eGI is calculated from HI, and HI describes how the digestibility of starch in a food test sample compares with that of starch in a reference, such as wheat (Ambigaipalan et al., 2011). It is believed that Faba bean starch is notably resistant to enzymatic digestion since it generally contains smaller proportions of RDS and SDS when compared to RS. Faba bean starch was reported to contain less than 20% RDS, meanwhile the remaining part was predominantly RS (46.7%) (Punia et al., 2019; Li et al., 2019) (Table 9.5). Similarly, RDS and SDS in Faba bean were 14.4% and 35.8%, respectively, however RS was as high as 50% (Sharma et al., 2020). Li et al. (2019) also noted that Faba bean contained a higher RS than pea, lentil and Roquette pea. Notwithstanding, the role that varietal difference plays in the digestibility of Faba bean starch looks quite plausible, considering the relatively low amount of RS (8.14–15.03%) reported for some cultivars by Ambigaipalan et al. (2011). The authors found Faba bean starch to be more easily digestible than black bean and pinto bean starches in their study.

Some structural factors have been noted to influence starch digestibility. These include starch source, amylose content, relative proportions of DP 6–12 short branch chains and DP 13–24 branch chains of amylopectin, chain molecular association, polymorphic composition, and presence of granular pores, fissures and channels (Ambigaipalan et al., 2011; Li et al., 2019). Interestingly, these factors might not retain their significant influence when pulse starches are cooked. This is based on the finding of Li et al. (2019) who found that the SDS and RS contents of some pulse-based starches did not significantly vary after cooking, even though they did in their native (uncooked) state.

With respect to cooking effect on Faba bean starch digestibility, Li et al. (2019) observed an increase (15.3–88.1%) in RDS while RS simultaneously dropped (46.7–5.9%). Again, retrogradation was found to improve Faba bean starch hydrolysis, even though a greater amylose leaching during storage was theoretically expected to result in a higher resistance owing to enhanced amylose-amylose interaction. The authors speculated that more amylose-amylopectin interaction probably took place instead, leading to the formation of a less-compact crystallite lattice which was more susceptible to conformational transformation, as well as hydrolysis by porcine pancreatic α-amylase.

Table 9.5 In-vitro digestibility of Faba bean starch

Property	Values	Reference
Rapidly digestible starch (%)	2.29–15.3	Ambigaipalan et al. (2011), Li et al. (2019), Sharma et al. (2020)
Slowly digestible starch (%)	34.5–77.64	Ambigaipalan et al. (2011, Li et al. (2019), Sharma et al. (2020)
Resistant starch (%)	8.14–49.8	Ambigaipalan et al. (2011, Li et al. (2019), Sharma et al. (2020)

Bello-Pérez et al. (2007) studied the effect of post-cooking storage on the in-vitro starch digestibility of fresh and dried Faba bean starches. Their results revealed that potentially available starch (AS) was lower in cooked dried bean starch than cooked fresh sample, and this was attributed to the lower moisture content occasioned by drying. This probably enhanced more starch interaction, hence a higher resistance to digestive enzymes. With respect to refrigerated (4 °C) storage, although there was no significant difference in the AS of the cooked fresh Faba bean starch during the first 24 h., further storage resulted in significant reductions. At the end of the storage period, cooked dried Faba bean starch had a significantly lower AS than its cooked fresh counterpart, presumably due to drying-induced starch modification which in turn affected the crystallinity of cooked Faba bean starch (Bello-Pérez et al., 2007). Again, the generally reduced AS during storage was associated with retrogradation and low storage temperature which might have favoured nucleation and crystal growth (Farhat et al., 2001; Biliaderis, 1991). Importantly, this notably decreased AS should not be assumed typical of all pulse starches, since differences in pulse sources and storage temperatures might play some roles. For instance, only a slight decrease was found in the AS of beans (variety not specified) stored at 20 °C for 30 days (Rosin et al., 2002) while the *mayocoba* variety of common beans (*Phaseolus vulgaris* (L)) demonstrated no reduction during post-cooking storage (Osorio-Díaz et al., 2005).

As regards the amount of RS of Faba bean starch during storage, there was a general increase but this was more notable in the cooked dried sample. In fact, there was no significant rise in the RS of cooked fresh Faba bean starch until after 48 h. of storage. On the contrary, fibre associated resistant starch (FARS) remarkably increased in both cooked fresh and cooked dried Faba bean starches during storage. Meanwhile, FARS was noted to be a minor fraction of RS in Faba bean and other fractions may include resistant native granules, otherwise described as type-2 resistant starch (Bello-Pérez et al., 2007). In the same study, alpha-amylolysis analysis revealed a similar effect of storage on the rate of starch hydrolysis in both cooked fresh and cooked dried Faba bean starches. It was noted that longer storage periods resulted in lower starch hydrolysis, with more effect being recorded in the dried sample. Again, estimated GI was lower in cooked dried Faba bean starch. The authors were notably emphatic on the role played by drying in the reduced digestibility and other related parameters of Faba bean starch during storage. In terms of comparison with field bean and lentil starches, Faba bean starch exhibited higher and lower rates of hydrolysis, respectively, both in native and gelatinised forms (Hoover & Sosulski, 1986).

9.7 Starch Modification Methods and Their Impacts on Physicochemical Properties

The industrial utilisation of starch is largely dependent on the physicochemical and functional properties and these properties are influenced by the botanical origin, composition (amylose and amylopectin) and plant species (Kaur & Sandhu, 2010;

Kaur et al., 2010; Chung & Liu, 2012; Liu et al., 2015). In the native form, starch has inherent characteristics such as poor resistance to shear and temperature that limits its industrial applications. Therefore, the physicochemical and functional properties of starch are often improved using different modification methods such as chemical, enzymatic, genetic and physical, and in some instances, a combination of these methods. Modification confers new functionality on starch and may facilitate and enhance its utility for different uses in industry (Jane, 1995). Although legume starch modification has increased in the last few decades due to the search for alternative starch sources to the conventional cereal and tuber starches, there seem to be very limited studies on Faba bean starch (Table 9.6), suggesting the need for future modification studies. This section discussed different methods that have been used to modify Faba bean starch and suggested future modification methods that could further improve the physicochemical and functional properties of the starch.

Table 9.6 Summary of modification methods for Faba bean starch

Type of modification	Conditions	Effect of modification	Reference
Chemical	Crosslinking using sodium trimetaphosphate (STMP) at 1, 2 and 3%	Decrease in amylose content, swelling power, solubility and peak viscosity, but pasting temperature, resistant starch, gelatinization temperature and enthalpy increased.	Sharma et al. (2020)
Chemical	Crosslinking using phosphoryl chloride ($POCl_3$-aqueous) at 1–2%, and a mixture of STMP and sodium tripolyphosphate (STPP)	Decrease in rapidly digestible starch and increase in resistant starch contents with crosslinking.	Dong and Vasanthan (2020)
Chemical	Crosslinking with phosphorus oxychloride	Decrease in water binding capacity, swelling power, pasting viscosity and starch hydrolysis, but an increase in pasting temperature and setback viscosity with crosslinking.	Hoover and Sosulski (1986)
Chemical	Lintnerisation with hydrochloric acid	Decrease in water binding capacity.	Buléon et al. (1987)
Physical	Irradiation at 5, 10 and 15 kGy	Decrease in pasting properties, syneresis and an increase in solubility, water absorption capacity and freeze thaw stability with increase in irradiation dose.	Sofi et al. (2013)
Physical	Heat moisture treatment (HMT) at moisture contents (15 and 30%) and temperatures (100 and 120 °C)	Decrease in swelling power and amylose leaching but an increase in gelatinization temperatures.	Piecyk and Domian (2021)
Enzymatic	Germination of seeds before starch extraction	Decrease in amylose, amylopectin and starch contents.	El-Shimi et al. (1980)

9.7.1 Chemical Modification

Chemical modification involves the incorporation of new functional groups into a starch structure to confer new functionality on starch (Haq et al., 2019; Chen et al., 2015). Although it remains one of the most widely used starch modification methods, the search for alternative methods has continued to increase, due to chemical residues and safety concerns that the chemical method presents, especially in food applications. The emergence of clean label starch technology has further increased the search for alternative modification methods. However, starch modified by chemical methods still has great potential for use in non-food applications, for example, in the paper and textile industries. Chemical modification is achieved either by substitution or crosslinking (Dong & Vasanthan, 2020) and involves one or more of acetylation, acid hydrolysis, cross-linking, esterification, oxidation, and grafting (Haq et al., 2019). Depending on the type of chemical modification used, starch may show improved resistance to shear and temperature, reduced retrogradation (Jane, 1995) and increased water solubility (Wang & Copeland, 2015). Numerous reviews on the chemical modification of starches from different botanical sources have been documented and these could be consulted for a better understanding of mechanisms and changes in starch properties after modification (Chen et al., 2015; Wang & Copeland, 2015; Vanier et al., 2017; Masina et al., 2017; Ashogbon & Akintayo, 2014; Zia-ud-Din et al., 2017).

Studies on chemical modification of Faba bean starch has focused mainly on lintnerisation with hydrochloric acid (Buléon et al., 1987) and crosslinking (Hoover & Sosulski, 1986; Dong & Vasanthan, 2020; Sharma et al., 2020). Lintnerisation or acid hydrolysis of starch has been used for over a decade to modify starch structure and was firstly used on potato starch by Lintner (1886). In their study, potato starch granules were hydrolysed in 7.5% HCl for 7 days at ambient temperature and the resulting hydrolysate was a high-molecular-weight starch, which formed a clear solution in hot water (Lintner, 1886). During acid hydrolysis, the glycosidic bonds in starch are broken using acids such as H_2SO_4 and HCl and this scission modifies the structure and functionality of starch (Hoover, 2000). The crystalline regions of starch seem to be more stable to acid hydrolysis than the amorphous regions which are reportedly more susceptible (Hoover, 2000). Acid hydrolysis reportedly decreased the ability of Faba bean starch to absorb water, increased the crystallinity and produced sharper X-ray diffraction peaks compared to native starch (Buléon et al., 1987). These authors focused on sorption behaviour and diffraction patterns of acid-treated starches, rather than the effect of the hydrolysis on functionality. Hence, future studies may be required to establish the impact of acid hydrolysis on Faba bean starch functionality. Future research is also required to elucidate the impact of acid hydrolysis on the molecular structure of amylose and amylopectin as well as on the gelatinisation and pasting properties of Faba bean starch. With regards to crosslinking, bi-functional chemicals such as phosphorus oxychloride, sodium trimetaphosphate (STMP) and sodium tripolyphosphate (STPP) have been used to reinforce Faba bean starch granules by reacting the starch with more than one hydroxyl group within the starch molecules. Crosslinking enhances the stability of starch paste in an acidic medium, improves thermal stability and thermo-mechanical properties of starch (Wang et al., 2022). This is achieved through the incorporation of new covalent bonds with existing hydrogen bonds into the starch granule structure (Sharma et al., 2020). An earlier study by Hoover and Sosulski (1986) on crosslinking of Faba bean starch using phosphorus oxychloride found a significant decrease in pasting viscosity, swelling power and water-binding capacity. However, the authors reported an increase in pasting temperature and setback viscosity of the starch after crosslinking (Hoover & Sosulski, 1986). Sharma et al. (2020) similarly reported a decrease in peak viscosity, swelling power, solubility and an increase in gelatinization temperature, gelatinization enthalpy, pasting temperature and resistant starch for Faba bean starch modified with concentrations (1, 3 and 5%) of STMP. The decrease in peak viscosity of crosslinked starches has been associated with the strengthening of swollen starch granules resulting from the formation of covalent bonds between amylose and amylopectin chains (Wongsagonsup et al., 2014). Crosslinking of Faba bean starch also resulted in a reduction in rapidly digestible and slowly digestible starch contents compared with the unmodified starch (Sharma et al., 2020). Dong and Vasanthan (2020) studied the resistance of Faba bean starch to amylase digestion under different crosslinking methods (different phosphorylation) and reported that amylase resistance had a relatively higher correlation with the degree of crosslinking than phosphorus content. The degree and type of crosslinking agent are important factors that influence the physicochemical properties of starch, and hence, future studies should focus on optimising these conditions to produce starches with unique characteristics for various industrial applications.

9.7.2 Physical Modification

Physical modification of starch involves the use of various physical treatments that do not involve the use of chemicals or results in any chemical modification of the starch other than limited cleavage of the glycosidic linkage (BeMiller, 2018). It is considered a green technology because it is more environmentally friendly (Zhu, 2015) and is considered safe when compared to chemical methods like acetylation and oxidation (Oyeyinka & Oyeyinka, 2018). Common physical methods used for starch modification include osmotic-pressure treatment (Pukkahuta et al., 2007), pulsed electric field (Han et al., 2009a; Han et al., 2009b), annealing (Oyeyinka et al., 2018), heat moisture treatment (Almeida et al., 2022; Piecyk & Domian, 2021), microwaving (Oyeyinka et al., 2021c) and gamma irradiation (Sofi et al., 2013). At the moment, only two physical methods, gamma irradiation (Sofi et al., 2013) and heat moisture treatment (Piecyk & Domian, 2021) have been reportedly used in Faba bean starch modification (Table 9.6). Sofi et al. (2013) reported the use of gamma irradiation at a varying dose of 0, 5, 10 and 15 kGy to modify Faba bean starch. The impact of irradiation on the functional properties of the starch sample was dose-dependent. For example, the water absorption capacity and freeze-thaw stability of the starch increased, while pasting properties and syneresis decreased with an increase in irradiation dose (Sofi et al., 2013). The increase in the ability of the starch sample to absorb water was associated with the depolymerization of starch to simpler molecules such as dextrins and sugars that have a greater affinity for water than starch (Wu et al., 2002). Structural changes as shown by the presence of fissures in SEM images of the irradiated starches and an increase in the intensities of the peak corresponding to the amorphous region as confirmed by FTIR spectroscopy suggest changes in the crystalline region of the starch (Sofi et al., 2013). These changes may relate well with the *in vitro* digestibility properties of the starches and warrant future investigations. Other physical modification methods, for example, infrared heating (Oyeyinka et al., 2021d) and microwave heating (Oyeyinka et al., 2019) with similar effects on starch physicochemical properties that have been reported for other legume starches, may also be applied in Faba bean starch modification.

Piecyk and Domian (2021) used heat moisture treatment as a physical means of Faba bean starch modification. Heat moisture treatment involves incubating starch at relatively low moisture contents (10% and 30%) at varying temperatures (90 and 120 °C) and time (15 min and 16 h) (Chung et al., 2009a). Heat moisture treatment generally reduced the swelling power and amylose leaching of Faba bean starch but reportedly increased the gelatinization temperatures (Piecyk & Domian, 2021). The reduction in swelling power after heat moisture treatment is thought to result from stronger interaction among the starch bonding functional groups due to internal rearrangement within the starch granules (Oyeyinka & Oyeyinka, 2018; Chung et al., 2009a, b). Due to the variation in the impact of temperature, time and moisture levels on heat moisture treated starches, the use of optimization techniques may be the next direction of research to model modification conditions for better functional and physicochemical properties of Faba bean starch.(Fig. 9.3).

9.7.3 Enzymatic Modification

Starch modification using enzymes involves the use of hydrolytic enzymes such as alpha-amylase, glucoamylase and pullulanase (Van Der Maarel et al., 2002). These enzymes are known to break down the glycosidic linkages (α-1,4- and α-1,6-) in starch molecules (amylose and amylopectin) (Van Der Maarel et al., 2005). The digestibility of starch by enzymes is an important modification method that could provide new starches with unique functionalities. For instance, very low amylose or waxy starches may be treated with debranching enzymes such as pullulan-6-glucanohydrolase (pullulanase) which linearises the branched-chain in amylopectin, producing starch with higher resistant starch (Lee et al., 2010). A study by Berry (1986) showed that the resistant starch content of potato starch increased when its amylopectin was debranched, followed by subsequent heating and cooling cycles. Increased resistant starch content after enzymatic modification has significant health

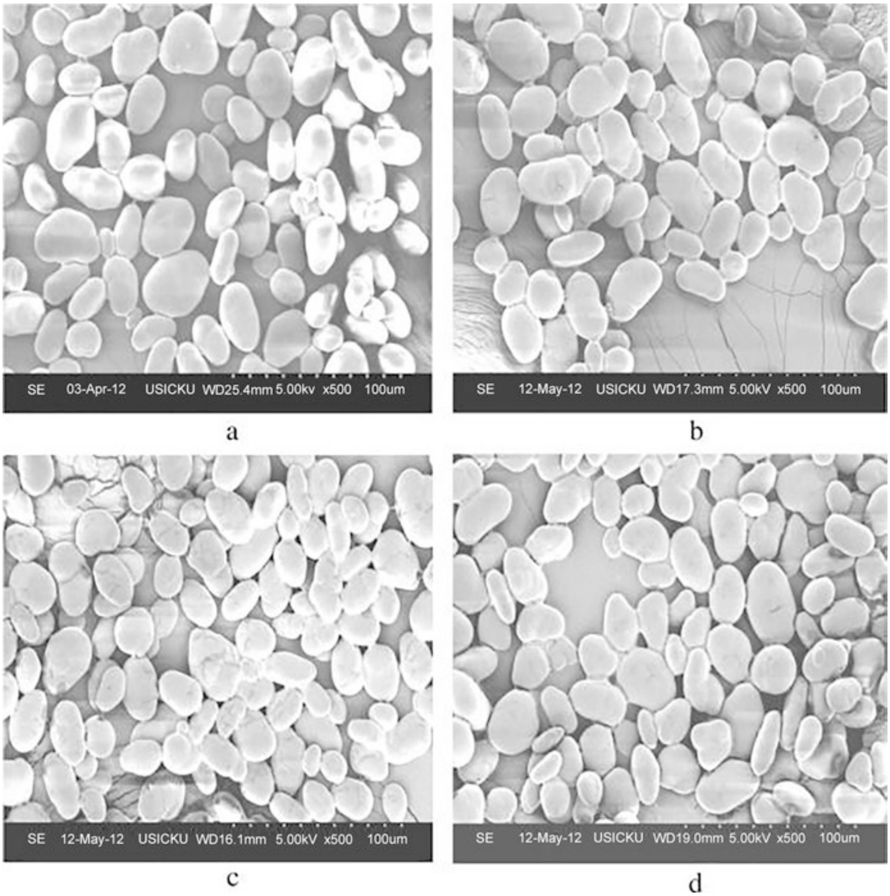

Fig. 9.3 Morphology of native and irradiated Faba bean starch (Sofi et al., 2013). (**a**) Native starch (0 kGy); (**b**) irradiated starch at 5 kGy; (**c**) irradiated starch at 10 kGy; (**d**) irradiated starch at 15 kGy; magnification (×1000)

implications because this class of starch is not digested in the intestine but is fermented by microorganisms in the large intestine to form short-chain fatty acids, which promotes gut health. Enzymatic modification of starch may be achieved either by the addition of enzymes to starch granules or the use of processing techniques such as germination that triggers enzymatic activities. Germination of seeds is regarded as a low-cost technology that can be used to enhance the nutritional value of foods including phenolic composition and functional properties for various food applications (Jimenez et al., 2019). During germination, hydrolytic enzymes are synthesized or activated and these enzymes are responsible for the modification of food macromolecules such as proteins and carbohydrates including starch. El-Shimi et al. (1980) studied changes in granule composition and morphology after germination of Faba bean and observed a decrease in starch content and composition, i.e. amylose and amylopectin as well as sugar content. For example, the raffinose content of the bean decreased with an increase in germination period and was not found in the samples after 8 days of germination (El-Shimi et al., 1980). The decrease in starch content and starch composition was attributed to the action of alpha-amylase, which increased many fold during germination (Young & Varner, 1959).

Just as germination employs the enzymatic modification of starch without prior starch isolation, a study by Jiang et al. (2020) investigated the use of alpha amylase in the hydrolysis of Faba bean starch while still in its extracted ‘milk’. The backdrop to this being the technological limitations previously posed by Faba bean starch when being considered as a source of plant-based dairy alternatives. Following enzymatic modification of starch in the study, a more acceptable yoghurt was successfully produced from Faba bean milk.

Although the effect of enzymatic modification, including germination, on starch functional and physicochemical properties have been well researched (Lee et al., 2010; Chinma et al., 2021; Zhou et al., 2004), very little is reported on the impact of this method on Faba bean starch functionality, suggesting the need for more research. Studies on structural changes using a scanning electron microscope, confocal laser scanning microscope, X-ray diffractometer, Fourier transform infrared spectroscopy and other techniques would be useful in elucidating the characteristics of modified Faba bean starch. Furthermore, the use of dual modification methods to produce synergistic effects on starch functionality and physicochemical properties are promising areas for future research. This is important because dual modification methods have been reported to create starches with novel and enhanced functionality that could find applications in food and non-food uses (Oyeyinka et al., 2021c). This will further unlock the potential in the grain and enhance its industrial application beyond the current level of usage.

9.8 Potentials of Faba Bean Starch

As part of efforts to reduce global dependence on common sources of starch, such as maize, the potentials inherent in some pulse-based starches for food and industrial applications are being uncovered (Oyeyinka et al., 2021a; Lienhardt et al., 2019). This can be attributed to their remarkable yields (16–47%) (Wani et al., 2016), distillery prospects (Walker et al., 2015), strong gelling abilities (Li et al., 2019; Wang et al., 2014), baking quality (Bresciani & Marti, 2019), as well as functionality (Niba, 2002; Guillon & Champ, 2002). While several studies have provided insights on the suitability of starch-rich pulses to replace their cereal, and root and tuber counterparts, there currently exists limited information with respect to Faba bean. Notwithstanding, data are available pointing at the alternative candidature of Faba bean starch, not just for a wider range of food products, but also for industrial and functionality purposes.

9.8.1 Food Products

Faba bean starch may be suitable for preparing food products which require a strong gel formation, e.g., glass noodles (Li et al., 2019). This is attributable to the common ability of leguminous starch granules to retain their integrity while swollen, and their strong network formation during cooling and storage (Wang et al., 2014). Glass noodles are typically produced using Mung bean starch, but partly due to its expensive nature and the search for varieties, alternative pulse-based starches are being investigated (Thapnak et al., 2019). Since current efforts seek to explore and expand the utilisation of less commonly known pulses, as well as their starches, future studies may be necessary to determine the prospects of Faba bean starch in the production of glass noodles. It would also make sense to extend this effort to the production of desserts that are gello-type in nature, for which the application of Faba bean starch has been suggested (Li et al., 2019). Likewise, in order to explore the opportunity that exists for legume-based starches in pasta preparation (Lienhardt et al., 2019), future trials with Faba bean starch are recommended. The weakened gel strength of tofu made from Faba bean following starch removal further corroborates the role of Faba bean starch in gel strength (Jiang et al., 2020).

From the economic point of view, it was advised that the use of protein isolates from starch-rich legumes be accompanied with their starch application in baking. This prospect was investigated by applying the starches from lentil, pea and Faba bean as partial substitutes in the production of bread (Morad et al., 1980b). Results from the research showed that loaf volume did not notably change with up to 5% substitution of wheat flour, and that crumb grains of bread containing as high as 10% Faba bean starch was acceptable. Again, the probable leaching of the beany flavour compounds during the extraction of the pulse starches presented them as better substitutes, relative to their flours, since the breads produced demonstrated no beany flavour. However, presumably due to lower reducing sugar vis-à-vis higher protein contents, crust colour was generally impaired, irrespective of the level of supplementation. Perhaps the addition of external reducing sugar as an ingredient may produce more browning for a more appealing crust appearance. Just as a similar study has determined the feasibility of replacing wheat flour with Faba bean starch in the production of crackers (Gangola et al., 2022), it is likely that the prospects of utilising Faba bean for bakery (Sozer et al., 2019; Chiremba et al., 2018) and extrusion (Chiremba et al., 2018) purposes are partly related to its starch characteristics.

9.8.2 Industrial Use

Due to their possible hydrolysis to fermentable sugars, the starches of legumes have long been recognized for potential distillery purposes (Tanner et al., 1977; Markham, 1994; Tanner & Hussain, 1979). While this awaits notable industrial application, the prospect has been recently demonstrated with Faba bean (Walker et al., 2015; Iannetta et al., 2015). Walker et al. (2015) determined the feasibility of ethanol production using Faba bean starch concentrate as an adjunct with malted barley grist. The authors found that the wort from Faba bean starch had higher total fermentable sugars (92.9 g/L) than sample from malted barley grist (77.3 g/L). Although the use of enzyme lowered the maltose and maltotriose obtained from Faba bean starch, there was enough compensation in the glucose produced, since this was remarkably higher than the amount obtained from malted barley grist. The same study also showed that the quantities of ethanol yield from the cereal and legume-based substrates were comparable. It was thus concluded that the use of Faba bean starch at over 40% inclusion in spirit production was feasible but further refinement of Faba bean starch-enzyme mash was recommended.

Furthermore, indirect advantages of using legume starch in distillery may include mitigation of environmental challenges, as well as improved feeds for animals (Lienhardt et al., 2019). According to Lienhardt et al. (2019), as a strategy to further reduce the environmental burden posed by Europe's dependence on soybean for feed-protein, as well as on cereals for alcohol and biofuel production, cultivation of pea and Faba bean, which yet amounts to only 1.5% of arable land in the European Union, should be encouraged. About 70% of Europe's source of protein for formulation of feeds for pigs, cattle, poultry and fish was reported to come from milled soybean grains (Lienhardt et al., 2019). Meanwhile, cultivation of Latin American soybean has been linked with negative consequences, such as environmental damage and deforestation (Persson et al., 2014), hence the rising interests to substitute soybean in animal feeds while also ensuring the sustainability of livestock and growing aquaculture systems in Europe (Lienhardt et al., 2019; Schader et al., 2015; De Santis et al., 2016; Hörtenhuber et al., 2011). Therefore, achieving this double objective is apparently one of the indirect benefits when cultivation of Faba bean is improved for its starch application in alcohol and biofuel industry. This is plausible since protein by-product from Faba bean can replace Latin American soybean in feed formulation and help address the environmental challenges associated with the latter (Lienhardt et al., 2019). Dried distillers grain with solubles, a by-product from cereal-based alcohol production, has been well reported as a substitute for soybean in feed formulation (Hörtenhuber et al., 2011; Weightman et al., 2011; Leinonen et al., 2018), but higher protein contents of such feeds represents a promising added advantage when legumes are used in place of cereals in alcohol production (Lienhardt et al., 2019). According to Iannetta et al. (2015), Faba bean starch concentrate performed well on the basis of tested Standard Ideal Digestibility (SID) in the feeds formulated for pigs and poultry. The authors further added that, with appropriate methionine supplementation, Faba bean starch represents a promising alternative that can reduce the reliance on soybean in pigs and poultry feeds.

A report by Sharma et al. (2020) suggests the suitability of Faba bean starch in the production of flexible packaging materials for foods. The authors also studied the effect of cross-linking the starch but found no difference in film thickness.

However, cross-linking with 5% trimetaphosphate resulted in enhanced tensile strength and elongation at break, while moisture content and physicochemical properties such as water vapour permeability and water solubility were decreased. The results from this study may trigger further research to determine the success of Faba bean starch, with appropriate modifications where necessary, in other popular industrial uses of starch, such as food glazing and emulsion stabilization.

9.8.3 Functionality

The search for foods that provide health benefits in addition to basic nutritional requirements has been on the rise in recent times. This feature is commonly described as 'functionality', and from the compositional and structural standpoints, starch is one of the contributory factors (Copeland et al., 2009). Using this concept, some extensive explanations have been provided on the remarkable influence of starch on blood glucose level, a crucial factor in the causality and management of diabetes and other related illnesses. One popularly discussed mechanism through which starch may lower blood glucose level and impact health benefits is the extent and rate of its digestion in the upper part of the digestive tract. The understanding of this relationship underlies the growing interest in RS, a category of starches which are incompletely digested in the human gut (Copeland et al., 2009).

Faba bean exhibits a substantial level of RS, varying approximately between 8% and 50% depending on varieties (Ambigaipalan et al., 2013; Sharma et al., 2020). This attribute has been explored to confer functionality on some commonly consumed foods. In a recent study by Gangola et al. (2021), one-quarter of durum wheat flour was substituted with Faba bean starch in a bid to enhance the physiological functions of a wheat-based pasta. The researchers found that RDS was significantly reduced in both uncooked and cooked pasta samples, while RS markedly surged. In their summary, it was implied that the addition of Faba bean starch did not just reduce the starch digestibility of the pasta, but this was also associated with glycaemic related effects on human diets. The authors later reported similar effects and prospects with crackers developed from wheat-Faba bean starch composite flours (Gangola et al., 2022). Meanwhile, animal trials have also suggested the potential of Faba bean starch to provide beneficial impact on the post-prandial and satiety properties of wheat semolina-based foods (Gangola et al., 2021; Chan et al., 2019). While these findings strongly support the effectiveness of Faba bean starch to meet consumers' increasing consciousness towards novel wheat-based foods with added functionalities (Gandhi & Zhou, 2014), extending future investigations to some consumers' acceptance indices, e.g., colour, as demonstrated by Tazrart et al. (2016) is suggested. It is also recommended that future trials on the use of Faba bean starch in bread making, as earlier investigated by Morad et al. (1980b), should cover starch digestibility effects.

9.9 Conclusions and Future Perspectives

The chapter demonstrates the remarkable share of Faba bean among pulses to be reckoned with on the basis of starch yields and characteristics, as well as the diverse usefulness and opportunities these may present. Wet milling appears the most predominant starch extraction method, with an approximate yield of 33–48%. Through appropriate modification methods, Faba bean starch appears flexible enough to suit a wide range of industrial applications. This is on the premise of data available on its altered functional and physicochemical properties, when physical, chemical and enzymatic methods of starch modification were employed. However, studies in this area are yet limited, hence applications of more methods, as well as their combination may be necessary to unlock more of the novel industrial potential of this promising starch. Again, physicochemical properties, including amylose leaching, swelling and solubility of Faba bean starch may respond differently to factors such as starch integrity, presence of cracked granules, and binding forces between starch components. Apparently, Faba bean starch granules may demonstrate a low leaching temperature range, and a substantial extent of leaching may be expected, owing to weaker binding forces between starch components. Although there are some contrasting reports on its thermal stability, the ability of swollen Faba bean starch granules to maintain their integrity represents a useful rheological advantage. Results reviewed on thermal properties suggest that Faba bean starch possesses relatively low gelatinization enthalpies, and that transformation during storage of cooked paste may be responsible for differences between gelatinization and retrogradation parameters. Finally, the book reveals the potentials of Faba bean starch in strong-gel food products, bioplastics, bakery, and distillery, while enhanced feed formulation and environmental preservation are identified as indirect benefits.

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Chapter 10
Faba Bean Proteins: Extraction Methods, Properties and Applications

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10.1 Introduction

Faba bean (*Vicia faba* L.), also known as broad bean, fava bean, field bean or horse bean is a legume crop, belonging to the family Leguminosae. There are two types of faba beans i.e., spring and winter faba beans, among which winter faba beans have higher content of protein than the spring one, specifying that the protein concentration increases under the condition of water deficit environment. Although these are consumed less in western countries but are one of the affordable sources of protein and energy in countries like Africa, Asia, and Latin America. It is majorly consumed as dried seeds than the fresh kernels (Vogelsang-O'Dwyer et al., 2020). It can also be consumed as green, dried, roasted, soaked, frozen, cooked or canned (Dhull et al., 2021). It becomes one of the best crops due to its high yield potential and the ability to use as green manure, providing a great potential to meet the dietary needs

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of the developing human sustenance by balancing the sustainability of agricultural production systems (Warsame et al., 2020).

Faba bean is one of the oldest crops and the third most important feed grain legume after soybean and cowpea (Singh et al., 2013). It has properties similar to soybean with around 27% of protein, has lower lipid content of 1% than soybean which has 18% and causes less flatulence than cowpea (Vogelsang-O'Dwyer et al., 2020). It is one of the cheapest and excellent source of lysine rich protein, vitamins, choline, lecithin, folate, and non-nutrient secondary metabolites such as polyphenols (Singh et al., 2013). It also has high mineral content like calcium, phosphorus, iron and zinc, but because of the phytate and iron binding polyphenols, it has very low absorption (Rahate et al., 2021). The mature seeds of faba bean are nutritionally rich in protein (26.1%), carbohydrates (58.3%), and dietary fiber (25.0%). It includes various bioactive compounds like phenolics and flavonoids providing antioxidant activities. However, it also comprises of anti-nutritional factors namely lectins, saponins, trypsin inhibitor, phytic acids, vicine, and convicine and condensed tannins, reducing its biological value. Oligosaccharides such as stachyose, raffinose, and verbascose, etc. is another component present in the faba bean, which causes fermentation as they resist digestion in the digestive tract and produces methane and other gases, thereby resulting in flatulence with abdominal pain and discomfort. Consumption in higher rates can also cause favism (vicine and convicine are responsible), a condition called hemolytic anemia which causes the loss of RBCs (reduced glutathione) (Dhull et al., 2021). On the other hand, lecithin reduces the bioavailability of polysaccharides and minerals, but can also be beneficial for diabetic patients as it forms complexes with α-amylases and reduce the level of glucose in blood. Cooking and sprouting destroys most of the anti-nutritional factors and hence, improves the nutritional properties of faba beans (Rahate et al., 2021).

Interest in plant-based diets has been immovably increasing by capturing the attentions from the consumers, scientists and other organizations because of the health and nutritional benefits associated with. In addition to these benefits, plant-proteins require less energy and resources in production than animal proteins (Sharan et al., 2021). Climate change and the growing population demanding innovative and regionally produced vegetable proteins, and thus many genetic efforts and breeding technologies lead to the improved version of faba beans, resulting into the adaptation to the environment, high yield, more nutrients, and limiting the major anti-nutritional factors. However, little effort has been made to quantify the effect of water restriction of protein content of newly improved strains (Vogelsang-O'Dwyer et al., 2020). Different extraction methods have been developed for different protein sources to understand the physical and chemical properties of faba beans together with increasing the efficacy and availability of the crops of high interest (Langton et al., 2020). Continuous research is still processed and thus it is important to evaluate using different methods to conclude a result for the improvement. This chapter describes the extraction methods, properties and applications of faba bean proteins.

10.2 Classification of Faba Bean Proteins

The quality of protein in faba bean is quite lower than that of animal protein as it lacks in sulphur containing amino acids such as cysteine and methionine, but if compared with the cereals it has higher content of lysine and arginine (Askar, 1986). The protein content varies from 20–41% and this extensive variation is due to various factors like flour (fraction or isolate), fertilization process, growth season, and planting site (Dhull et al., 2021). However, the seed coat of faba bean may contains less protein and carbohydrate as compared to the cotyledons and whole seeds. Percentage of total solids in mature seeds is three times more than that of immature seeds. Thus, mature seeds are higher in calories, proteins, minerals, and starch, while immature ones are much better source of vitamin A and C (Askar, 1986). Faba bean includes a variety of proteins that can be classified based on their solubility in different types of solvents namely, albumins (20%), globulins (60%), glutelins (15%), and prolamins (8%) (Sharan et al., 2021). The globulins contribute a major part of storage proteins in legumes, affecting the rheological and textural properties of the proteins (Rahate et al., 2021). In globulins, there are legumin and vicilin (salt soluble proteins) comprising of high molecular weight and complex structures but their ratio plays a vital role in utilizing these proteins for fortification in various products like breads and biscuits (Dhull et al., 2021). The storage proteins present in the faba beans provide nutrients that are essential for seed germination and seedling growth, present in the seed cotyledons but are enzymatically inactive. The storage proteins contain two subunits one is globulins, having 7–11 S fractions but lacks sulphur containing amino acids, and the other one is prolamins, having trypsin inhibitors and phytolectins, comprising of sulphur containing amino acids (Rahate et al., 2021). However, the faba bean is classified into two type's likely globulins and non-globulins as shown in Fig. 10.1.

10.2.1 Globulin Proteins

The salt soluble proteins called globulins comprises of 85% by weight and are rich in aspartic acid, glutamic acid, leucine and arginine. Globulins are further classified based on their sedimentation coefficients i.e., 7S proteins (known as vicilin and convicilin), and 11S proteins (known as legumin) preserved in the faba bean. The vicilin exists as trimers while the legumin is a hexameric holoprotein, however, both are made up of polymorphic subunits and encoded by multigene families. Though, vicilin and legumin can also be separated respectively using isoelectric precipitation at different pH 5.5 and 4.8.

Legumin Mature seeds of faba bean comprises of 55% of legumin of the total seed proteins. There are two types of major subunits of legumin, namely A and B, forming legumin major subunits. Legumin A contains the residues of methionine while the B is free. These subunits exhibit heterogeneity in the electrophoresis and

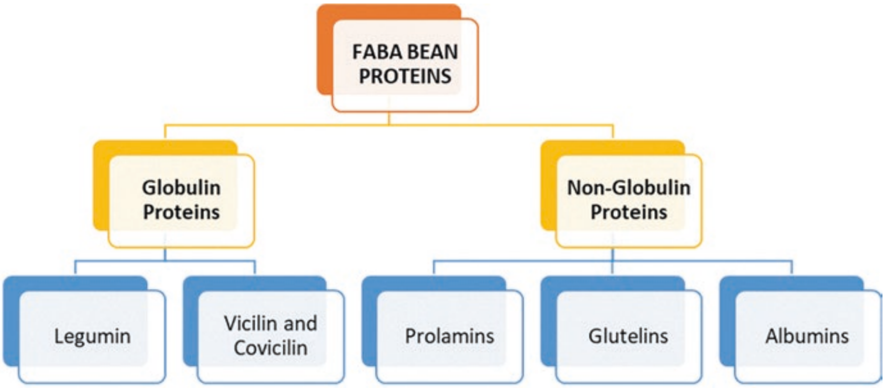

Fig. 10.1 Classification of faba bean proteins

ion-exchange chromatography, and also other two subunits, called as legumin minor subunits were discovered with the molecular weight of 75 and 80 kDa. All the four subunits comprise of α- and β- chains, linked with a disulfide bridge.

Vicilin and Convicilin Faba bean comprises of about 30% of vicilin and about 3.2% of convicilin of the total seed proteins. Their polypeptides consisted of 50 and 70 kDa respectively, and are both cysteine free without any disulfide bridges. However, vicilin breaks into two 3S molecules at pH below 3 and above 11.

10.2.2 Non-globulin Proteins

Prolamins They are alcohol soluble proteins rich in leucine, proline, and glutamic acid, but lack in lysine and tryptophan. They can be solubilized in the mixtures of alcohol/water, propan-1-ol/water or the mixtures containing high amounts of glutamine or proline.

Glutelins These are soluble in sodium hydroxide (NaOH) solution, showing amino acid profiles similar to the prolamins but having higher amounts of glycine, methionine, and histidine.

Albumins They contain higher sulphur-containing amino acids than any other storage proteins in faba beans. They are primarily metabolic proteins that may or may not comprise of enzymatic functions like protease inhibitors, lectins, albumin-2, and defensins 1 and 2, and Bowman-Brik inhibitors.

Enzymes present in the seeds of faba beans regulates the synthesis, transport, and storage of proteins and starch during the seed development. This includes the sucrose-biding proteins which are homologous to vicilin and another enzyme called phosphoenolpyruvate carboxylase, found in the cotyledons but help in the synthesis of organic acids and amino acids (Sharan et al., 2021). There are further many important accessories present in the faba bean seeds that help in maintaining the structural and functional properties of the protein and other nutritional factors.

10.3 Extraction of Faba Bean Proteins

The commercial significance of faba bean proteins is that it can be extracted into forms like enriched flours, concentrates or isolates at a lower cost. Protein enriched flour contain protein up to 65% w/w on a dry basis (db), on the other hand, concentrates contain >65% w/w (db) and isolates contain >80–90% w/w (db) (Boye & Barbana, 2012). Factors such as pH, particle size, solvent to flour ratio, type of salt used, ionic strength and temperature influences the extraction of protein fractions. Usually the techniques used for protein extraction are dry extraction methods and wet extraction methods (Sivasankari et al., 2019). However, dehulling has been reported to significantly improve the protein content of faba bean, whereas other processing methods such as soaking, germination, and extrusion has very little effect on the protein content.

10.3.1 Dry Extraction

Faba bean protein rich flour is obtained by dry extraction process (Fig. 10.2). Pin milling, an impact milling process along with air classification is generally employed for the protein extraction. Air classification is a sustainable process involving a series of cyclones equipped with either a classifier wheel or a restriction valve (De Angelis et al., 2021). The protein and starch fractions are separated based on their size and density differences as the former fraction is light and finer than the later which is heavy and coarser. Spiral air streams are used to separate these two fractionates. Starch agglomerates embedded in the protein matrix under repeated milling showed cell breakage which result in strong protein and starch bond to loosen up (Coda et al., 2015). Dry extraction is advantageous as it requires less utilization of water and energy, thus more economical and sustainable (Schutyser et al., 2015). However, the major disadvantage is that protein yield is less as the protein from membrane and stroma of chloroplasts cannot be milled out from the starch (Chiremba et al., 2018).

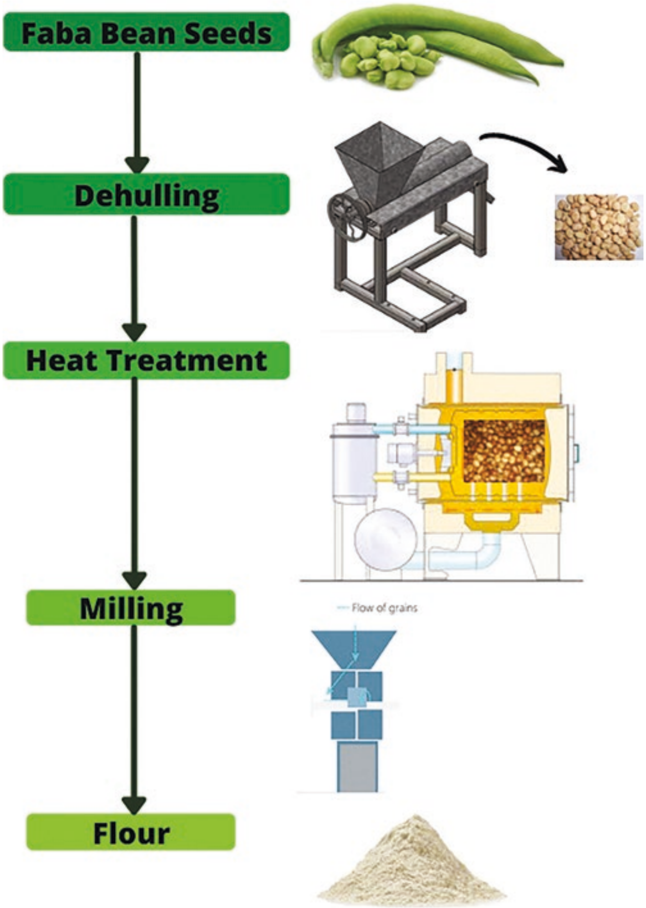

Fig. 10.2 Flowchart representing dry extraction process of faba bean protein

10.3.2 Wet Extraction

The starting material for wet extraction process is faba bean flour which is commercially obtained by standard milling. In wet extraction method as given in Fig. 10.3, prior milling results in effective removal of fibre and cellulosic plant materials, thereby enhancing the actual extraction. Dehulling and milling are carried out either as a single or separate unit operations for effective disintegration of plant materials which facilitates protein extraction. Equipment's such as centrifugal mills, hammer mills, ball mills, roller mills and disc attrition mills can be successfully employed to achieve this (Boye & Barbana, 2012). Defatting can be eliminated as faba bean contains lesser amount of lipid content (Abdel-Gawad, 1993).

Faba bean isolates are produced using the aqueous extraction methods including alkaline, neutral or acid extraction (Boye et al., 2010). Alkaline extraction is a widely accepted method as it utilizes the ability of protein to solubilize in alkaline pH. The mixture pH is adjusted to alkaline values and continuously stirred to remove any insoluble substance from protein rich supernatant. pH and temperature are to be monitored carefully during the process. Acid extraction includes solubilising the protein in low pH range prior to recovery. This technique is less frequently utilized as it has significant influence on the yield and purity of protein extracted. Once the protein solubilisation takes place under acidic or alkaline conditions, pH is adjusted to isoelectric point of the desired proteins to cause their precipitation. Centrifugation is followed after the isoelectric point is reached to recover protein and subsequently followed by washing, neutralizing and drying. Salting out is a process which involves dehydration of protein using high neutral salt solution having a molarity >1 M. Dehydrated proteins interact with each other by hydrophobic bonds resulting in aggregation and precipitation of proteins. Another alternative techniques for protein recovery are microfiltration and ultrafiltration. This pressure driven process

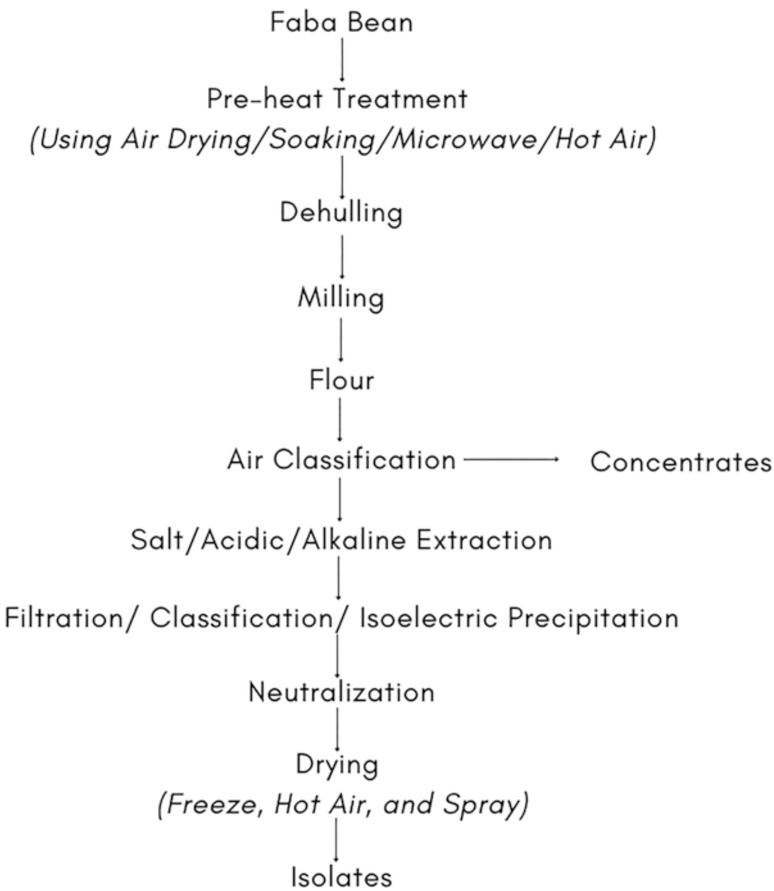

Fig. 10.3 Flowchart indicating wet extraction process for faba bean proteins

utilizes porous membranes that is selective in nature. It retains larger compounds while allowing passage of smaller compounds. Microfiltration uses membranes which have a capacity to retain larger particles with a molecular mass greater than 300,000 Da and a particle size range of 0.02–10 micron. It can be used to either retain the proteins of interest or remove the interfering proteins. Ultrafiltration membranes are used to retain smaller sized particles of range from 0.001 to 0.02 microns and molecular mass of range 300 to 300,000 Da. Membranes with particular weight cut off should be selected to achieve a particular protein of interest. There are many more techniques that can be used for protein recovery like cryo precipitation, electrodialysis, use of organic solvents etc (Boye & Barbana, 2012). Cryo precipitation involves use of lower temperatures to precipitate proteins in crystalline, amorphous or gelatinous state (Pantanowitz et al., 2003). Electrodialysis, on the other hand, is assisted with bipolar membrane and brings about the protein precipitation either by electro-alkalinization or electro-acidification (Bazinet et al., 1998). Furthermore, the organic solvents like acetone and ethanol can be utilized to precipitate the protein (Singh, 1995).

Once the crude protein is extracted and recovered, its downstream processing is necessitated which can be achieved by giving repeated solvent washing followed by centrifugation and filtration. This step ensures removal of non-protein soluble compounds entrapped within the protein precipitate spaces (Mattiasson & Hatti-Kaul, 2003). In addition, diffusion can be employed to remove small molecular weight contaminates by selective and passive diffusion across semi-permeable membrane (Cheryan, 1998). Chromatographic techniques are is used to analyse as well as purify proteins. Gel filtration chromatography is one of the most commonly used technique to purify proteins as it offers a simplistic and effective approach. Ion exchange chromatography, affinity chromatography and reversed phase chromatography techniques can also be utilized for the purification process. Proteins separated by chromatography can be detected by using UV spectroscopy, refractive index, evaporative light etc. (Pastorello & Trambaioli, 2001).

10.4 Characterization of Faba Bean Proteins

Functional properties are the outcome of the physicochemical phenomenon occurring during processing, storage and consumption of food products. In food products, these are driven by the specific properties of protein such as structure and their aggregation, hydration, solubility, foaming ability, emulsifying properties and gelling properties (Felix et al., 2019; Lam & Nickerson, 2013).

10.4.1 Solubility

Solubility is an important prerequisite for a protein to play other functional properties in the food system. Solubility is essential for the emulsification by facilitating the migration of proteins to and spreading at the oil–water interface (Wu et al., 1998). pH is a crucial factor for solubility, as it affects hydrophobicity and surface charge of proteins which in turn influence the equilibrium between the protein-solvent (hydrophilic) and the protein–protein (hydrophobic) interaction, and electrostatic repulsion, respectively (Karaca et al., 2015). The solubility of 7S and 11S globulins from faba bean is dependent on the pH and ionic strength. Kimura et al. (2008) found that at low ionic strength, 7S and 11S globulins from faba bean had low to intermediate solubility at both pH 5 and 7. At a concentration of 0.5 M NaCl, the solubility of both 7S and 11S increased to around 90% at both pH 5 and 7. High intensity ultra-sonication reduces the particle size of protein dispersions, increasing water solubility due to a larger interaction area between protein and water molecules. Faba bean proteins hydrolysates with lower molecular weights exhibited higher solubility because smaller peptides produced by hydrolysis can form stronger hydrogen bonds with water and become more soluble. Hydrolysis of faba bean proteins by alcalase enzyme improves the solubility by 8–10% at pH 8 (Liu et al., 2019). In the same way, Xu et al. (2016) revealed that hydrolysis of glutelin by trypsin can change molecular weights, increases flexibility and enhances the solubility (10–60%) of the proteins.

10.4.2 Surface Characteristics

Some physicochemical characteristics of protein, including molecular size, surface charge, surface-hydrophobicity, surface tension, steric hindrance and molecular flexibility, have great influence on its functional properties (Karaca et al., 2011). Among these factors, surface charge, surface-hydrophobicity and surface tension are proposed to be important protein features that determine functional properties such as solubility, emulsifying and foaming properties (Shevkani et al., 2015; Yang et al., 2018). The surface charge carried by proteins primarily arises from the ionization of surface groups, which has a positive effect on solubility and emulsifying stability of proteins. A high protein surface charge not only promotes greater hydration of proteins, but also induces high repulsive interfacial charges (Schwenke, 2001). According to Martínez-Velasco et al. (2018), high intensity ultra-sonication process reduces the surface tension of faba bean proteins. The lowering in surface tension was related to the greater amount of soluble protein molecules present that could be adsorbed to the air-water interface. Protein conformation and protein interfacial behaviour could be changed due to surface-hydrophobicity (Rahmati et al., 2018; Yang et al., 2018). More exposure of aromatic and aliphatic amino acid residues of protein represents the higher surface hydrophobicity (Jarpa-Parra et al., 2015). Percentage of 7S and 11S globulins composition of faba bean proteins or ratio of globulins and albumins affects the surface hydrophobicity of proteins. Globulin proteins are likely to be more hydrophobic than albumins and 11S proteins have more hydrophobic nature than 7S proteins (Chang et al., 2015; Liang & Tang, 2013).

10.4.3 Water Absorption Capacity and Oil Absorption Capacity

It is generally understood that water absorption capacity and oil absorption capacity of proteins are related to the texture, mouthfeel and flavour retention of products. Water holding capacity (g of water /g of protein) of faba bean proteins was seen as a function of pH as it increased with pH as reported by Żmudziński et al. (2021) that at pH 4, 5, 6, 8, water holding capacities were 2.2, 1.9, 2.5, and 3.4 respectively. Water holding capacity of faba bean protein isolates extracted with ultrasound and enzymatic hydrolysis was measured to be between 2.1 and 4.7 g/g (Ouraji et al., 2020). Dry processed faba bean proteins have a high solubility in water and low water-holding capacity (Otegui et al., 1997), so that dough prepared from faba bean proteins are sticky, making them difficult to handle. Fat absorption capacity of faba bean protein was 87 g/100 g (Vogelsang-O'Dwyer et al., 2020). Vioque et al. (2012) reported higher fat absorption capacity of faba bean protein with possible reason that the conformational change of the protein exposes more hydrophobic groups and other non-polar groups on the protein surface, which could interact with oil molecules to enhance the oil absorption capacity of proteins. Molecular weight of faba bean protein fractions also affects the oil absorption capacity as it decreases with molecular weight of the protein isolates. Smaller peptides are less proficient in entrapping the oils (Eckert et al., 2019).

10.4.4 Foaming Properties

Foaming properties (capacity and stability) of protein determine its utilization in food products such as ice cream, cakes and meringues (Adebiyi & Aluko, 2011; Shevkani et al., 2015). Foaming capacity could be affected by the solubility, molecular flexibility, conformation and protein molecular weight (Zhao et al., 2018). Protein surface-hydrophobicity and molecular weight mainly influence the initial rate of protein adsorption at air-water interface, a higher surface hydrophobicity and lower molecular weight help protein molecules to quickly diffuse to the air-water interface, which led to encapsulating air particles and increasing foaming capacity of proteins (Yang et al., 2018; Zhao et al., 2018). Foaming capacity of faba bean protein varies according to pH, at pH 4, 5, 6, 7 it is 25%, 31%, 50%, and 67% respectively (Eckert et al., 2019). Lipid content has negative effects on foaming ability of proteins as lipids can behave as antifoaming agents (Kougias et al., 2015).

Foam formed with faba bean protein concentrate was more stable at pH 4 than at pH 2 and 12 (Arogundade et al., 2006). Therefore, pH had significant effect on foaming stability, with a significant increase at acidic pH values. The foaming stability was improved by greater protein solubility because this increased viscosity and facilitated formation of a multilayer cohesive protein film at the air-water interface of the foams (Jarpa-Parra et al., 2016; Lawal, 2005).

10.4.5 Emulsifying Properties

The ability of a protein to form and stabilize emulsions plays an important role in its application as food ingredients. Except for the protein solubility, surface charge and surface-hydrophobicity, the emulsifying properties of protein are also affected by many other parameters, including protein composition, conformation state, and molecular flexibility. Emulsifying abilities of protein samples by measuring the sizes of their emulsions were interpreted as smaller the sizes are, the better the emulsifying abilities. According to Kimura et al. (2008), 7S globulin protein of faba bean exhibited the larger particle size of emulsions than the other legumes like soybean, French bean globulins. Because the 7S globulins from the faba bean are not N-glycosylated like as soybean globulins, carbohydrate moiety of the protein contributes to the emulsifying properties of the 7S globulins (Karaca et al., 2011). Faba bean protein and dextran forms a stabilized emulsion. Liang and Tang (2013) also indicated that the emulsifying capacity of vicilin was significantly more effective than legumin at pH 7.0, thereby concluding the faster adsorption rate of the former at the oil-water interface.

Modification of faba bean protein by moderate hydrolysis using alcalase enzyme increases the surface hydrophobicity which could be ascribed to exposing more hydrophobic groups and the emulsions prepared by modified protein results in higher physical and oxidative stability (Liu et al., 2019). It has been revealed that protein isolates from most of the legumes including faba bean can competently reduce the interfacial tension by 50% in canola oil-water mixtures (Johnston et al., 2015). After suitable modifications, the emulsifying activity and emulsion stability of faba bean proteins can be improved and that could be a capable plant based emulsifier in food products.

10.4.6 Gelling Properties

Heat-induced gelation of protein is a very important functional property, which plays a significant role in sensory and textural properties in various food applications. In general, the gelling formation of globular proteins involves several steps such as denaturation, aggregation and network formation. The least gelling concentration is widely used to evaluate the gelation capacity of food proteins, and a low least gelling concentration value indicates better gelling ability for the protein. Gel-forming capacity of protein is highly dependent on patterns of interaction and bonding such as hydrogen and covalent bonds as well as electrostatic and hydrophobic interactions (Adebiyi & Aluko, 2011). Globular proteins, such as those found in faba bean protein isolates, usually form two types of gels, depending on how much charge the native protein carries. Faba bean proteins have an isoelectric point of 5.0–5.5 often with NaCl addition. Most favourable percentage for gel formation of the faba bean protein is 15–15.5% (Langton & Hermansson, 1992). Makri et al. (2006) used 15.4% w/w protein concentration for preparation of faba beans gels. Coarse particulate gels can be formed at pH 5 and for the finer gels required pH 7 and this is independent of extraction method and sodium chloride addition. Significant interactions were noticed for compressive stress and strain at fracture for the gels made from alkaline protein extracts of faba bean (Langton et al., 2020). The thermal denaturation midpoint temperatures of 11S and 7S globulins in faba bean are higher than those in soybean (95.4 °C vs. 93.5 °C for 11S, and 83.8 °C vs. 78.5 °C for 7S) at ionic strength of 0.5; this indicates faba bean protein has better thermal stability than soybean protein (Kimura et al., 2008).

10.5 Modifications of Isolated Protein

Once the protein is isolated by using an appropriate technique, multiple changes like protein denaturation, aggregation and sometimes loss in few functionality properties of the proteins takes place. Modification is hence considered as a solution to overcome these problems. Researchers showed that protein modification can be done by using physical, chemical and biological methods (Akharume et al., 2021). Furthermore, modification allows transformation of non-functional or inert protein fractions into functional proteins (Djemaoune et al., 2019). Some of these methods and their effects have been presented in Table 10.1.

10.5.1 Physical Modification

Physical modifications generally mean modification or alteration in the molecular structure of the biomolecule of interest achieved by application of certain processing. The processes discussed below either improve the functionality of faba beans or create new functionality. Some of the commonly operated modification methods are discussed below:

Table 10.1 A summary of various methods employed to modify faba bean proteins

Processing techniques	Experimental conditions	Research findings	Result	References
High pressure processing	Hydrostatic pressure: 200–600 MPa Time: 3–4 min	Non-covalent bond disruption Destabilization Structural changes of proteins	Increased solubility, water holding capacity, emulsifying and foaming properties	Devi et al. (2013), Mozhaev et al. (1996)
High pressure homogenization	Incubation: 20 min at 90 °C Cooling: 15 min at 4 °C Centrifugation: 20 min at 12,000 × g Pressures: 30 MPa, 60 MPa, 90 MPa, and 120 MPa	Reduction in particle size Impact on the hydrogen bonds of secondary protein structures	Increase in solubility, higher emulsification and foaming properties	Zengwang et al. (2021)
Extrusion	Temperature: 100–130 °C Moisture: 30–70% Screw speed: 150–160 rpm	Destruction of anti-nutritional factors Puff dry product	Solubility Texture Emulsifying Gelation properties Digestibility of proteins can be improved	Akharume et al. (2021), Nasrabadi et al. (2021), Alfaro-Diaz et al. (2021)
Sonication or ultrasound processing	Frequency: 20–100 kHz	Change secondary and tertiary structure of proteins Increase protein linkage Induce aggregation of proteins	Result in oxidation Reduce potential allergenicity Reduce specific functionality	Chemat et al. (2020), Muthupandian (2015), Rahman et al. (2020), Yildiz et al. (2017), Jiang et al. (2014)
Microwave treatment	Frequency: 2450 MHz Power: 950 W Temperature: 170 °C for 30 min	Inactivate endogenous enzymes	Results in less protein destruction Removal of beany flavour	Jiang et al. (2016), Gürbüz et al. (2018)
Food irradiation	Gamma rays: 0–10 kGy	Enhanced oxidative stability Increase antioxidant property	Safe handling Prevents any further contamination Increases refrigerated shelf-life Delayed mold growth	Rady et al. (2020)

(continued)

Table 10.1 (continued)

Processing techniques	Experimental conditions	Research findings	Result	References
Derivatization		Alterations of reactive side chains of protein	Better functional characteristics Improved protein functionality	Zink et al. (2016), Nasrabadi et al. (2021), Lam and Nickerson (2013)
pH shifting method	pH range: 4–8	Protein conformational changes (molten globule) Increased protein unfolding	Emulsion improving quality Promote protein reactivity	Muneer et al. (2018)
Enzymatic hydrolysis	Transglutaminase	Peptide bond breakage Induce the cross linking of proteins	Improved textural proteins Improved protein biological, and nutritional value	Villamil et al. (2017), Akharume et al. (2021), Aguilar et al. (2019)
Lactic acid fermentation	Static conditions: 30 °C for 48 h Incubation under anaerobiosis	Decrease in anti-nutritional factors Increase amount of free essential amino acids	Improved digestibility Nutritional and functional quality enhancement	Verni et al. (2019), Coda et al. (2015)

10.5.1.1 High Pressure Processing (HPP)

It is a technique which uses hydrostatic pressure of 200–600 MPa approximately for a certain amount of time generally 3–4 min. It is a type of cold pasteurization for shelf life extension (Devi et al., 2013). According to the researchers, HPP has fewer effect on the protein's primary structure, though non-covalent bond disruption was reported and concluded that extent of destabilization depends on the amount of pressure applied. Structural changes induced in proteins under pressure include increased solubility, water holding capacity, emulsifying and foaming properties etc. (Mozhaev et al., 1996). According to Hall and Moraru (2021), HPP resulted in increased protein solubility due to increase in surface hydrophobicity which happened due to unfolding of protein structures.

10.5.1.2 High Pressure Homogenization (HPH)

This method involves use of homogenizer which forces liquid matrix into a specialised valve. After passing through the valve the size of particles are reduced allowing the emulsion to become stable (Patrignani & Lanciotti, 2016). By reduction in particle size, there are alterations in protein functionalities like increase in solubility, improved emulsifying and foaming properties etc. HPH has shown significant impact on hydrogen bonds of secondary protein structures of faba bean protein (Zengwang et al., 2021).

10.5.1.3 Extrusion

Extrusion is another modification process in which the raw material is allowed to flow under force assisted with mixing, heating and shearing and resulted in puff dry product. Protein functionalities such as solubility, texture, emulsifying and gelation properties can be improved using high temperature short time treatment along with extrusion (Akharume et al., 2021). The high temperature and pressure during extrusion resulted in destruction of anti-nutritional factors and thus improved digestibility of the proteins as well (Nasrabadi et al., 2021). Extrusion can be used as a pre-treatment to many other modification processes like ultrafiltration and enzymatic hydrolysis (Alfaro-Diaz et al., 2021). A research on extruded Faba bean showed that the protein content was not lost during the processing although their size and volume mass was increased (Strauta & Muizniece-B, 2016).

10.5.1.4 Sonication or Ultrasound Processing

It is an emerging branch of technology which has shown great potential in food industry waiting to be utilised fully. This technique relies on green solvents which are non-toxic and clean in nature. In addition, it requires low investment cost and has shorter extraction time (Chemat et al., 2020) . In food processing, ultrasound frequency from range 20 to 100 kHz is used. Ultrasound is applied to a liquid medium in the form of waves by creating an alternative compression and refraction cycles. This creates voids in the liquid in the form of bubbles or cavities. This is known as cavitation. Cavitation induces macro turbulence in the liquid media which enhances the mass and heat transfer (Muthupandian, 2015). This results in oxidation, alter secondary and tertiary structure of the food proteins (Rahman et al., 2020), increases protein cross linkages and reduces potential allergenicity (Yildiz et al., 2017), induces aggregation of proteins and reduces specific functionality (Jiang et al., 2014).

10.5.1.5 Microwave Treatment

It can be used as pre-treatment to inactivate endogenous enzymes like lipoxygenase and peroxidase which are generally responsible for beany flavour (Jiang et al., 2016). When compared with conventional thermal treatment, it was found that microwave treatment resulted in less protein destruction (Gürbüz et al., 2018). Klug et al. (2018) concluded that microwave treated faba beans showed improved sensorial quality, best texture, consistency and colour and decreased condensed tannins. However, Xin and Yu (2021) compared the effects of microwave and autoclaving process on faba bean and showed that the autoclave heating has stronger and greater effect on the protein content.

10.5.1.6 Food Irradiation

Treatment of food by radiation ensures safe handling and prevents any further contamination. According to studies, gamma radiations applied to faba bean seeds prior to processing showed an increase in their antioxidant property (Rady et al., 2020). Ali et al. (2019) concluded that gamma radiation caused significant increase in their phenolic contents and flavonoid compounds and that radiation used had no detrimental effect on composite constitutes of the Faba bean seeds.

10.5.2 Chemical Modifications

These modifications involve chemical reagents which causes chemical reaction followed by pH alteration for modification.

10.5.2.1 Derivatization

Derivatization is a chemical modification process in which the reactive side chain of protein is altered. Processing like acylation, phosphorylation, esterification, and deamination have been utilized to give food proteins better functional characteristics (Zink et al., 2016). Glycation is a commonly used food grade reaction to improve protein functionality as it is safe to use and does not require exogenous chemicals. It is generally achieved through Maillard reaction or by cross linking enzymes like transglutaminase or laccase (Nasrabadi et al., 2021). Pre-treatment with ultrasound, pulsed electric field or irradiation can influence glycation process favourably (Lam & Nickerson, 2013). These techniques are not in major use in food industry as there are use of many hazardous chemicals.

10.5.2.2 pH Shifting Method

This method involves extreme acid or base environment resulting in protein conformational changes known as “molten globule”. It has shown emulsion improving quality. They promote protein reactivity by increasing the protein unfolding (Muneer et al., 2018).

10.5.3 Biological Modifications

Enzymatic method can be classified into enzymatic hydrolysis or enzymatic cross linking.

10.5.3.1 Enzymatic Hydrolysis

Hydrolysis involves peptide bond breakage and results in improved protein biological and nutritional value (Villamil et al., 2017). Transglutaminase is a known enzyme used to induce the cross linking of proteins which results in improved textural properties (Akharume et al., 2021). Enzymatic hydrolysis can be used as both pre and post treatment for protein modification (Aguilar et al., 2019).

10.5.3.2 Lactic Acid Fermentation

It has been reported that it has a potential to be used as a pre-treatment. This technique showed overall nutritional and functional quality enhancement in the case of faba beans (Verni et al., 2019). Fermentation of faba bean flour by *Lactobacillus plantarum* has shown a decrease in anti-nutritional factors along with increased amount of free essential amino acids and improved digestibility (Coda et al., 2015).

10.6 Applications of Free and Modified Proteins

Faba bean proteins have found their application in substituting many traditional ingredients in conventional foods as presented in Fig. 10.4. The growing trend of vegan diet has made faba bean protein a possible alternative to fit in this category. Recently market has seen introduction of dairy free food products by utilising faba bean concentrates and isolates as an active ingredient. They have shown potential to replace traditional ingredients in many foods like pasta, crackers, mayonnaise, sausages and meatball analogs. Most research are based on replacement by faba bean flour in meat, wheat flour, semolina and eggs (Boye et al., 2010; Nasar-Abbas et al., 2009). Research concluded that utilisation of faba bean protein in bakery industry has a huge potential. It has shown increased nutritional quality along with improved baking performance. In a research conducted by Hoehnel et al. (2020), high protein breads were prepared by substituting the wheat flour with two faba bean ingredients namely dehulled flour (containing lesser protein), and air classified high protein flour. It was found that protein rich flour was a better choice than the dehulled faba bean, however the baking performance was improved in both the cases. A study was conducted to develop enriched pasta and it was found that substituting faba bean flour for 35% of durum wheat semolina during the processing of the pasta enhanced

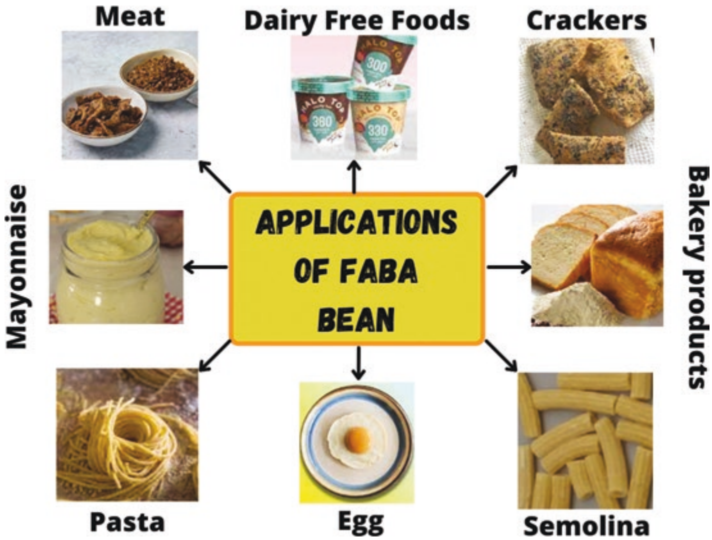

Fig. 10.4 Applications of faba bean proteins in product preparation

the nutritional quality (Greffeuille et al., 2015). Another research was conducted to understand antioxidant property offered by faba bean when incorporated into meatballs. Both irradiated and non-irradiated faba bean proteins were incorporated into meatballs and both had shown significant antioxidant activity and oxidative stability resulting in increased refrigerated shelf life (Rady et al., 2020). A recent study tried to investigate the incorporation of legume protein stabilizers in emulsion based delivery system to serve in functional foods and beverages. Fish based oil emulsion which is rich in omega-3 fatty acids were stabilized by using three different types of legume protein namely lentil, pea and faba bean. The investigation results showed that emulsion produced using the legume protein caused more oxidative stability. Proteins can influence oxidation in emulsion through various mechanisms like non-adsorbed proteins may bind to the metal ions preventing them to reach lipids surface, adsorbed protein may bind metal ions and bring them into close proximity with droplet surface, adsorbed positively charged may repel cationic metal ions, adsorbed metal ion may form a physical barrier that sterically hinders the ability of metal ions to interact with peroxidase and proteins have antioxidant side groups that can scavenge free radicals (Berton-Carabin et al., 2014; Gumus et al., 2017). Another recent research has shown faba bean's potential to be used to produce gluten free bakery products that can be easily used for incorporation in diet for patients suffering from autism. Replacing traditional wheat flour with faba bean flour and cowpea flour showed the baking properties are not affected by this replacement. Also the sensory quality were found out to be good along with the extended shelf life of the product (Atef et al., 2011). Another interesting and developing field of application is the preparation of edible film. Faba beans have found their application in this renewable and natural solution for food packaging. Due to the characteristics like biodegradability and easy solubility to form into flexible films, faba bean protein isolate films have proven to be a sustainable option when providing film to light sensitive foodstuffs (Saremnezhad et al., 2011).

10.7 Technical Challenges Associated with Commercialization of Faba Beans

Faba bean, owing to their high nutritional value and excellent protein quantity, has a great potential to meet the consumer's growing demands for plant based protein source. However, their food use is still minimal due to the formation of an undesirable beany flavor by the cause of endogenous enzymes (Jiang et al., 2016). In addition, the faba bean crop has high susceptibility to diseases and pests as well as unable to withstand adverse environmental conditions, thereby making its cultivation limited. Many abiotic stresses like drought, salinity, heat and frost, along with the biotic stresses like foliar diseases, pests, viruses, and weeds also hamper the large-scale production of faba beans (Alghamdi et al., 2012). During the harvesting of faba bean, standability and quality becomes a major challenge. Although faba bean has thicker seed coat that can help to reduce damage but still needs to be handle gently to prevent any harm. Chocolate spot (*Botrytis sp.*) is already a concern to deal with but other diseases also have been discovered recently like Alternaria leaf spot and *Stemphylium* blight causing distress in the cultivation process (Adams, 2020). Black bean aphid is one of the major pests and its complete removal from the faba bean is highly challenging (Austin, 1986). Due to the variety of shapes and sizes, problems of blockage are created by using seeding equipment making the seeding challenging, even the equipment used for harvesting are also not well-developed, thus resulting in poor yield and establishment (Matthews & Carpenter, 2001). Faba bean has a perfect profile of balanced amino acids but has low level of methionine and cysteine along with the involvement of many anti-nutritional factors like enzyme inhibitors, phytates, tannins, oligosaccharides, vicine and convicine. Nevertheless, molecular breeding technologies for these are available but approaching genetic improvement is not an easy task. Faba bean also cannot be stored for a long time especially in the conditions of high temperature and moisture and thus extra care have to be taken to prevent browning and to enhance its economic value. Furthermore, if the moisture is restrained it can directly affect the digestibility of proteins, thereby maintaining moisture during faba bean production is a highly cumbersome process. Based on the current knowledge it becomes difficult to predict the potential of faba beans. It can also be harvested at "milky stage" which is an immature stage and people consume fresh as vegetables but this is limited due to the short shelf life of this stage and thus harvested in its maturity to achieve maximum nutritional qualities (L'Hocine et al., 2020). Containing various components like anti-nutritional factors can reduce the feed intakes and protein digestibility and overcoming completely is a big process to stand against it (Austin, 1986). Processing is itself a challenge to make the yield more effective. Dehulling can help to remove many of the phenolic compounds but not anti-nutritional factors and thus there is a requirement to combine with other treatments to make it successful. Fermentation is another process which can help to improve nutritional properties but it is not sufficient enough to improve the protein digestibility. During enzymatic modifications, especially transglutaminase treatment can improve the adhesiveness of pasta but cannot polish its hardness and chewiness. Microwave treatment has more advantages over the other thermal treatments due to its electromagnetic waves. However, it also promotes the formation of insoluble complex between protein and starch that can decrease the protein solubility and on extensive use it can also increase lipid autoxidation developing rancid off flavor (L'Hocine et al., 2020). Specialized equipment for sowing and harvesting is not available for faba bean. In many countries like India, it is not a popular legume and is limited in small areas in selected states. Hence the use of designed machineries does not prove to be economical but these machines could help a lot to modify the crop (Sundaram et al., 2012). There is need to improve the heat tolerance using genotype to extend its production in unconventional areas. The breeding result is slow comparatively due to the nature of mechanism to resist various anti-factors (Redden et al., 2018). Approaching the variety development and extension could encourage farmers in the areas of unfavorable agronomic conditions but there is a lack to access these (Alghamdi et al., 2012). To achieve more, there is need to have better biotechnological tools and genetic markers which are not widely adopted (Redden et al., 2018). The development of genetic markers is also costly for these along with the little pre-existing genomic information (Askar, 1986). Hence these are some of the challenges that the food industry is facing and overcoming them can lead to the road of improvement which could help to reach out more consumers who desired to have plant-protein based diet.

10.8 Genetically Modified Faba Beans

Since 1976, after the discovery of some exotic species of faba beans their genetic variations have started to be studied (Abdalla, 1976). Continuous cross breeding resulted in many variations in faba beans in terms of seed shape, size and colour (Maalouf et al., 2019). A rise in cross fertilization is necessary for the higher yield, stability and abiotic stress resistance. The synthetic varieties produced from this cross fertilization have shown an improved population (Gasim & Link, 2007). The emergence of genetic variants arise due to increased abiotic stresses like drought, heat, waterlogging and frost which effect the growth of the legumes (Naser, 2016). Another reason is the biotic stresses which include diseases, insects, pests, viruses and parasitic weeds (Sahile et al., 2008). Although this modification method have not yet been utilized for protein extraction still it has great potential when it comes to increasing protein content in Faba bean varieties. Duc et al. (1999) stated that protein content in the faba bean varied depending upon the different genotypes and there was a higher correlation between amino acids and total protein content. In another study, breeding technique was utilized to manipulate the contents by affecting the legumin/vicilin ratio. Globulin which makes up the protein content of seed proteins (more than 80%) has a constituent named as legumin which is encoded by few genes known as legumin A and B (Müntz et al., 1999). The vicilin coding genes is located on chromosomes II near the centromere (Fuchs & Schubert, 1995). As protein content is dependent on the expressions of these genes therefore manipulating these genes by using modern genetic quantitative methods and genomics technologies or by using regulatory genes variants can lead to variation in protein quantity and quality of faba bean (Warsame et al., 2018). Although this technique has ensured good results however it is still not a very promising source to rile upon as mutations are often seen while applying this method.

10.9 Future Prospects

The faba bean has both ideal and emerging market and as with all these, access to future demand is one of the most important decisions in growing crops and managing cash flow needs (Adams, 2020). The pressing needs for high protein animal feed is considered and concluded that there is a great scope for the expansion of faba bean cultivation (Podimatas & Karamanos, 1991). Considering the properties like high dietary value, numerous uses, and potential to grow under wide range of climatic and soil conditions, faba bean is taken into one of the best performing crops to increase the sustainability and world supply of plant protein (L'Hocine et al., 2020). The situation for faba beans is pretty similar to that of small-scale crops, highlighting the need for collaborative research programs that work closely with commercial-oriented programmes to ensure the effective adoption of the technology (Gnanasambandam et al., 2012). The development of novel techniques to introduce genes into faba bean via plant transformation guarantees to present plant breeders the possibility to triumph over hybridization obstacles and barriers associated with the one's developments for which very little herbal resistance has been identified (Alghamdi et al., 2012). So, there is scope to improve modern breeding techniques of faba bean to make it more amendable to improvement. Modern breeding strategies can be combined with the latest innovation in genetics and genomics carrying along with some traditional breeding methods could provide many potential applications for the development of various faba bean varieties (Gnanasambandam et al., 2012). In addition, the application of processing technology is considered an interesting method for its products with optimum nutritional value and consumer acceptance. Also, the functional and structural modelling approaches can improve canopy simulation, especially for faba bean crops but the main issue is ensuring the plasticity of the canopy (Singh et al., 2013). Significant efforts are required to implement an education programme along with the national and international collaboration that can facilitate the effective production of faba bean (Gnanasambandam et al., 2012). Despite all the good qualities of faba bean, the main bottleneck is anti-nutritional factors, taste, and aroma. Improvement in these could help to expand their range and including them in their diet could help a lot, especially for the plant protein dependent populations (Singh et al., 2013). However, the increasing use of legume-based foods to meet the consumer health, environmental, and ethical food practices present faba bean a great opportunity, which are increasingly being recognized as a promising protein source than animal and soybean. Faba bean have a great future. Being rich in protein, it may be a viable solution to a protein-deficient diet for many poor people as well. Once processed, added value can increase its nutritional value and can reach to more consumers (Sundaram et al., 2012). In future, food market is expected to flock to new varieties having lower vicine/ convicine along with other anti-nutritional factors, thus, hoping to find a competitive advantage through the demand for food ingredients (Adams, 2020).

10.10 Conclusions

Faba bean is important both as pulse as well as vegetable crop and this crop is recommended for their benefits to the human nutrition. Not only this, it has high nutritional value, and better medicinal effect and thus considered as important crop. Being a legume, faba bean is also an excellent source of lysine-rich protein along with the variety of nutrients like proteins, carbohydrates, B-group vitamins, minerals, starch and dietary fibers. But how much nutritional properties it can provide, it is still overshadowed by the presence of anti-nutritional components and if these could be removed, this crop would be more advantageous and acceptable than any protein-based crops. It is generally well suited in higher moisture areas or under irrigation. However, the best way to incorporate this crop is follow the process of crop rotation, as this crop has ability to fix the nitrogen from the atmosphere and hence could increase the flexibility at the time of harvesting, improves soil, and increases soil organic matter. Fewer varieties have been recorded in comparison with the other crops and thus production of this crop is vulnerable to the environmental stresses. Hence, there is a requirement and urgency to develop varieties that can be resistant to them. It is one of the most versatile crops holding the great potential to meet the global needs. Thus, to maximize the potential of faba bean, it is necessary to meet both producers' expectations and consumers' demand for nutritious, healthy, safe, delicious, and ready to eat products. This requires continuous research and development efforts in genetics and cultivar improvement, agricultural and crop system management, as well as new processing techniques to address the agricultural, nutritional, and sensory limitations of faba bean and its products. Faba bean can be used in a variety of protein-rich food as a substitute for animal protein, well suited to changing consumer trends and current environmental needs.

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Chapter 11
Biofortification: Quality Improvement of Faba Bean

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11.1 Introduction

Faba bean (*Vicia faba* L.) is one of the major legume crops and belongs to genus *Vicia* L. in the family *Fabaceae*. Faba bean known as field bean, horse bean, and broad bean is regarded as one of the ancient accustomed legume among humans (Fig. 11.1) (Abebe et al., 2014). For over 8000 years it is a part of the diet in the Mediterranean, and it has spread throughout the world from here. China is the world largest producer of faba bean, they contribute 50% of worlds production and they are closely followed by Ethiopia, thus making Ethiopia the largest producer of faba bean in Africa (Chopra et al., 1989; FAOSTAT, 2007). There are various cultivars with large and small seeds (Bond et al., 1985). About 26,000 accessions are reportedly held in gene banks, collections could be found in ICARDA International Centre for Agricultural Research in the dry areas in Syria and the Vavilov Institute in Russia. Faba bean is one of the most important legume crops cultivated due to its high yielding potential, nutritional composition and the role as cover and forage crops (Maalouf et al., 2018a). Faba beans had been known to improve cereal based system and soil fertility through nitrogen fixation (Maalouf et al., 2018a; Jensen et al., 2010). Faba bean is low cost food rich in protein and adapts to all the ecological regions of the world, hence it is grown from the arctic circle to the equator and equally from the high altitudes to sea level. The majority of undernourished populations are in the developing countries of the world, they rely on faba bean as a crucial protein source for the low income group and rural populations. The high protein content of faba bean has made it a cardinal legume and a locum for meat among the

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Fig. 11.1 Faba bean seeds

teeming indigent groups (Crepon et al., 2010). In developed countries, faba beans are a composition of animal feeds of protein level between 20–41%. It stands as an avenue for economic sustainability for the farmers and equally a source of foreign currency for the under developed countries. Faba beans are generally utilized in crop rotation with cereals, basically to improve the soil health through fixation of atmospheric nitrogen (Sahile et al., 2008). In the Mediterranean, Middle East, Ethiopia and China, it is a common breakfast item, while the roasted seeds are cherished in India (Duke, 1981). Faba bean straw are highly valued, it is of premium importance in Sudan and Egypt, while the straw is employed for fuel and brick making in Ethiopia and Sudan. Faba bean is generally classified according to its seed size and colour (Etemadi et al., 2017). It varies from large seeds variety (>1.0 g/seed) to medium (0.5–1.0 g/seed) and small seeds (<0.5 g/seed) (Etemadi et al., 2017). It is commonly divided into four groups; *Vicia faba var. major* is the broad bean with large flat seeds, also known as broad beans; *Vicia faba var. equina* has medium sized seeds known as horsebean; *Vicia faba var. mino*r is the tick bean with small round seeds; and *Vicia faba var. paucijuga* has small seeds. Duc et al. (1999), also reported that faba bean can be categorised with respect to the content of tannins in the integuments and the content of vicine + convicine (VC) in the cotyledons. Micronutrient malnutrition has been the major problem in the developing countries because lots of people are suffering from micronutrient deficiency. Mineral and vitamin are essential in our daily diet but in developing countries, deficiencies in these parameters pose a public health problem to the consumers. The major mineral deficiency such as iron and zinc are common and widespread affecting more than half of the human population. This affliction could be alleviated through four major ways such as food supplementation, fortification, dietary diversification and biofortification. To alleviate malnutrition, Mulualem (2015) suggested that biofortification of crop is the best way of improving the quality of faba beans through breeding strategies. Biofortification is one of the cost effective and sustainable agricultural processes which can reduce vitamin and mineral deficiencies in the diet (Bouis et al., 2017). Therefore, food biofortification with micronutrients is very important for health, as it helps in alleviating the effect of "hidden hunger" or malnutrition at a relatively low cost (Horton et al., 2008). Through biofortification process, different genotypes of faba beans with drought tolerance, heat and frost tolerance, weed and disease tolerance, salinity tolerance etc. had been produced and released to increase productivity and yield of the crop. Likewise, the nutritional values (protein, zinc, iron, starch, fibre etc.) of the crop are improved while the antinutritional (tannin and phytate) compositions of the crop are reduced or eliminated in some species. Elimination of these antinutritional factors in some species and genotype of faba bean is useful for human health development and improvement since the essential trace elements from the dietary sources are available for absorption. It has been reported that phytate complexes bind divalent cations resulting in reduced bioavailability of the micronutrient while tannin complexes bind with protein resulting in reduced bioavailability of protein. This chapter presents quality improvement of faba bean through biofortification.

11.2 Production of Faba Beans (Broad Bean) Among the Continents

The area cultivated and yield of faba bean in 2015 to 2020 are shown in Table 11.1. Faba bean is rated as the third important grain legume in terms of the area cultivated, yield and production (Singh et al., 2013). In 2015, Africa countries cultivated larger areas (828,911 ha) than other continents but the yield was lower (15,191 hg/ha) than that of Asia, Europe and Oceania. But from year 2016 to 2020, Asia cultivated more areas with higher yield than other countries. There were increases in the yields in Africa and Asia countries while the yield decreased drastically in 2019 in Oceania countries. Increase in the yield may be as a result of replacement of the old variety (landraces) to improved varieties which are resistant to drought, heat, diseases etc. Reduction in the yield may be due to attack by insect, seed type, environmental conditions, soil condition/ nutrients, cultural practices adopted during cultivation

Table 11.1 Cultivated area and yield of faba bean

	Area harvested (ha)[a]					Yield (hg/ha)[a]				
Year	Africa	Americas	Asia	Europe	Oceania	Africa	Americas	Asia	Europe	Oceania
2015	828,911	178,007	797,720	437,978	163,900	15,191	12,008	20,043	29,665	17,315
2016	711,963	169,975	866,222	488,762	350,457	17,591	12,103	19,932	30,034	12,085
2017	749,323	171,245	893,725	502,472	232,732	19,352	12,304	21,218	32,543	20,778
2018	793,849	185,143	920,618	635,219	313,051	20,112	12,106	20,609	22,281	13,276
2019	756,158	182,373	887,804	553,613	233,967	19,709	12,086	20,677	28,773	9976
2020	762,542	187,394	867,721	638,950	214,892	19,554	12,230	20,833	28,613	14,565

Source: FAOSTAT database (2022)
[a]Aggregate values

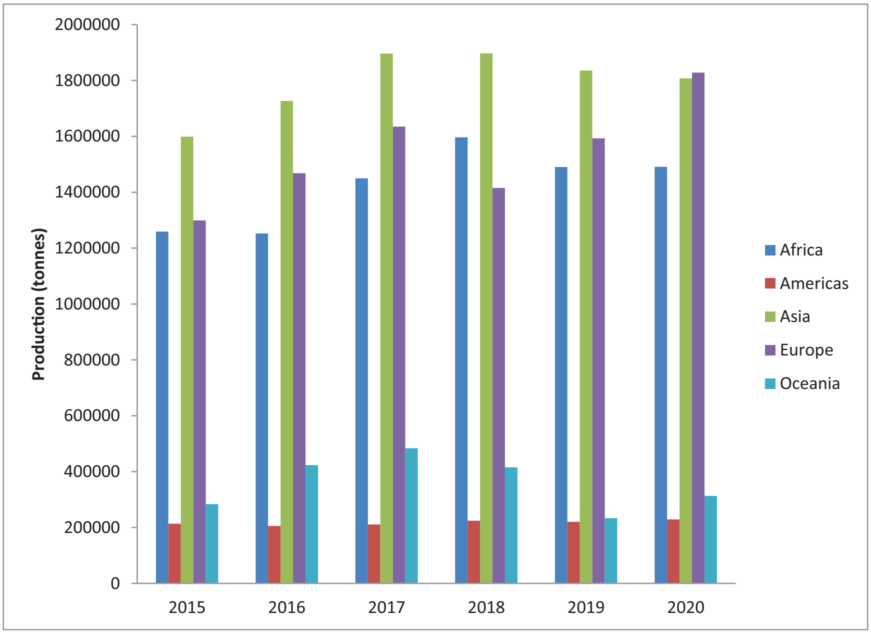

Fig. 11.2 Production of faba bean from 2015 to 2020. (Source: FAOSTAT database (2022))

etc. Asia countries are the leading producers of faba beans from 2015 to 2019 followed by the European countries as shown in Fig. 11.2. However in year 2020, production of faba beans was highest in the European countries. Oceania and Americas produced the least quantities of faba bean from 2015 to 2020. There were decline in the production of the faba bean from 2018 to 2020 and this may be due to susceptibility of landraces and cultivars to biotic and abiotic stresses with *Orobanche crenata*, which is the the major factor in North African countries such as Morocco (Maalouf et al., 2018a).

11.3 Factors Affecting Faba Beans Productivity

Researchers have identified numerous factors affecting the cultivation and production of faba beans. These factors caused biotic (parasitic weed, foliar diseases, and soil borne borne diseases) and abiotic (drought, heat, water logging, frost) stresses in the crops thereby affecting the yield and nutrients of the crops (Abdellatif et al., 2012; Maalouf, et al., 2018b). Among the factors are:

11.3.1 Drought

This is a major environmental factor affecting the physiological and biochemical properties of the crop by limiting faba bean growth, development and productivity (Li et al., 2018; Abid et al., 2020). Drought can be described as water deficit or change in water status leading to stress in the plant. Drought affects faba bean seed quality because it's among the factors regulating the seed protein content. Studies have shown that faba bean grown during drought conditions have impaired nitrogen fixation but increased the protein and sulphur contents of the faba bean (Rharrabti et al., 2001; Singh, 2007; Alghamdi, 2009). However, Smith (2018) reported that drought have no significant effect on the mineral contents and amino acids concentration in the crop. According to Amede and Schubert (2003), faba beans are more sensitive to drought than other legumes. Katerji et al. (2011) explained that drought caused reduction in grain and straw yield especially during flowering, early podding and grain stages. Drought stress caused increase in flowers number while the pods/seed numbers were greatly reduced due to high rate of abscission in faba bean (Sekara et al., 2001). De Costa et al. (1997) observed that different faba bean cultivars react to different water regimes and shortage of water lead to reduced leaf initiation, canopy size, expansion and biomass production. Reduction in faba bean yield and productivity was aided by increased soil salinity level during drought. Abid et al. (2020) suggested the use of 1 mM of β-aminobutyric acid (BABA) to improved the drought tolerance of faba bean. It was observed that the leaf relative water content, transpiration rate, stomatal conductance, photosynthesis rate were increased while the water use efficiency, malondialdehyde, electrolyte leakage levels and hydrogen peroxide (H_2O_2) were decreased. There was reduced cell membrane damage as a result of oxidative stress (Abid et al., 2020). Adaptation to drought depends on the species (within and between species) and genotypic differences as reported by Abdellatif et al. (2012).

11.3.2 Temperature

Faba bean is highly sensitive to heat stress especially during reproductive and seed filling stages. The optimum temperature required for flowering is 22–23 °C according to Patrick and Stoddard (2010). Extreme heat is detrimental to the production of faba bean in some countries such as Sudan, Ethiopia, Egypt etc. The effect of high temperature could lead to small and short stem crop with few pods and branches (Maalouf et al., 2018b). Extreme heat (42 °C) causes reduction in the yield, growth rate, photosynthetic pigments concentration and membrane stability (Hamada, 2001; Bishop et al., 2016). Bishop et al. (2016) explained further the effect of heat stress on faba bean during floral development. In the study, it was discovered that heat stress caused reductions in the yield of faba beans during reproductive development which may be due to gametophyte damage and failure of fertilization. Heat stress caused variations in the cell wall components, starch, soluble sugars, lipid etc. while different patterns were observed in the oxidative stress enzymes of faba bean (Filek et al. 1997; Lavania et al., 2015). Frost is another temperature related factor that caused excessive yield loss in faba beans at early stage of flowering but two genotypes of faba bean (IX474/4-3 and 11NF010a-2) have been reported to have low sensitivity during reproductive and vegetative stages by Alharbi et al. (2021). Frost is categorized into radiation and advection frost based on the climatic and temperature conditions (Snyder & Abreu, 2005). The extent of damage caused by frost to faba bean is determined by the growth stage, duration, frost severity and frequency (Dalezios, 2017). Faba beans are reported to have moderate tolerance to frost because of the thick pod walls which protect the seeds during growth and development (GRDC, 2017). Severe frost affects the flower, yield and losses as a result of distorted growth which weakens the stem and subjects it to disease attack during early vegetation and flowering. Other studies on the effect of frost on faba bean varieties had been done in Australia, Central Alberta, and Europe and the best faba bean frost tolerant varieties had been recommended (Maqbool et al., 2010; Henriquez et al., 2018; Alharbi et al., 2021; Neugschwandtner et al., 2022).

11.3.3 Diseases

The yield of faba bean is affected by several biotic and abiotic factors. In Africa several pathogens are documented to be associated with faba beans (Nene et al., 1988). The production system and agroecological conditions set the importance of the pathogens (Najar et al., 2000). Faba bean is reported to be affected by over hundred types of viruses. However, of great economic importance in Africa and Asia are 16 viruses with varying symptoms such as yellowing, stunting and necrosis (Najar et al., 2000). The faba bean leaf roll virus is of extreme importance. It causes stunting and yellowing of the crop. Additionally, the beet western yellow virus, faba bean necrotic yellow virus, milk vetch dwarf virus, chick pea chlorotic dwarf virus and finally soy bean dwarf virus are all of significance and causes yellowing and stunting of the crop. The viruses are transmitted by aphids and they are limited to the stem. The chick pea chlorotic dwarf virus is spread by the leaf hopper. In some cases, complete crop failure has been attributed to these viruses (Najar et al., 2000). Another chief pest of faba beans is phytonemaode. All over the world, plant parasitic nematodes brings about significant reduction in yield of many crops (Fabiyi & Olatunji, 2018; Fabiyi et al., 2018a, b, 2019, 2020a, b). They have impacted largely in the production of pulse crops (Feyisa, 2021). The nematode genera that have been documented to parasitize the rhizosphere of faba bean are *Pratylenchu*s, *Rotylenchulus*, *Tylenchoryhnchus*, *Xiphinema*, *Ditylenchus* and *Tylenchus* (Feyisa, 2021). Among the list, *Xiphinema* and *Ditylenchus* are reported to be predominant. This corroborates the report of Sikora and Greco (1990), they established that severe damage is caused by *Ditylenchus dipsaci* and *Pratylenchus.* Investigations by Cobbett (1969), revealed that *Pratylenchus pinguicaudatus* is one of the important plant parasitic nematode that is associated with faba bean. The presence of *Pratylenchus* spp. on faba bean was affirmed by Di Vito et al. (1994) and Greco and Di Vito (1994) with the isolation and identification of *Pthornei* in the root zone of faba bean. Hopper (1991) reported that faba beans are not resistant to nematode pests and *Ditylenchus dipsaci* is the most damaging. Among the faba bean diseases listed by Torres et al. (2006) are downy mildew (*Peornospora viciae*), rust (*Uromyces viciae-fabae*), Ascochyta blight (*Ascochyta fabae*), foot rots (*Fusarium* spp.) and chocolate spot (*Botrytis fabae*). Faba bean is affected by parasitic and non parasitic weeds. The common parasitic weeds that affect faba bean in North and East Africa is broomrape (*Orobanche* spp.) (Torres et al., 2006; Maalouf et al., 2018a, b).

11.3.4 Waterlogging

Other factors include waterlogging which affect faba bean during the growth, flowering and physiological trait (chlorophyl) thereby reducing the yield of the crops. It had been observed that faba bean is the most tolerant to water logging among the legumes (Solaiman et al., 2007). Malik et al. (2015) stated that waterlogging caused poor germination and affected photosynthesis in legumes which in turn lead to decrease in dry matter accumulation. However, Pampana et al. (2016) stated that waterlogging reduced soil oxygen thereby causing inhibition in root respiration, decreased root and shoot growth. Also, there are reductions in photosynthesis, yield, plant growth, biological nitrogen fixation, the formation, function and survival of nodules (Davies et al., 2000). This can later result in death of the plant during the end of waterlogging as duration of waterlogging had severe effect on the plant. Due to these factors, biofortification of the faba bean is necessary to improve the yield and nutrients of the crop through plant breeding processes.

11.4 Overview of Biofortification in Developing Countries

Dependable food production is hinged on dealing with sparseness of micronutrients. The invisible snag of hunger which loiters around half of the world's population is analogous to paucity of proteins, vitamins and micronutrients which are requisite in the human diet. (Graham et al., 1999; Bouis, 2003; Paine et al., 2005). A puissant panacea to nutritional shortfall is biofortification. Over half of the world population is hugely affected by dearth of zinc, iron and vitamin A in their diets, preschool children and women are the most vulnerable. About 42% of children whose age's ranges between 6 months to 4 years are anaemic, while women within reproductive age have low concentration of haemoglobin (WHO, 2017a). High percentage mortality, poor growth and perceptive impediment has been noted with nutrient deficiencies (UNDP, 2003; UNSCN, 2004; WHO, 2017a, b). Nutrient deficiencies could be managed through supplementation and enrichment of the staple foods; it is a novel management practice to check multi nutrient deficiencies in third world countries under the United Nations Sustainable Development Goal projected for the year 2030 (Haas et al., 2005; Bailey et al., 2015; United Nations, 2016). High quality breeding methods coupled with novel biotechnology approaches are involved, the method ensures that rural areas which are considered as remote and who's populations are undernourished are touched most especially in sub-Saharan Africa and Asia (Arsenault et al., 2010). Furthermore, in developing countries, farm productivity could be increased with biofortification of crops without any environmental consequence. Farmers will look out for the mineral improved seeds because the trace elements are equally responsible for disease resistance in plants with reduced environmental stress. Through this approach, national growth is achieved by means of development of the health and wellbeing of the citizenry, while work capacity is accomplished with high level of educational attainment (Lockyer et al., 2018). The first step to biofortification is a collaboration between nutrition, health and agricultural research centres. This is essential for staple crops like cassava, wheat, sweet potato, rice and maize, so as to bring about the best nutritional and agronomic qualities in the new cultivars of the crops (Goto et al., 1999; Gregorio et al., 2000; Tomlins et al., 2004; Van Jaarsveld et al., 2005). Nutrient retention through cooking is evaluated, while cultivars that are promising are evaluated for bioavailability of micronutrients for the nutritional impact if any before the new cultivars are released. Inquest in to the social factors, economic state and dietary requirement of the rural populace is also a factor to be considered in the development of bio fortified crop lines. For example, in a country where rice is commonly eaten, it is suggested that rice should be supplemented with iron to upgrade the iron consumption status of the populace (WHO, 2018). Close to 20 million of the world population are currently consuming bio fortified crops, this has augmented the diets in areas where food choices are limited coupled with poor agrarian soils (Bouis & Saltzman, 2017). To realize a good biofortification regime of staple foods, for the general community and populace, plants within built natural micronutrients may be cross bred with a staple crop to bring about crops with the preference traits. Fertilizers with micronutrients may be used during the growing period of the crops so that the crops would take this up and a determined level of micronutrients is imbued in the crops. Finally, accumulation of micronutrients in staple crops could be executed through gene modification. Here, micronutrients that do not exist in the staple crop could be inserted by way of gene modification. For babies in third world countries, complementary feeding programs could be established such that micronutrient fortified baby formulas would be served (WHO, 2016; De-Regil et al., 2013). Although, targeting the national population for biofortification is usually a herculean task, it is thus easier to focus on food production and distribution logistics, with this in mind, suitable target population is identified and the required nutrient is set (Lividini et al., 2017). After this, high quality genes are picked out while important attributes such as weather tolerance and disease resistance are equally considered. The last stage is testing of the fortified crop, if farmers would be willing to produce them and the opinion of the public on the new fortified crop is also sought (Birol et al., 2015). Once all the stages are completed, the new crop will be released in to the market. In some cases, the bio fortified crops are met with rejection by a fraction of the population because of colour difference from the traditional crop which they are familiar with. For example, a staple crop fortified with vitamin A, may come with orange or bright yellow colour as against the white native crop that the populace is accustomed to. This may bring about a little set back in to the adoption of the staple crop by the community. In this circumstance, there is the need for jingles and educational programmes until the crop is accepted.

11.5 Methods of Biofortification

Biofortification is a process of increasing the amount of minerals and vitamins in a crop through agronomic practices, transgenic and plant breeding (Bouis & Saltzman, 2017). This is done to some staple foods in order to combat global micronutrient malnutrition. Thavarajah et al. (2014) stated that biofortification of certain pulse crops such as lentils, field pea and chickpea have been limited to some North America regions. An approach which focuses on manoeuvring of plant genome while mineral fertilizers could be applied during the crop growth to enhance solubility of micronutrients in the soil, was reported to be effective by White and Broadley (2009). The techniques that could be employed in biofortification of crops include.

Agronomic biofortification is a temporary way of increasing micronutrient in plant through the use of chemical fertilizers or foliar sprays (Cakmak, 2014). This is done especially when the target is to increase micronutrients which are absorbed directly by the plant such as zinc, but is not effective and efficient for micronutrients synthesized in the plant which cannot be absorbed directly (Lyons & Cakmak, 2012). By way of this method, zinc and iron could be augmented in nutrient deficient soils. Yield and accumulation of iron and zinc in grains has been achieved through fertilization (Alloway, 2008). Usually, iron chelates and acidification of the soil are used in place of inorganic iron in fertilizers due to precipitation and oxidation which prevents the use of inorganic iron by plants. This has proven to be efficacious in improving iron uptake and accessibility by plants (Wakeel et al., 2018). Research has demonstrated that application of foliar zinc is significantly more effective than fertilization in grains such as wheat, maize and rice. Solubilisation of zinc by soil bacteria is equally a reliable method which has been effective in increasing zinc concentration in shoots and roots of crops such as soybean and wheat (Madhaiyan et al., 2010). The use of plants like vetch broad bean and clover for nitrogen fixing purposes coupled with urea covered with zinc has been documented to increase the concentration of zinc in desired crops (Madhaiyan et al., 2010). The quality and vegetative growth of basmati rice was improved through surface fertilization using urea coated zinc rather than fertilisation with $ZnSO_4$ (Pooniya & Shivay, 2015). A cost effective method is the biofortification of selenium in wheat. The selenium is added via foliar spray and equally during seed germination and soaking process of the plant. This method has been used to augment selenium deficiency in human population (Masarovičová & Kráľová, 2012). In recent times, iron deficiency has been combated by the addition of iodate salts and soluble iodide to water used for irrigation purposes to upgrade iron concentration in edible plant parts (Lyons et al., 2004). Surface application of KIO_3 is equally known to improve iodine content of rice, corn and wheat (Budke et al., 2020). This has also been established to be effective other than application through the soil. This method has been used in the fortification of apples with iodine (Cakmak et al., 2017). Early development of milk stages in cereals has been aided via fortification with iodine, high percentage of iodine was detected in the grains at harvest (Cakmak et al., 2017). Selective breeding has additionally been used as a method of biofortification. Conventional plant breeding technique requires identification and development of parent lines with high mineral or vitamin levels and cross breeding them to produce plants with the desired nutrient and agronomic traits (Bouis et al., 2017). The high nutrient profile parental lines are screened and utilized for production of molecular markers for marker assisted selection in pulses. Recombinant inbred lines for conventional breeding are successful in pulses due to availability of wide gene pool (Kumar & Banerjee, 2022).

Varieties of crops that are rich in micronutrients are crossed with crops that are deficient in some essential nutrients and traits (Malik & Maqbool, 2020). This procedure actually has some difficulties like absence of heritability and of genetic diversity. Thus monitoring for a long time and support is needed. This bottle neck has brought about the use of bio fertilizers in to lime light. This is regarded to have a lot of advantages, primarily because, environmental pollution is eliminated. Micro-organisms in the soil are very efficient in biofortification of crops. They make nutrients available to crops in usable forms (Dotaniya et al., 2016). Arbuscular Mycorrhizal Fungi (AMF) is employed lately in breeding programs, it increases productivity of crops, crop root development is assisted and uptake of essential nutrient by the plants is supported largely (Gashgari et al., 2020). Micro-organisms like *Pseudomonas chlororaphis* is reported to promote nutrient uptake and substantial plant growth (Sharma et al., 2003). A broad gene pool of faba bean has therefore been developed over the years, including local landraces, mass selections from landraces, open-pollinated populations, inbred lines, and cultivars (Duc et al., 2010; Karaköy et al., 2014). The EU database of faba beans registered varieties consist of 256 faba bean cultivars which are currently registered for growing in Europe (European Commission, 2017). According to Fouad et al. (2013), registered varieties feature a range of highly differing characteristics with limited genetic variation. Major traits targeted in selecting faba bean varieties include yield potential, quality, consistent performance, standing ability, suitability for human consumption or the feed market, days to maturity, seed size, as well as resistance to disease and abiotic stress.

The major focus of legume breeding, including faba bean, is yield. However, in many regions, faba bean crops are subject to different conditions of biotic and abiotic stress and, as such, yield is ultimately dependent on cultivar resilience to multiple stress conditions. Hence, breeding new cultivars with increased resilience to abiotic stresses, such as heat and salinity, continues to challenge breeders (Siddique et al., 2013; Nebiyu et al., 2016). Furthermore, winter hardiness is an important trait in screening for cultivars to be cultivated during the cold season (Link et al., 2010). The importance and wide variation of traits relating to morphology, agronomy, and quality have been previously investigated and demonstrated for local faba bean genetic resources of different origins (Karaköy et al., 2014; Terzopoulos & Bebeli, 2008; Nasto et al., 2016; Basheer-Salimia et al., 2014; Zong et al., 2009). Some researchers were of the opinion that breeding programs need to incorporate a more complex evaluation and traits use such as root architecture, shoot architecture, parameters relating to stomatal function and disease resistance (Duc et al., 2015; Zhao et al., 2018; Khan et al., 2010; Khazaei et al., 2013; Torres et al., 2006).

Transgenic plant breeding is required in crops where the target nutrient does not exist naturally at the required levels (Bouis et al., 2017). According to Kumar and Banerjee (2022) transgenic methods for folate, iron, zinc micronutrient biofortification in pulses are in progress. The use of gene editing technology blocks the production of antinutrient fractions and enables microorganisms to be incorporated through the pathways for exploitation of metabolic engineering. Micronutrient deficiency in crops could also be improved by identifying genes controlling nutrient concentration through genomic technique. In wheat biofortification, methods like marker assisted selection (MAS), identification of quantitative trait loci (QTL) and GS, which are marker-assisted selection, quantitative trait loci and genomic selection has been used respectively. In this regard, genomics advancement has promoted biofortification of many important crops. Molecular markers and map loci are used to moderate traits and qualities of interest (Ali & Borrill, 2020). The genomic regions concerned with areas of desired traits are controlled by MAS. Sequenced genome of pulse crops have been used for micronutrient enrichment, multigene transfer and removal of antinutrients from edible tissues and restructuring of metabolic pathways (Beebe, 2020). This method depends on wide genetic pool for the transfer of targeted genes from one plant species to another which is independent of their taxonomic and evolutionary status (Garg et al., 2018). The genomic method has been employed widely in the fortification of maize with vitamin A. Cultivars with abundance of beta carotene are usually selected. Understanding MAS has been used to improve vitamin A content in maize cultivars from 1.80 to 8.14 μg/g (Goredema-Matongera et al., 2021).

11.6 Benefit of Biofortification

An enhanced level of vitamin A, zinc and iron are presently being used in developing countries (Meji et al., 2017). The benefits of consuming biofortified foods cannot be over emphasised. Vitamin A is available in foods like meat, liver and eggs. These are not within the reach of people with indigent life style. However, with the fortification of orange sweet potatoes, yellow cassava and orange maize, beta carotene is now included in the diets of the impoverished (Johnson & Mohn, 2017). The intake of biofortified foods by breast feeding mothers goes a long way in supplying the infant with vitamin A. If the breast milk does not contain sufficient amount of vitamin A, the infant will be deficient with other analogous reverberations (Black et al., 2008). Thus material intake of supplemented foods is of high necessity. The efficacy of biofortification in rural settings is often determined by the level of vitamin A in breast milk. With reference to reports from FAOSTAT (2018), over 105 million metric tonnes of orange sweet potato was produced and this was introduced to African countries and south Asia. The orange sweet potatoes are known to contain 30–100 mg/kg of beta carotene, relative to the traditional varieties which contains 2 mg/kg (De Moura et al., 2015). The requisite daily intake for children is 150 g, while adults especially women needs 300 g (Hotz et al., 2012a, b), biofortified staple foods have assisted in supplying these daily essentials to the rural populace. Reports by Jalal et al. (1998) indicted that serum levels of retinol increased with the consumption of orange sweet potato on a daily basis for 3–10 weeks, while liver vitamin A in children was further elevated (van Jaarsveld et al., 2005). Among Bangladeshi women, significant level of beta carotene was recorded in women consuming the orange fleshed sweet potato against what was recorded in their counterparts feeding on the white sweet potato (Jamil et al., 2012). Serum retinol was observed to increase significantly in children fed with orange sweet potato three times a week, tissue wasting and low weight relative to age was equally low significantly (Low et al., 2007). Comparably, incidence of diarrhoea was cut down at 39% in children fed with orange flesh sweet potato (Jones & de Brauw, 2015). In like manner, McNiven et al. (2016) reported that children had increased level of plasma retinol after the intake of orange sweet potato for 2 years. Cassava bio fortification intervention programmes also came up with positive outcomes. Although the traditional cassava contains no pro-vitamin A. Biofortified yellow cassava varieties were introduced into the democratic republic of Congo and Nigeria in 2011 (Harvest Plus, 2014). Intake of yellow cassava by children in Kenya also elevated serum beta carotene significantly to 88% (Talsma et al., 2015). In experiments conducted with older women fed with bio fortified cassava porridge, an increase in plasma beta carotene was also recorded (La Frano et al., 2014). In Zambia, vitamin A content in the liver was increased to 73% with the consumption of yellow maize over a 90-day period (Gannon et al., 2014). Zinc inadequacy has been up graded by zinc fortified rice (Arsenault et al., 2010; Qin et al., 2012). Correspondingly, zinc fortified wheat is available in Bolivia, Pakistan, China and India. Pearl millet which is a staple crop in Africa and India has also being fortified with iron and zinc. Outcome of investigation on the consumption of zinc and iron fortified pearl millet in infants revealed that there was increase in total body iron and serum ferritin. In the Philippines, significant increase in serum ferritin and body iron was recorded in women fed with iron fortified rice (Haas et al., 2005). Bean fortified with iron is known to increase haemoglobin, serum ferritin and total body iron. In parallel, there was evidence of cognitive response improvement with parameters such as memory search, memory retrieval and spatial selective attention (Murray-Kolb et al., 2017). All staple crops fortified with micronutrients are generally known to supply relevant amount of nutrients needed, research has supported that crops fortified with iron increased the iron levels in the experimental subjects and populations (Finkelstein et al., 2015). In view of all the above, fortified faba beans will go a long way in addressing the nutritional requirement of the populace while improving the quality of faba bean.

11.7 Improvement in the Quality of Faba Beans

The quality improvement of faba beans to meet human demand had been the major target of research and this had led the researcher to focus on different methods to achieve this purpose. Plant selection/breeding according to Robinson et al. (2019), had been the major reason for improvement in the olden days but now it is limited to disease resistant plant, colour, taste, traits of yield etc. Improvement of faba beans are done through biofortification process leading to improved nutritional quality of the crop. Faba bean had been reported to have antinutritional factors which bind with the minerals and make them unavailable to consumers. Such antinutrients according to Turco et al. (2016) and Robinson et al. (2019), include phytate, tannin, alkaloid, saponin etc. which bind with the minerals and protein in the beans and make them unavailable to the consumer thereby impairing their health status. Gutierrez et al. (2008) established the existence of zero-tannin cultivars made from zt-1 and zt-2 (two recessive mutations). Ivarsson and Neil (2018) differentiated the zero-tannin crop based on the colour of the flower produced and this determines the yield performance and susceptibility to diseases. Abdellatif et al. (2012) studied drought stress tolerance of faba bean using morphological traits and seed storage protein pattern. Variety 'Giza 3' showed higher susceptibility to drought stress while the variety 'Giza 843' was more tolerant to drought stress. Seven accessions of heat tolerant varieties with high rate of pollen viability under 35 °C, high pod number and seed number per plant were identified. These accessions were INRA1631, IG11743, IG11843, VF626, VF351, VF522 and VF420 (Maalouf et al., 2018a, b). Two higher plant nitrogen faba bean accessions, 45/018/F8/7307/06A and Sakha1 were developed and compared to other genotypes (Maalouf et al., 2016). Faba beans with partial resistance to chocolate spot were also released. These were Obsie (ILB 4427 XCS20DK), 'Moti' (ILB 4432 X Kuse-2-27-33), 'Walki' (ILB 4615 X Bulga 70) and 'Gebelcho' (ILB 4726 X 'Tesfa') (Maalouf et al., 2018a, b). The improved heat resistant faba bean varieties (Hudeiba-93 and Basabeer) were developed in collaboration with International Center for Agricultural Research in the Dry Areas (ICARDA) in 1993 and 2000 and Eddamer in 2012 in Sudan. According to Maalouf et al. (2018a, b) faba bean lines with resistance to *Orobanche*, disease resistance and heat tolerance were released with joint effort of ICARDA breeding programme and NARS partners, and faba beans varieties such as Najah, Chourok, Hashbenge (ILB4358), Giza843 and Misr3 were released in Tunisia, Ethiopia and Egypt respectively. Adhikari (2021) reported the release of improved faba bean variety (FBA Ayla) which has superior seed quality, disease resistance and high yielding in Australia. Improvement was also achieved in the yield of faba beans by Youseif et al. (2017) using Rhizobium/Agrobacterium strains in green house and significant increase was reported. Other improved genotypes available are the salinity tolerance and frost tolerance type which are able to withstand salinity and frost respectively. Faba bean genotypes containing tannin and low tannin contents were analysed and discovered that Ca, Mn, Mg, Cd and protein contents were higher in low tannin genotypes than the tannin genotypes (Khazaei &

Vandenberg, 2020). Faba bean cultivars namely Nubaria 2, Sakha 1, Sakha 3, and Sakha 4 were subjected to foliar application of fulvic acid (FA), the vegetative characters and yields were greatly improved. According to Abdel-Baky et al. (2019), treatment with 9 gL−1 FA improved the nutritional qualities of faba bean significantly. Numerous faba bean genotypes had been developed and studied by Khan et al. (2015) and Gasim et al. (2015), the nutritional profiles of selective varieties were comparable to other legumes in protein, mineral contents etc.

11.8 Nutritional and Antinutritional Composition of Faba Beans

Faba bean is a valuable multipurpose crop which is grown for its nutritional and medicinal value. As reported by Etemadi et al. (2019), its seeds, pods and leaves are rich in protein and almost all elements required in the human diet. Aside protein, faba bean is also rich in, complex carbohydrates, dietary fibre, choline, lecithin, minerals and phenolic compounds (Mohseni & Golshani, 2013; Etemadi et al., 2018). The protein and starch content in faba beans were recorded to range from 275–374 gkg^{-1} and 411–475 gkg^{-1} respectively (Hood-Niefer et al., 2012). Yang et al. (2018) and Gu et al. (2020) reported protein contents ranging from 20–41% in faba beans. Faba bean protein is composed of globulin, albumin, glutelins and prolamins (Rahate et al., 2020). Likewise, the protein contains essential and non essential amino acids are dependent on the variety of the faba beans (Nosworthy et al., 2018). USDA (2021) reported higher percentage of carbohydrate in faba beans with high starch contents. Faba bean is a good source of both soluble and insoluble dietary fiber (Singh et al., 2014). The major bioactive compounds in the beans are flavonoid, phenolic compounds, terpenoids and lignans (Dhull et al., 2021). It has also been reported by Adamu et al. (2015) that faba bean is low in fat, sodium and free of cholesterol. Moreover, the leaves are good sources of copper in the human diet (Etemadi et al., 2019). As a medicinal plant, faba bean contains large amount of L-Dopa (Etemadi et al., 2018), a precursor of dopamine used as an important ingredient in the treatment of parkinson's disease and hormonal imbalance (Surwase et al., 2012; Hu et al., 2015; Paul and Gupta 2021). Faba bean ranks after velvet bean in terms of L-Dopa content (Soares et al., 2014). In addition to the common antinutritional components of legumes, faba bean contains vicine and convicine which with glucose-6-phosphate dehydrogenase (G-6-PD) deficiency can lead to acute haemolysis, a disease known as favism (Arese & Flora, 1990; Labba et al., 2021). Active derivatives of Vicine and Convicine contained in the seed: divicine and isouramil are toxic to human carriers of a widespread genetic defect (G-6-PD). The levels of antinutrients however vary according to the specific faba bean cultivar, stage of maturation, climate of cultivation, soil properties etc. (Kumar et al., 2015).

11.9 Conclusion

Faba bean is an important pulse and vegetable crop. Both dry and fresh seeds are recommended for their benefits to human nutrition as a dietary source of fiber and protein. However, from an agronomical point of view, adding faba bean to crop rotation systems improves soil, since atmospheric N_2 is fixed above 200 kg N ha^{-1}, and increases soil organic matter. Its inclusion in rotation systems therefore contributes to significant improvements in the sustainability of agricultural systems. Production of this legume species is vulnerable to biotic and abiotic stresses, such as ascochyta blight, broomrape infestation, water logging, and drought. These constraints require the urgent development of new varieties that are resilient to stresses. The new varieties should combine many characteristics, with the main aim of achieving aatmospheric $N_{2,}$ high yield and high protein content. Production of improved faba bean varieties would provide beans with different features and for different purposes. This will confer special characteristic in the crop and improve the nutrition of the consumers. Improved faba bean will solve the problem of micronutrient malnutrition in the developing countries. Also, the improved varieties would combat the production constraints which reduced the productivity of the crop.

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Chapter 12
Faba Bean Utilization: Past, Present and Future

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12.1 Introduction

Faba bean (*Vicia faba* L.) is a worldwide important legume crop that goes by a variety of names, including broad beans, horse beans, and field beans. It is one among humanity's first crops, along with wheat and barley in the fertile crescent (van der Zee, 2013). Unlike other legumes such as soybean and pea, faba beans may be grown in a wide range of climates, even those with a short growing season (Labba et al., 2021). Though some types of the beans may be used as animal feed (Wadhawan et al., 2021), they have long been a staple food largely grown for human consumption in the Mediterranean region, India, Pakistan, and China, owing to its capacity to thrive in a variety of climate zones (Revilla, 2015; FAO, 2017). Faba beans are grown for their high protein content (20–41%) and carbohydrate content. They're also a rich source of minerals, vitamins, and a variety of bioactive substances. Antinutritional substances such as phytic acid, lectins, trypsin inhibitors, saponins, condensed tannins, and favism-inducing compounds, on the other hand, are known to reduce their nutritional value. Equally significant is the role of faba beans in ensuring the long-term viability of agricultural systems, as it is highly efficient in symbiotic nitrogen fixation (Karkanis et al., 2018). Faba beans are also emerging as

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a sustainable source of high-quality plant protein, with the ability to help meet the world's growing need for more healthy and nutritional diets. In addition to its high protein content and well-balanced amino acid profile, faba beans contains health-promoting bioactive compounds such as phenolic compounds, GABA, and L-DOPA, all of which have health-promoting effects (Martineau-Côté et al., 2022).

With a decline in global acreage from 3.7 to 2.1 million ha between 1980 and 2014 (FAO, 2017), faba beans global production has increased significantly in recent years due to growing interest in plant-based nutrition by consumer groups, food industries, scientists, and organizations regarding nutritional and health aspects of sustainable diets (Karkanis et al., 2018; Sharan et al., 2020). Although faba bean has a long history of usage as food for humans, it is mostly employed as an animal feedstock in most advanced countries since animal products are the primary source of protein in the diet, making faba beans an underutilized human food crop (Labba et al., 2021). As a result of greater awareness of the health benefits and environmental sustainability of plant-based diets, there is currently a paradigm shift in consumer preference and diet (IndustryARC, 2019). Furthermore, the economic, environmental, and health implications of producing and consuming animal products have sparked growing research and public interest in sustainable diets through discovering alternatives to animal-based diets. The mode of use of faba beans is also affected by this trend as research and practice activities stimulate a dietary shift from resource-demanding animal proteins to sustainable diets that are higher in plant-based proteins. On the other hand, as a pulses crop, faba beans can offer solutions for the gluten-free industry as vegetable-based ingredients (for example, flour, starch, fiber, and protein) that can provide sustainable, nutritional, economic, and health benefits (Ibeabuchi et al., 2017; Shevkani et al., 2019; Khazaei et al., 2019; Vatansever et al., 2020). Although faba-based goods are few and unpopular, it is generally known that processing and purifying pulses into isolates and constituent components adds value to the raw product (Tsolakis et al., 2019). Considering this, the goal of this chapter is to provide an overview of faba bean utilization, with a focus on its historical, present, and future applications.

12.2 Potentials of Faba Beans

Changes in dietary choices, as well as a growing population, have had a substantial impact on worldwide protein consumption, raising concerns about food security and sustainability (Fasolin et al., 2019). Interestingly, consumption of dairy products and meat (animal-based diet) is expected to rise by 158% and 173% respectively (Tsolakis et al., 2019). To ensure food security, improvement in productivity through expansion of agricultural practices is necessary to guarantee increased food production which will inevitably result to climate change and over-exploitation of natural resources (FAO, 2017). As a result, the largely untapped potential of plant-based protein sources presents an opportunity to meet these nutritional needs while also promoting the shift to more sustainable food production systems (Hoehnel et al., 2019).

12.2.1 Faba-Bean in World Food Security

In recent years, several factors such as climate change, the COVID-19 pandemic, and related containment measures and lockdowns, have pushed the world away from the Sustainable Development Goal (SDG) of eradicating hunger and food insecurity in all forms (FAO, IFAD, UNICEF, WFP, & WHO, 2021). Pulses like faba bean are critical to our global fight for food security, especially in this era of climate change, because the world is in a very different place than it was six years ago when it committed to the SDG. In a world where 663 million people were undernourished in 2017 and 697 million were severely food insecure in 2018 (Roser & Ritchie, 2019), faba bean can provide exceptional nutritional value because it is one of the cheapest sources of protein, high in minerals (iron, calcium, and zinc), and low in fat (Sohl, 2016).

Given that global water demand is expected to increase by more than 40% by 2030, less water-intensive food solutions will be essential. Faba beans are one of the most environmentally friendly crops ever grown, requiring extremely little water compared to cereals (wheat, barley, etc.) and up to twenty times less water than meat-producing animals, as well as having the potential to fix atmospheric nitrogen (Sohl, 2016). As a result, adequate funding is required to prioritize research into increasing faba bean production as a sustainable crop. For example, the International Center for Agricultural Research in the Dry Areas (ICARDA, 2016) demonstrated the development of a new disease-resistant faba bean cultivar, as well as development of high-yielding cultivars with high protein, low fat and antinutritional content, and resistance to biotic and abiotic stresses (Karkanis et al., 2018). Achieving this will provide a sustainable supply of faba beans, allowing for greater product diversification since the number of processed, ready-to-eat, and convenience foods containing faba beans is limited (Sohl, 2016). Though faba beans are an underutilized and unpopular legume crop, agricultural challenges associated with climate change and water shortage (drought) in this rising population can be overcome with the correct investment and smart production procedures to attain food and nutrition security.

Furthermore, alternative food protein sources that could serve as potential replacement to animal proteins have seen a surge in demand recently. This dietary transition is being driven by several factors, including sustainability, desire for healthy lifestyle, rising income, and ethical concerns. A shift to a more plant-based diet may be essential in order to combat climate change while ensuring food security for the world's rising population (Poore & Nemecek, 2018; Willett et al., 2019). However, because foods of animal origin such as eggs, milk, and meat are well-balanced in vitamins, minerals, amino acids and, generally high in protein, caution should be exercised when proposing plant-based substitutes to optimal adequate nutritional quality (Jeske et al., 2018; Vanga & Raghavan, 2018; Agbai et al., 2021). As a result, additional plant-based products with protein levels equivalent to dairy and meat, as well as their derivatives, are needed. Though faba beans contain more starch than soybeans, they can provide a good source of high-quality protein and so could be used to make milk substitutes, meat analogs, and related products (Vogelsang-O'Dwyer et al., 2021).

12.2.2 Unlocking Pathway to Sustainable Diet

The predicted trend in population growth and climate change underscore the need for significantly enhanced global food production to meet the growing demand (Martineau-Côté et al., 2022). As a result, agricultural practices and food patterns are changing. According to Chakraborty and Newton (2011), global food production must grow by 50% by 2050 to meet the demand from the expected additional population increase. Approximately 750 million people, or one out of every ten people on the planet, are estimated to be plagued by acute food insecurity and are still hungry today (FAO, 2020). Attaining this goal is difficult, and it is made more difficult by climate change, which is exacerbated by different climate stressors and the COVID-19 pandemic (Shiferaw et al., 2011; Qaim, 2020). According to current estimates, the global population will exceed 10 billion people by 2050, with agriculture accounting for up to 30% of greenhouse gas emissions (Willett et al., 2019). Meat production on the other hand, contributes significantly to these emissions by consuming vast amounts of water and feed and occupying large land areas (Tilman & Clark, 2014). Excessive animal-based protein consumption has also been linked to a variety of non-communicable diseases and metabolic disorders, including obesity (Wang & Beydoun, 2009), type 2 diabetes (Chen et al., 2020), heart disease (Abete et al., 2014), and malignancies (cancer) (Abete et al., 2014). (Sinha et al., 2009; IARC, 2015). There is a need to create new, high-quality, and more sustainable protein sources for the reasons stated above, as well as greater consumer awareness regarding carbon emission reductions to assure a sustainable environment.

Legumes are widely acknowledged as excellent alternatives to animal-based proteins due to a variety of economic, environmental, and medicinal qualities (Erbersdobler et al., 2017). Soy (*Glycine max* L.) and pea (*Pisum sativum* L.) dominate the legume-based protein industry (Technavio, 2017). However, as the demand for these crops grows, it is vital to diversify and introduce new additional pulse crops, such as faba beans. Faba beans have been shown to have higher protein content (20–40%) in addition to rich bioactive constituents when compared to other legume crops and cereals (Gu et al., 2020; Dhull et al., 2021). This has recently generated increased interest in its cultivation and utilization for various purposes. The trigger points for this upsurge in faba bean interest is because of its great potential as a sustainable source of dietary protein with nutritional and functional relevance (Multari et al., 2015; Sharan et al., 2020). For instance, the increasing demand for sports and nutrition products produced from plant protein ingredients is driven by the growing trend of gyms and bodybuilding centers that compel individuals to consume these products to boost immunity as well as strengthen and build muscles (Technavio, 2017). Also, the growing awareness on health-related issues (diabetes, cerebrovascular, obesity, schaemic heart disease, cancer, etc.) associated with the consumption of animal-based protein and dairy products, the increased number of people adopting veganism, and health benefits associated with consumption of plant-based proteins (prevention and management of certain diseases such as diabetes, hypertentsion, etc.) are the major drivers advancing the growth of global plant protein market in years to come (Dinu et al., 2017; McMacken & Shah, 2017; Sharan et al., 2020). The importance of faba beans as a sustainable legume crop is not only limited to its high protein content, nutritional property, functional property, and/or health benefits, but due to its untapped agronomic advantage with the ability to fix atmospheric nitrogen which can help minimize application of nitrogen fertilizers in agrosystem (Herridge et al., 2008; Venkidasamy et al., 2019).

12.3 Utilization of Faba Beans

Despite the unique nutritional content of faba beans, the presence of antinutritional compounds, strong unpleasant flavour profiles, and cooking challenges have generally hampered its widespread usage as a pulse in human diets (Lopez-Martinez et al., 2017; Rahate et al., 2020). However, faba beans are one of the most popular legume crops owed to its versatility. Besides maintaining soil fertility and providing food for humans, it is utilized as a fodder and lowers soil borne diseases when employed in crop rotation agricultural systems (Landry et al., 2016). The mature seeds are high in bioactive substances, proteins, minerals such as phosphorus and calcium, as well as vitamins, and can be eaten fresh or cooked in various forms (FAO, 2019). The seed size and cultivar are also crucial factors that affects the consumption form and market value. According to research, large-seeded cultivars are frequently consumed for food, while small- to medium-sized seeds are primarily utilized for animal feed. Faba beans can be subjected to various treatments and processed into flours, isolates, concentrates, or blended with other food materials to obtain innovative products of higher nutritional value. In this section, the past, current, and future applications of faba beans are addressed below.

12.3.1 Faba Bean Utilization – Past

12.3.1.1 Utilization of Faba Bean for Human Consumption

Faba bean has a long history in human consumption and is traditionally consumed in the Mediterranean and Middle East regions, and some Asian countries (Singh et al., 2013; Pasqualone et al., 2020). Seeds and pods, to some degrees, are consumed as vegetables either fresh, frozen or canned whereas dried beans are often consumed as a low-cost meat alternative due to its high protein content as they are more widely available. Faba beans are often used to make soups, purees and snacks. For example, the popular Egyptian dish 'Ful Medames' is made from stewed Faba beans seasoned with spices. It is often consumed with flat bread and boiled eggs at breakfast. Other traditional Faba bean dishes similar to the 'Ful Medames' are widely consumed in other Mediterranean and Middle East countries, such as 'Shahan ful' in Ethiopia, 'Ful bi'l-kammun' in Tunisia, Bissara in Morocco, Bakla in Turkey, 'Macco' and 'Puré di fave e cicorie' in Italy (Pasqualone et al., 2020). Although Faba bean pods are mainly used in animal feed, fresh Faba bean pods are fried and consumed as a vegetable dish in Greece (Pasqualone et al., 2020). Faba bean is also one of the legumes commonly used in the popular dish Falafel, and germinated Faba bean is boiled to make the Egyptian 'Nabet' soup (Singh et al., 2013).

Apart from the seeds and pods, Faba bean sprouts from the germination of Faba bean are consumed as vegetables in salad or stir-fried dishes. Flour produced from grinding of Faba bean is used to make bread and cookie similar to wheat flour. Some of the traditional Faba bean dishes involved a natural fermentation of faba bean flour such as 'Siljo', a traditional condiment commonly consumed during the fasting period in the central highlands of Ethiopia (Mehari & Ashenafi, 1995). The gemination and fermentation processes employed in making traditional Faba bean dishes may reduce the antinutrients content in Faba bean and improve its nutrient digestibility. Consumption of fermented food products in human diet is associated with many health benefits. Despite its high protein content, only about 10% of the Faba bean produced in industrialized countries is used as food for human consumption and more than 60% of Faba bean is destined for animal feed (Oquendo et al., 2021).

12.3.1.2 Utilization of Faba Bean in Animal Feed

Soybean has traditionally been the main source of protein in animal feeds (Lienhardt et al., 2019) due to its high biological value protein and steady supply. Compared with Faba bean, soybean has a larger environmental footprint and higher cost. Faba bean may provide a sustainable and low-cost alternative source of protein to replace soybean in livestock feed. However, Faba bean has a lower content of essential amino acids methionine and tryptophan compared to soybean (Jezierny et al., 2010). It also contains antinutrients such as tannins, polyphenolic compounds, vicine and convincine, which can affect the feed efficiency and nutrient digestibility. It has been reported that tannin and polyphenolic compounds can form complexes with protein in the feed and reduce the protein digestibility in monogastric animals (Garrido et al., 1991; Jansman et al., 1995). The presence of antinutrients pose some challenges to the utilization of Faba bean in livestock feed industry. These challenges need to be addressed in order for Faba bean to be widely and effectively utilized. Extensive research has been conducted to evaluate the effect of partial or complete replacement of soybean meal with Faba bean in livestock feed on the growth performance, feed conversion efficiency and meat quality in poultry, pig and cattle, as well as the yield and nutritional profile of dairy milk and chicken eggs.

12.3.1.3 Effect of Faba Bean Inclusion in Poultry and Pig Feeds

Rubio & colleagues (Rubio et al., 1990) conducted randomised controlled experiments where the maize-soybean based chicken feed was partially replaced with Faba bean at concentrations ranging from 125 g/kg (12.5%) to 500 g/kg (50%) of dried feed for three to four weeks. The growth and feed conversion ratio (as indicated by food intake to weight gain ratio) of the chickens assigned to the diet containing 12.5% Faba bean were similar to those in the control diet. However, chickens from the higher Faba bean diet groups (25% of the feed or above) had a higher food intake to weigh gain ratio, indicating a lower feed conversion efficiency, compared to chickens that were fed a control diet or a diet containing the lowest level of faba bean (12.5%). In another feeding trial where the control diet was wheat-soybean mix, hens assigned to the diet containing the highest level of Faba bean (40% in the feed) had a similar weight gain compared to hens on the control diet, but a lower weight gain compared to hens that were fed a lower concentrations (8–32%) of Faba bean despite no significant difference in the feed consumption between the control and experimental groups (Fru-Nji et al., 2007). Although the two feeding trials are not directly compatible due to different control and experimental diets and feeding regime, results from both trials suggested that higher levels of Faba bean in the feed have a negative impact on the growth performance of birds compared with feeds containing lower levels of Faba bean or the control diet where soybean is the main source of protein.

In addition to its effect on growth performance observed with high Faba bean diets, changes in the gastro-intestinal structure and function were also evidenced with an increase in the relatively lengths of duodenum, jejunum, ileum and caeca and intestinal transit time (Rubio et al., 1990). In the same study, chickens that were fed high Faba bean diets had microvilli atrophy and decreased caecal concentrations of some short chain fatty acids including acetate, butyrate and propionate, suggesting a reduction in fibre fermentation which may be related to the impaired intestinal function. However, changes in the gastro-intestinal structure and function were less severe when autoclaved Faba bean was used compared to raw Fava bean (Rubio et al., 1990). This suggests that antinutrients present in Faba bean may be responsible for the negative impact of high Fava bean diets on the growth performance as the process of autoclaving is expected to inactivate the heat labile anitnutrients in Faba bean like lectins and protease inhibitor.

In contrast, more recent studies showed that the inclusion of Faba bean at 20–30% (Moschini et al., 2005; Gous, 2011; Biesek et al., 2020) or up to 50% (Moschini et al., 2005) in chicken feed did not significantly affect the growth performance of broiler chickens compared with those on the control soybean diet. Similar findings were also reported in turkeys with the inclusion of Faba bean at 30–35% in their feed (Przywitowski et al., 2016; Drazbo et al., 2018). The inconsistent findings between the earlier trials and the more recent studies may partly be due to the differences in the amount of antinutrients present in the Faba bean in those studies. With the advanced breeding technique, Faba bean cultivars with lower antinutrients content including tannins, vicine and covincine have been produced, but are not widely available.

Similar to the effect on growth performance, meat qualities including protein content and physiochemical properties were compatible between the control and experimental diets where soybean was partially replaced with 25% Faba bean in chicken feed (Biesek et al., 2020) or 30% Faba bean in turkey feed (Przywitowski et al., 2016). In the turkey study (Przywitowski et al., 2016), the sensory profile of turkey meat was also assessed and no difference in the sensory profile between control and experimental groups was reported. The proportion of breast vs. leg meat was no different between turkeys fed a diet containing Faba bean at 20% (Ayed, 2011) or 50% (Moschini et al., 2005) when compared to the control soybean meal.

Egg production was not affect by the inclusion of lower concentrations (up to 16%) of Faba bean in the feed of laying hens, but decreased when the diet containing 24% or higher Faba bean (Fru-Nji et al., 2007). A similar trend was observed for egg mass. A 19% reduction in egg mass was reported when the feed containing 40% Faba bean (Fru-Nji et al., 2007). Small differences in egg yolk colour, yolk and albumin fractions were observed in hens fed Faba bean containing diets. The authors speculated that antinutrients in faba bean may partly responsible for the negative effect of faba bean feed on egg production and egg mass (Fru-Nji et al., 2007).

Similar feeding trials were conducted in pigs. A negative linear relationship between Faba bean content in the diet and daily weight gain of pigs was reported in an early feeding trial (Castell, 1976) despite a relatively lower levels of Faba bean content in the experimental diets (up to 15%). In contrast, daily weight gain was compatible between pigs in the control soybean diet and experimental diets with Faba bean concentrations ranging from 18% (Gatta et al., 2013) to 20 – 30% (Tusnio et al., 2021). Meat qualities of pigs, including the nutrient composition, meat colour and tenderness, were compatible between the experimental (containing 18% faba bean) and control diets (soybean meal) (Gatta et al., 2013). The authors suggested that the level of antinutrient in the diet containing 18% Faba bean had no effect on the growth of the pigs. However, low tannin Faba bean is recommended for livestock feed to minimize its impact on nutrient digestibility and growth performance of pigs. This recommendation is supported by the evidence that inclusion of high tannin content (3.3% catechin equivalents) Faba bean in the pig feed reduced the ileal digestibility of dietary protein and increased endogenous protein excretion (Jansman et al., 1995) compared to low tannin Faba bean.

12.3.1.4 Effect of Faba Bean Inclusion in Ruminant Feed

Effect of the inclusion of Faba bean in ruminant feed is expected to be different to those observed in poultry and pig due to their different digestive systems. Faba bean protein is highly digestible in ruminants (Oquendo et al., 2021) and nitrogen is easily degraded in rumen which may lead to a lower value of digestible protein. This was demonstrated in a number of studies showing that the crude protein degradability in feed containing Faba bean (16–17%) was higher compared to soybean meal in sheep (Zagorakis et al., 2015) and dairy cows (Cherif et al., 2018). Different processing methods can affect nitrogen degradability with a finer grinding of legumes in the feed increased its degradability (Crepon et al., 2010) while heat treatment reduced its degradability (Cherif et al., 2018).

Similar to those observed in poultry and pig trials, inclusion of Faba bean at lower concentrations (17–35%) in the feed of dairy cows had minimal (Al-Saiady, 1998) or no adverse impact on the milk yield or milk composition (Tufarelli et al., 2012; Cherif et al., 2018), whereas inclusion of Faba bean at concentrations of 50% (Hansen et al., 2021) or 70% (Johnston et al., 2019) resulted in a decrease in the protein content of the milk. The authors attributed the lower milk protein content to a lower rumen fermentation of Faba bean starch as indicated by a higher faecal concentration of starch, and therefore less energy was available for protein synthesis from rumen microbials (Hansen et al., 2021). It is possible that the lower methionine content in Faba bean protein may also contribute to the lower milk protein content. Despite the recognised impact of the different types of fat in human health, limited studies have examined the effect of the inclusion of Faba bean in the feed on the fatty acid profile of the dairy milk produced. Interestingly, the saturated fatty acid content was higher, unsaturated fatty acid and long-chain fatty acid contents were lower in the milk from dairy sheep fed a diet containing Faba bean compared to either chickpea or soybean based commercial concentrate (Bonanno et al., 2016). The higher saturated fatty acid content in the milk is a less desirable feature for human consumption as saturated fat intake is linked to the risk of cardiovascular disease. More research in this area is recommended to examine the effect of the inclusion of various levels of Faba bean in dairy feed on the fatty acid profile of the milk. Such data will inform feed formulations to optimise both milk production and fatty acid profile which has added benefits for human health.

12.3.1.5 Use of Faba Beans in Aquafeed

Decreasing availability of marine source protein for aquafeed has led the industry to explore plant-based protein sources. The proportion of marine vs. plant-based protein sources in the feed of farmed fish like Atlantic salmon has changed significantly over the few decades, from primarily marine protein with no plant protein to predominantly plant-based protein (De Santis et al. 2016b). Fish species that are carnivorous such as Atlantic salmon, the protein content of legumes generally does not supply adequate protein as a direct replacement for fish meal. Therefore, protein concentrate or isolate from legumes are often used as a partial replacement for fish meal (De Santis et al. 2016a, b). There is consistent evidence that partial replacements of fish meal or soybean protein concentrate with Faba bean protein concentrates at lower levels (7–14% in the feed) have no adverse effect on their growth performance (De Santis et al. 2016a, b). Interestingly, inclusion of Faba bean in the feed of salmon resulted in inflammation in the distal intestine was observed in the diets containing Faba bean, particularly at high levels (>14%) of Faba bean (De Santis et al. 2016a, b). However, this did not affect the growth performance or survival rate of the fish. The significance of this observation is unclear. It would be interested to examine whether the inflammation is localized in the intestine or systematic, and if it affects the meat quality and the potential impact of consuming the fish on human health.

In summary, despite the drawback of antinutrients present in Faba bean, partial replacement of soybean meal with Faba bean at appropriate levels in livestock feeds can achieve growth performance, meat and eggs yield or quality similar to feeds with soybean as the main protein source. The driving force for utilization of Faba bean in livestock feed is due largely to its lower cost and environmental sustainability. Although the appropriate levels of Faba bean to achieve optimal economic benefits in different livestock feeds has not been well defined, the available evidence suggested that the inclusion of Faba bean at lower concentrations (up to 20–30% in the poultry, pig and dairy feeds and up to 15% in fish feed) appears to has minimal or no adverse impact on the growth performance and other economic indicators whereas high levels of Faba bean in the diet has adverse impact on those performance indicators, which would result in a lower economic benefit. Future research to determine the appropriate levels of Faba bean in livestock feeds and a combination of processing methods to reduce or eliminate antinutrient content and improve nutrient digestibility of Faba bean used in livestock feed is warranted to optimise economic return and reduce environmental impact of the increasing global demand on protein sources.

12.3.2 Faba Bean Utilization – Present

For millennia, faba beans have been a key staple food in various parts of the world since it is one of the main and cheapest sources of protein for much of Africa, Latin America, and certain regions of Asia (Ali et al., 2014; Rahate et al., 2020). However, it is consumed less in Western countries and is primarily utilized in animal feed composition in these region (Wadhawan et al., 2022). Due to the presence of antinutritional components in the legume, only around 15% of the globally farmed faba bean is used for human use (Gupta, Gangoliya & Singh, 2013; Rahate et al., 2020). Despite the high nutritional value of faba beans, antinutritional factors such as tannins, lectins, trypsin inhibitors, vicine, and convicine are responsible for favism, as well as decreased protein digestibility, polysaccharide, and mineral bioavailability (Rahate et al., 2020). While promising research progress has been made toward developing a faba bean cultivar or variety with low tannin and vicine/convicine content, these antinutritional elements can be eliminated or reduced to the barest minimum. Dehulling, soaking, extrusion, fermentation, irradiation, boiling, enzyme treatment, germination, and autoclaving are some of the processing treatments that have been found to remove antinutritional factors in legumes while also allowing the development of new products or substrates with improved nutritional profiles and techno-functional attributes (Nwosu et al., 2019; Eke-Ejiofor et al., 2021; Ikegwu et al., 2022).

As far as human consumption is concerned, faba beans are considered beneficial. It has acquired popularity in the food and feed industries due to the high quality of its protein fraction. Currently, it can be consumed as fresh vegetable, green or dried seed, dehulled, or cooked/canned (Dhull et al., 2021). Beyound this, faba beans is utilized to produce different nutrient-rich products. For example, several techniques such as wet and dry fractionation technology have been employed to obtain the protein fraction of faba beans in the form of protein isolates and protein concentrates (Vatansever et al., 2020). With little or no interaction with fiber and oligosaccharide components, these protein ingredients are a valuable ingredient with a wide range of applications in the food and beverage, nutraceutical, pharmaceutical, and personal care/cosmetic industries (Vogelsang-O'Dwyer et al., 2021). To understand the current utilization of faba beans with emphasis on the additional benefits of its fractions or components, we shed some light on the crucial role of faba beans protein fraction in terms of its techno-functional characteristics in food formulation system.

12.3.2.1 Food Product Formulation

Even with the different forms of consuming faba beans (For example, it can be eaten as spicy fermented bean paste, soups, boiled sprouted beans, stewed beans, etc.) (Singh et al., 2013; Rahate et al., 2020), it has not been used extensively by the food industry. Further, few studies have been reported on the use of faba bean flour in the production of pasta and spaghetti, gluten-free products (cake and bread), extruded snacks, protein isolates, and other faba bean products (Abou-Zaid et al., 2011; Smith & Hardacre, 2011; Giménez et al., 2013; Rahate et al., 2020; Dhull et al., 2021).

In bread, pasta and spaghetti formulation, improved nutritional value, good techno-functional characteristics and acceptable sensory properties are the prerequisites for fortifying cereals with faba bean flour. A protein-enriched bread obtained by the inclusion of faba bean flour (rich in bioactive compounds) into wheat flour was reported by Wang et al. (2018). The incorporation of fermented faba bean flour into a cereal-based substrate was found to enhance nutritional indices, biological value, protein chemical score, improve the *in vitro* protein digestibility (IVPD) and reduces the glycemic index (GI) (Verni et al., 2019). Compared to a conventional bread, fermented faba bean-fortified bread has about five times increased amino acid content (Inoue et al., 2003; Coda et al., 2017).

However, in the case of pasta, Tazrart et al. (2016) reported higher dry matter loss, a significant increase in protein content, fiber, mineral (zinc, iron, and calcium) contents, resistant starch, IVPD, and lower cooking time, when semolina was substituted with 10–15% faba bean flour. Interestingly, the observed improvement in nutritional indices increased proportionately with the faba bean flour substitution level. In addition, an enhanced protein and dietary fiber content as well as satisfactory quality attributes were reported by Giménez et al. (2013) in a spaghetti-type pasta produced from a combination of corn and faba bean flour in a percentage blend ratio of 70:30 via an extrusion-cooking method. Also, in the production of a gluten-free pasta by Rosa-Sibakov et al. (2016), the textural characteristics of faba bean flour pasta compared favourably with that of control pasta but the texture of fermented faba bean flour was adversely affected by fermentation as observed by higher chewiness and hardness.

An extruded snack product from faba beans produced with the aid of a small twin-screw extruder was reported to have more than four times the fiber content and three times the protein content of the commercially available extruded corn product (Smith & Hardacre, 2011). Faba bean protein isolates (~ 94% protein content) produced by Singhal et al. (2016) using alkaline extraction followed by isoelectric precipitation were found to compare favourably with those of commercially available isolates from pea, soybean, etc. Also, faba-bean protein-rich flour (a combination of flour and isolate) has been reportedly produced by Vogelsang-O'Dwyer et al. (2021) using acid extraction followed by isoelectric precipitation.

12.3.2.2 Beverage Formulation

The functional beverage market includes but not limited to fortified juices, sports drinks, energy drinks, dairy and dairy alternative drinks is estimated to increase at a Compound Annual Growth Rate (CAGR) of 8.66% (Linchpin, 2022). The COVID-19 pandemic and increasing health awareness among consumers fuels a shift from carbonated drinks and fruit juices to functional beverages that can boost the immune system while providing other nutritional needs (Avis, 2021; Ofoedu et al., 2021). In an attempt to increase the industrial application and commercial value of legume, Samaei et al. (2020) fortified apple fruit juice with faba beans hydrolysates. From this study, the faba bean hydrolysate served as an innovative functional ingredient in the preparation of a functional beverage that is rich in antioxidants and amino acids. However, a tofu product has been prepared from faba beans using different experimental regimen to optimize the protein content, sensory properties, and tofu yield (Zee et al., 1987; Dhull et al., 2021). In the brewing industry, faba beans have been shown to be a potential raw material in producing a novel legume-based beverage (Black et al., 2019). In this study, faba beans was used as a novel brewing adjunct in beer production by combining malted barley with dehulled faba bean kernel flour in a percentage blend ratio of 70:30 respectively. Results showed that the dehulled faba bean kernel flour adjunct beer has no significant difference in the taste score of a blind acceptance test when compared with conventional beer. In addition, researchers have investigated production of imitation milk, cheese, and yoghurt from faba beans (Ferawati, 2021). This shows that as the range of functional products or applications demanded by consumers increases, people are exploring innovative ingredients that meets the functional needs of the consumers.

12.3.3 Current Constraints to Faba Bean Utilisation

As research continuously unveil the potentials of pulses (Campos-Vega et al., 2010; Chandra-Hioe et al., 2016; Singh et al., 2013), the World yet struggles to maximise their remarkable benefits. However, there are some limiting features that characterise this group of crops, posing serious drawbacks to producers, processors, and consumers alike (Akintayo et al., 2021a, b; Crepon et al., 2010; Monti et al., 1994). This section presents the major constraints to the utilisation of faba beans, with an attempt to group them as (a) biotic and abiotic factors, and (b) compositional factors. The compositional factors are then further discussed under the headings of toxicity and antinutritional tendencies, technical difficulties, and sensory impairment.

12.3.3.1 Biotic and Abiotic Aactors

Biotic and abiotic stresses were described as natural constraints, which do not just distabilise and reduce the yields of pulse crops, but also hamper their genetic potentials (Maalouf et al., 2021; Monti et al., 1994). While variation exists from one agroclimatic condition to the other, typically characterising biotic stresses in pulses are diseases, insect pests and weeds (Monti et al., 1994). Precisely, chocolate spot, rust, Ascochyta blight, and powdery mildew have been noted as the major biotic challenges facing faba bean production (Maalouf et al., 2021). Ascochyta blight in faba bean is caused by *Ascochyta faba,* a necrotrophic pathogen that kills cells prior to mycelial development (Davidson & Kimber, 2007). Loss in faba bean yield linked to this disease can amount to 90% in vulnerable cultivars (Hanounik, 1980). Causing chocolate spot *is Botrytis fabae* Sard., and typically manifesting as foliage damage, impaired photosynthetic activities, and hindered faba beans production globally. According to Sahile et al. (2008), losses due to chocolate spot can be as high as 60–80% in Maghreb region, which include Libya, Tunisia, Algeria, and Morocco. On the other hand, North Africa and Ethiopia may experience moderate to high losses, as a result of rust caused by *Uromyces fabae* (Shifa et al., 2011; Tivoli et al., 2006) while powdery mildew, a disease associated with *Erysiphe pisi* (Maalouf et al., 2021), was reported to affect all faba bean growing regions in Sudan (Hussein, 1982).

Weeds may also constitute a major drawback in the production of faba bean. Being a slow growing crop in the early stages, faba bean is vulnerable to weed competition that can reduce legume yield by 25–40% (Maalouf et al., 2021). Parasitic weeds such as *Orobanche and Phelipanche spp* may cause notably reduced cultivation area and productivity (Abang et al., 2007; Gressel et al., 2004; Maalouf et al., 2011). For example, farmers were noted to have abandoned their faba bean production, particularly in Northern Ethiopia, where *Orobanche crenate* had expanded to (Abebe et al., 2013). Again, there is the concern with annual weed, which poses some major issue for legume production in North Africa and West Asia (Maalouf et al., 2021).

As for abiotic stresses, factors relating to soil-water content, climatic temperatures, and soil fertility constitute serious problems for many faba bean production areas in the world. For instance, instability in yield may be associated with variation in the degree and distribution of rainfall (Siddique et al., 2001). Similarly, regions such as Ethiopian lowlands, southern Egypt, and Sudan, may encounter a huge threat to production as a result of extreme heat (Maalouf et al., 2021). Bishop et al. (2016) added that heat stress could immensely harm faba bean development during the reproductive stage. Again, frost tolerance damage may destabilise faba bean yield in North Egypt and North America (Landry et al., 2015, 2016), just as regions dominated with vertisols in high Ethiopian lands may witness setbacks caused by waterlogging and acid soils (Keneni et al., 2010).

12.3.3.2 Compositional Factors

12.3.3.2.1 Toxicity and Antinutritional Tendencies

Limitations to faba bean utilisation can be largely attributed to its antinutritional factors and toxicity potentials (Crepon et al., 2010). Apparently, this compositional drawback is common with many other pulses and continues to feature prominently in discussions aimed at advancing their utilisation (Akintayo et al., 2021b). Explaining the antinutritional and toxic potentials of faba bean, Crepon et al. (2010) noted how tannin, vicine and convinvine could be problematic to the nutrition of monogastric animals. Again, the authors analysed the toxicity posed by divicine and isouramils (the derivatives of vicine and convinvine) to human health.

Though there are contrary reports on the effect of faba bean on pig nutrition (Grosjean et al., 2001; Jansman et al., 1995; Vilarino et al., 2004), Crepon et al. (2010) concluded that energy and protein values, reduced in pig fed with tannin-containing faba bean. As suggested, contrasting data might be due to interaction of other components, different amino acid compositions, and different tanning powers, but further researches may need to confirm this hypothesis. Similarly, apparent metabolisable energy, as well as egg size were reported to be lower in poultries fed with faba bean (Crepon et al., 2010; Olaboro et al., 1981). While erythrocyte haemolysis may explain the reduction in egg size (Muduuli et al., 1981), some earlier trials suggest the role of pelletising as a remedy to the impaired energy and protein efficiency (Carré et al., 1987; Lacassagne et al., 1988). In a bid to enhance the suitability of faba bean in animal nutrition, development of varieties with low levels of tannin, convincine, and vicine deserves breeding encouragement. Other antinutritional factors such as trypsin inhibitors, saponins, alpha-galactosidase, alkaloids and phytates may be encountered in faba beans, but these do not pose a major challenge since simple domestic operations like cooking and soaking may eliminate them by up to 100% (Multari et al., 2015). Likewise, Singh et al. (2013) noted that the concentrations of lectins in faba bean can be troublesome but common home thermal food preparation methods are adequate to destroy them. It is important to state that the prevalence of oligosaccharides such as stachyose, raffinose and raffinose in faba beans may also constitute digestive discomfort due to their fermentation in the gut.

As far as individuals who are deficient in glucose-6-phosphate dehydrogenase (G6PD) are concerned, faba bean consumption may pose a risk of haemolytic crisis (Arese et al., 2005; Multari et al., 2015). This acute condition, otherwise known as favism, could result from the damage suffered by red blood cells within 24–36 h of faba bean consumption, and small children and old people may be more vulnerable (Crepon et al., 2010). Though vicine and convincine are non-toxic, as a consequence of the broken glucosidic bond between glucose and hydroxyl groups during their hydrolysis, divicine and isauramil are generated. It is pertinent to add that this hydrolytic reaction is catalysed by beta-glucosidase, an enzyme that demonstrates a maximal activity in ripe faba bean seeds. Cooking, drying and concentrated acid could deactivate the enzyme, however children and elderly people, who are deficient in G6PD may be at a higher risk, since their gastric juice exhibits low level of acidity. Detailed explanations are available about the influence of divicine and isauramil on favism in G6PD-deficient individuals (Crepon et al., 2010; Multari et al., 2015).

12.3.3.2.2 Technical Difficulties

Some technical difficulties during faba bean processing have been linked to compositional factors. For example, hard-to-cook phenomenon, which is attributable to phenol-protein interaction, development of insoluble pectate, and lignification during storage, remains a common limitation to the utilisation of many valuable pulses (Akintayo et al., 2021a, b; Nasar-Abbas et al., 2008b). Implication of this is that prolonged cooking will be required if the satisfactory softness, palatability and protein digestibility are to be attained. Dhull et al. (2021) highlighted how this phenomenon has limited the utilisation of faba bean consumption. Further attendant consequences of HTC include loss of valuable nutrients in the course of prolonged cooking (Nasar-Abbas et al., 2008b) and the adverse controversial effects that characaterise the use of cooking aids (Akintayo et al., 2021b). To circumvent this, the utilisation of many pulses including faba bean require additional steps such as pretreatments. Again, the high starch content of faba bean limits its suitability for the formation of emulsion gels, such as yoghurt and tofu. This poses problems of starch gelatinisation and poor protein recovery, therefore prior starch removal or hydrolysis is required (Jiang et al., 2020). The same study had to consider the addition of some external oil in order to compensate for the crop low oil content. This is necessary if the standard oil content of the emulsion gels are to be met.

12.3.3.2.3 Sensory Impairments

As a result of an interplay between their volatile and non-volatile compounds, most pulse-based food products are generally characterised with undesirable flavours. Akintayo et al. (2021b) recently emphasised how this may hinder the acceptance of food products with proven nutritious values. According to Sharan et al. (2021), the compounds responsible for unpleasant flavours may be inherent to the crops or developed during food supply operations such as harvesting, processing and storage. The authors went further to relate the greeny, grassy and beany sensory properties of faba bean to its aldehyde and alcohol contents. Alcohols and aldehydes in the crop constitute over 60% of its volatile compounds (Akkad et al., 2019; Oomah et al., 2014). Other implicated volatile compounds are 3-isopropyl-2-Methoxypyrazine (pea-like and earthy aromas), 2-pentylfuran (green, beany, and earthy notes), and limonene (citrus, green, and fruity odours) (Sharan et al., 2021). Also, the oxidation of certain fatty acids by endogenous lipoxygenase can trigger the development of unfavourable volatile and non-volatile off-flavour compounds, but certain chemical and thermal pretreatments have been recommended as a solution to the problem. Chemical options such as EDTA and sodium bicarbonate may be explored (Akintayo et al., 2021b). Likewise, thermal treatments such as the use of microwave heating, oven heating, steaming, autoclaving and kilning are possible remedies (Jiang et al., 2016).

With respect to non-volatile compounds, sapid molecules, which typically develop during the growing stage of pulses, impact their characteristic bitter and astringent tastes. These compounds include flavonols, isoflavones, saponins, and phenolic acids (Sharan et al., 2021). For example, bitter or metallic tastes, as well as astringency, can result from the actions of saponin (Liener, 1994). Equally, phenolic compounds may trigger astringency when they form insoluble precipitates with salivary proteins (Drewnowski & Gomez-Carneros, 2000), while there is also the possibility of bitter taste development (Troszyńska et al., 2006).

Tannins, which may constitute about 72–82% of the total phenols in the hulls of coloured faba beans have also been highlighted as one of the potential limitations of the sensory quality of faba beans. This is because beans having dark brown testa colour are associated with poor consumer acceptance in the market (Sharan et al., 2021). Furthermore, conditions such as temperature, light, oxygen, and seed moisture content can cause discolouration of faba bean (Nasar-Abbas et al., 2008a, 2009).

12.4 Future Trends

Some future applications of faba bean starch are implied in Chap. 9. Here, the focus is on the prospects of the crop, as well as its proteins and bioactive compounds, as recognised candidates for novel food applications and functionality purposes. In the past, traditional food preparation techniques such as boiling, frying, stewing and pureeing predominated the human use of faba bean in developing countries while developed countries majorly utilised the crop in feeding certain animals (Hawtin & Hebblethpiait, 1983; Singh et al., 2013). Currently, faba bean utilisation as foods is extending beyond developing countries, and in a wider range of food forms as well. This trend may be connected with the increasing awareness of its food and nutrition security potentials on one hand and the array of emerging techniques available to circumvent its inherent limitations on the other. With the evolving novel use of pulse-protein isolates and concentrates in the enrichments of food and the growing awareness of the prospects inherent in the faba bean for the development of more nutritious, healthier and functional foods, the future of the crop appears promising (Dhull et al., 2021). The reasons for this preposition are based on the available evidence discussed below.

12.4.1 Prospects in Cereal-Based Products

Research have investigated the potential of adopting faba bean as wheat replacement in the preparation of traditionally wheat-based products. These include bread, pastas and biscuits (Dhull et al., 2021). As demonstrated by Tazrart et al. (2016), some of the potential benefits of substituting wheat flour with faba bean flour in the production of pasta include less cooking time; improved functionality; and enhanced protein quality and bioavailability. There are other similar data about the prospects of pasta production from 100% faba bean (Rosa-Sibakov et al., 2016) as well as corn-faba bean composite (Giménez et al., 2013) flours. Modification of faba bean flour may however be helpful to address limitations encountered in some cooking characteristics of the resulting pasta products (Dhull et al., 2021; Rosa-Sibakov et al., 2016).

Faba bean flour has shown to be a candidature to reckon with as the global interests for nutritious gluten-free breads continue to increase. This was examined by comparing the suitability of faba bean and soy flours as complements with corn starch in the production of gluten-free bread (Sozer et al., 2019). It turned out that bread samples containing faba bean flour performed better than samples containing soy flour, in terms of volume, porosity, and texture. The same study reveals how fermentation could help unlock more advantage in the aspects of protein digestibility and efficiency without significantly impairing sensory quality. More recently, the suitability of six different faba bean varieties for the production of gluten-free cookies was judged feasible, though flour pretreatments and sensory improvements currently warrant more investigation (Schmelter et al., 2021).

12.4.2 Substitutes for Animal-Based Products

In the wake of increasing health and predicted future unsustainability concerns surrounding animal-based foods, such as meat and dairy products (Akintayo et al., 2021b; Multari et al., 2015), efforts being intensified to actualise the candidacy of pulses, are now extending to faba beans (Jiang et al., 2020; Multari et al., 2015). First of all, faba bean has been demonstrated to deserve consideration in the production of plant-based dairy alternatives. Using alpha-amylase enzymatic starch hydrolysis to address limitations posed by the starch content of the crop, an alternative plant-based yoghurt production was reported successful (Jiang et al., 2020). Though compared to other legumes such as soya beans and Bambara groundnut, there is currently dearth of information on faba bean yoghurt, therefore further researches are recommended. For example, future study may compare the dry milling operations reported by Jiang et al. (2020) for yoghurt production with wet milling process, since the latter appears more popular for legume milk extraction. Again, different starch modification methods, as well as detailed nutritional information of resulting yoghurt, would be necessary in related future reports. By reviewing the nutritional, functional, and medicinal properties of faba bean, demonstrated its potential as a partial replacement of meat in human diet (Multari et al., 2015). The practicability of this may be justified by the successful production of tofu from starch-free faba bean flour (Jiang et al., 2020), as well as its earlier reported better quality when compared to sample from soya bean (Zee et al., 1988). Tofu, typically produced from soya bean, is one of the popular inexpensive nutritious plant-based substitutes for cheese or meat. It has been interestingly described by as a 'meat without bone' (Rekha & Vijayalakshmi, 2013).

12.4.3 Industrial Potentials of Protein Isolates and Concentrates

The functionality of faba bean isolates were reported comparable to those of its commercially available animal and plant based counterparts, such as egg, whey, soya bean and pea protein isolates (Dhull et al., 2021; Singhal et al., 2016). Singhal et al. (2016), who investigated the functional and physicochemical properties of protein isolates from seven genotypes of faba bean, found some remarkable functional properties, valuable for industrial applications. These include good protein solubility with potential relevance in protein drinks and infant foods formulation, and notable oil holding capacity that can be used to enhance binding and fat retention in meat products. It was also revealed that the making of bread, cake batters, meat sausage and salad dressings could significantly benefit from the emulsifying properties of faba bean protein isolates. Again, densification process has been shown to produce faba bean protein concentrates with potential applications in food emulsions and added advantage of reducing the usual wastage typical of common protein extraction methods (Felix et al., 2018). While more information has been reported on the future roles of faba bean protein as a replacer of egg yolk powder in mayonnaise (Ouraji et al., 2020) and beef in beef patties (Sulaiman et al., 2018), do Carmo et al. (2021) recently showed that analogue meat with acceptable firmness and elasticity can be produced using faba bean protein concentrates.

12.4.4 Nutraceutical Potentials

Clinical trials with over 50 young adults have shown that the inclusion of faba bean protein isolate and concentrate to pasta promoted satiety and reduced postprandial glycaemia (Chan et al., 2019). The function, which could be attributed to the protein and fibre quality of the pulse, would be useful in the development of a functional food for the prevention and management of obesity and type-2 diabetes. A related study by Gangola et al. (2021) has again corroborated this acclaimed health benefit of faba bean-fortified pasta. Also, crackers with added faba bean flour also showed similar physiological functions to the consumers (Gangola et al., 2022).

The free levadopa (*L*-dopa) in faba beans has been linked with potential utilisation in the prevention of diseases such as Parkinson's diseases and hypertension (Singh et al., 2013). This bioactive compound is the source of the commercial drug L-DOPA used in the treatment of Parkinson's disease (Multari et al., 2015). The proposed treatment of Parkinson's disease using faba bean is on the ground that *L*-dopa is a precursor of dopamine which helps in improving motor function of patients with Parkinson's diseases. Meanwhile, synthetic *L*-dopa is associated with some adverse consequences which may limit its effectiveness (Liu et al., 2000). Interestingly, consumption of cooked faba bean seedlings or pods was not just observed to improve motorcell-related symptoms of Parkinson's disease, but the results were similar to those of synthetic *L*-dopa (Apaydin et al., 2000). This effect was later presumed to be connected with some other components of faba bean, such as *C*-dopa (Mohseni-Mehran & Golshani, 2013). To allay the fear of favism and ensure adequate *L*-dopamine while using faba bean for its therapeutic role in treating Parkinson's disease, the use of the fresh green pods is encouraged (Multari et al., 2015). The recommendation was based on the fact that (1) the fresh green pods contain a substantially higher amount of *L*-dopa than the dry cotyledon and (2) vicine and convicine are majorly found in the seeds.

Furthermore, an earlier report supposed that the natriuretic effect of *L*-dopa could help in controlling hypertension (Jambunathan et al., 1994). Similarly, the compound may be a natural alternative to synthetic drugs like Viagra used to improve libido (Hulse, 1994). Finally, some reports have implied some link between favism and malaria (Crepon et al., 2010; Singh et al., 2013). This may call for future investigations to unveil any potential therapeutic information that can help proffer novel protective mechanism against malaria. From these available data, it is safe to predict the promising future roles of faba bean in the manufacture of food supplements, nutraceuticals, or functional foods, as the case may be.

12.5 Conclusion

As the growth in global population beget increased meat consumption, rise in purchasing power and inflation, as well as changes in dietary habits, all of which pose a serious challenge to sustainable development, legumes such as faba beans are increasingly being researched as alternatives to animal protein. Faba bean is one of the most versatile pulses, with a high protein content, favourable processing, and agronomic qualities, as well as the ability to help meet the world's growing demand for nutritious, sustainable, renewable, and affordable protein. To turn faba beans into an acceptable nutrient-dense product, numerous processing techniques such as soaking, cooking, dehulling, autoclaving, enzyme treatment, extrusion, sprouting/germination, and fermentation are used to reduce the inherent antinutritional components.

Beyond its traditional uses as animal feed and consumption as fresh bean, stewed bean, soups, fried or cooked, faba beans can be effectively used for reformulating various types of food such as bread, pasta, extruded snacks, imitation meat, and functional beverages, because of its excellent nutritional profile (high amino acid content) and interesting techno-functional properties. Given its bioactive-rich nature, faba bean is also well-known for its health-related benefits in decreasing cholesterol, hypoglycemic, antioxidative, and the prevention of cardiovascular disease. However, more research and development in the genetic and varietal improvement of faba beans is required in order to fully exploit its potential in a sustainable manner while focusing on novel ingredients and products with optimum nutritional value and consumer acceptance.

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Chapter 13
Current and Potential Health Claims of Faba Beans (*Vicia Faba*, L.) and Its Components

Amrita Poonia, Urvashi Vikranta, Nisha Chaudhary, and Priya Dangi

13.1 Introduction

Consumers have come to believe that meals have a direct impact on their health during the previous two decades, and they are increasingly looking for nutritionally upgraded items in practically every supermarket aisle. One or more key mineral elements are deficient in two-thirds of the world's population. Food legumes serve a vital and diverse role in farming systems and poor people's diets all over the world. They are perfect crops for attaining three developmental goals in a specific community at the same time: poverty reduction, improved human health and nutrition, and increased environmental resilience. The fava bean 111111111 (*Vicia faba*, L. *major)* is one of the world's oldest crops, ranking sixth in terms of production behind soybeans, peanuts, beans, peas, and chickpeas (Khazaei & Vandenberg, 2020). The species has a high nutritional value, both in terms of energy and protein, making it excellent for use as food and feed.

Protein intake patterns are shifting as a result of the steady increase in protein consumption. Protein-fortified foods have spread beyond dairy and meat into a number of other dietary categories, indicating a growing trend toward plant-based proteins. Fava beans have a high protein level, appropriate amounts of vital amino

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acids, resistant starch, and dietary fibres. It is also high in micronutrients such vitamins and minerals including iron, zinc, folate, and other B vitamins, as well as phytochemicals. Fava-bean flour has the largest protein content and the lowest carbohydrate content, making it more effective than other pulses in terms of protein contribution to total energy. Pulse flour is gluten-free by nature and might be used to boost the nutritional value of gluten-free foods including pasta, breads, and snacks. It has a fat level of less than 2%, which gives it an advantage over other pulse flours with higher fat content and allows it to be used in product formulations with longer shelf lives and lower rates of rancidity. The higher the total dietary fibre content, the better the bowel function, weight management, and risk of coronary heart disease, type 2 diabetes, and gastrointestinal disorders are reduced (Dhull et al., 2021). Plant and legume proteins have lower bioavailability than animal proteins due to higher levels of poorly digestible protein fractions and a high content of anti-nutritional factors such as enzyme inhibitors, phytates, and tannins. However, processing methods should be considered to improve digestibility and protein bioavailability. Different soaking procedures, germination, cooking, and dry heating can diminish or remove anti-nutritional components (galactosides and phytic acid) in fava beans. As a result, nutritional bioavailability is not reduced. Faba beans are high in phenolic antioxidants as well as a variety of bioactive chemicals. Polyphenols in faba beans can be found in a variety of places throughout the plant (e.g. leaves, roots, and seeds). Numerous studies have found that polyphenols from faba beans have anti-oxidant, anti-inflammatory, and anti-diabetic properties. Diabetics can benefit from the polyphenol-rich faba beans, which can aid to avoid heart disease and lower blood glucose levels.

The United Nations announced 2016 the International Year of the Pulse to encourage a spotlight on pulses as sustainable and nutritionally important crops, touting them as “nutritious seeds for a sustainable future.”

13.2 Consumption Pattern of Faba Beans

The plant is native to roughly 55 nations, as previously claimed. The overall harvested area is 2.56 million hectares, and the total dry grain yield is around 4.56 million tonnes. As of 2019, Asia and Africa were responsible for 881,501 and 763,139 hectares of dry fava bean output, respectively, with yields of 2067.3 kg/ha and 1924.8 kg/ha. Faba bean is the fourth most widely grown cool-season grain legume (pulse) globally after pea (*Pisum sativum* L.), chickpea (*Cicer arietinum* L.), and lentil (*Lens culinaris* Medik.), with annual production of around 4.5 million tonnes from nearly 2.5 Mha as presented in Food and Agriculture Organization Corporate Statistical Database (2019). In terms of fava bean economy, different countries have distinct demand and production. To meet their demands, Morocco and Egypt are estimated to import 9% and 43% of fava bean, respectively. When looking at the production chart, many biotic and abiotic pressures caused a drop from 5.4 million tonnes in 1961–62 to 3.2 million tonnes in 1991–93, followed by a 33% increase in 2008–10 (Gantait & Mukherjee, 2021).

13.3 Faba Beans: As Food and Feed

In areas where possibilities for cultivation of other protein crops are limited, faba bean (*Vicia faba* L.) is a grain legume that provides feasibility to increase local protein self-sufficiency both as feed and food. The majority of faba bean varieties produced have a high tannin content, which limits their utility due to tannins' effect on energy content. Faba bean with high tannin content is effective in pig diets, where it can be added at up to 350 g/kg, despite its anti-nutritional influence. Because of their high protein content, faba bean seeds are ideally suited to poultry diet. When fed to broilers at levels as high as 250 g/kg, faba bean can completely replace soybean meal in their diets. Extreme meals containing about 50% faba beans, on the other hand, have been found to drastically limit zinc and manganese absorption in many animal species. In growing rats, a diet containing just faba beans as a source of protein resulted in a reduction in growth, muscle mass, and liver weight. Tannins and/or vicine and convicine (v-c) have been greatly reduced in faba bean seeds according to recent genetic advancements. The energy value and protein digestibility of faba bean for pigs and poultry are increased by removing the tannins from the seeds. By removing v-c, the energy value of faba bean in broiler chickens is increased, and the possibility of using faba bean in laying hen diets is increased. Because the effect of the two anti-nutritional elements on the nutritional value of broiler chicken is additive, removing both tannins and v-c from faba bean is the most promising progress (Crépon et al., 2010).

13.4 Nutritional Composition

V. faba is unique in that it is both inexpensive and a good source of protein. Protein content was comparable to meat and fish protein levels. As a result, it is commonly referred to as "poor man's meat." The fruit of *V faba* has a high nutritional value and is rich in proteins, carbs, complex vitamins, folic acid, niacin, and vitamin C, dietary fibre, and macro and micro nutrients, according to the analytical data. Globulins (79%), albumins (7%), and glutelins (7%) make up the protein fractions (20–41%). Micronutrients were also present in the fruit, in addition to significant nutrition. Minerals like Ca, P, K, Mg, Na, S, Al, B, Ba, Co, Cr, Cu, Fe, Ga, Li, Mn, Ni, Pb, Sr, and Zn are among them. The region, germination time as well as variety show variations in the nutritional profiling of the legume. Low-tannin white flowered faba beans are rich in Ca, Mg, Fe, and Zn .Our diet often lacks these vital minerals. *V. faba* seeds contain high quantities of physiologically relevant lipids. The overall lipid content of the seed oils has been found to be sumptuous (2.30–3.91%).

Saturated adipose acids such as pamitic acid and stearic acid have been detected, as well unsaturated adipose acids such as myristic, pentadecanoic, arachidic, behenic acids, oleic acid, linoleic acid, and linolenic acid. The high lipid content values could be used to provide a lot of energy calories for humans (Prabhu & Devi Rajeswari, 2018).

13.4.1 Dietary Nutrients in Faba Bean

Proteins, complex carbohydrates, dietary fibre, choline, lecithin, minerals, and secondary metabolites such as phenolic substances abound in the faba bean (Etemadi et al., 2018a). Furthermore, faba bean seeds are low in fat, cholesterol-free, and sodium-free. The faba bean is one of the most significant staple legumes for human consumption around the world. Beans, such as soybeans, garden beans, and faba beans, can be used in a variety of ways, resulting in greater cultivation and supply. In terms of nutritional quality, this is critical to achieving long-term food security. Micronutrient insufficiency is known as the world's "hidden hunger." Micronutrients like Fe and Zn are abundant in legume seeds (Khazaei et al., 2019). All forms of life on the earth require iron and zinc for survival and proper physiological function.

13.4.2 Minerals

Phosphorus content is in the sequence seed > pod wall > leaf among the several edible portions of the faba bean. In terms of nutrient absorption, faba bean cultivars differ. In terms of Phosphorus content, there was a lot of diversity among the faba bean kinds. Unlike Nitrogen and Phosphorus, which were found in higher concentrations in the seed section, the highest Potassium concentration was found in the pod wall, which was 38% higher than seeds and 44% higher than leaves, respectively. When ingested with immature seeds, pods are regarded an essential nutrient source in Mediterranean diets; thus, accumulation of Potassium in pods can be an important dietary supply of Potassium. Calcium (Ca) accumulates mostly in faba bean leaves, unlike Nitrogen (N), Phosphorus (P), and Potassium (K), which have the lowest leaf accumulation. Ca content in the faba bean leaves was more than three times that of the pod wall and eight times that of the seed. Magnesium (Mg) concentrations were highest in the leaf, pod wall, and seed, in the same sequence as Ca. The leaf had a magnesium level that was more than twice that of the seeds. Although calcium is an immobile element and magnesium is a mobile nutrient, their partitioning patterns in plant organs may indicate that mobilisation of Ca and Mg from vegetative plant parts to seeds and pods is modest. The high levels of calcium and magnesium in leaf tissue may be beneficial for human nutrition in locations where leaves are ingested (Peng et al., 2004 & Etemadi et al., 2019).

The concentrations of Fe in several organs of the faba bean were markedly variable, with leaf > pod > seed being the most abundant. Fe concentrations in the plant's leaf component were 8.7-fold and 3.2-fold greater than in the seeds and pod walls, respectively. Some legumes, such as faba bean, have significant levels of Fe binding polyphenols, which prevent Fe absorption. Faba bean seeds, on the other hand, could be regarded an essential dietary supply for persons suffering from Fe insufficiency. In the same way, Zn and Mn accumulation differs between plant parts. The distribution of these two elements in various regions of the faba bean was seed > leaf > pod wall, while the distribution of Cu was seed=leaf > pod. The leaves of the faba bean can be eaten as a rich source of copper in human diets (Etemadi et al., 2019).

13.4.3 Nitrogen or Protein Content

The order of nitrogen accumulation in several components of the faba bean is seed > pod wall > leaf. Because nitrogen is mobilised from the leaf and pod wall to the seeds throughout the seed-filling stage, more nitrogen buildup in seeds is expected than in other regions. However, the amount of nitrogen in distinct cultivars varies greatly.

13.5 Bioactive Compounds

Because of their nutritional makeup and bioactive substances, Leguminosae plays an important role in human health. Bioactive chemicals that play an important role in avoiding the onset of age-related chronic illnesses (Conti et al., 2021). Legumes include bioactive substances that control glucose metabolism and have antioxidant and anti-inflammatory properties. There is a growing awareness of how legumes are an important source of bioactive compounds (such as phenolics, saponins, and peptides) with a wide range of healthy activities, all of which share antioxidant properties, which are necessary to prevent or delay oxidative stress and disease in the elderly. With the world's population ageing, healthy ageing is becoming a public health priority for preserving residents' quality of life while lowering healthcare expenses.

Faba bean contains a variety of bioactive phytochemicals, including phenolic compounds, flavonoids, lignans, and terpenoids. Protocatechuic acid, ferulic acid, vanillic acid, caffeic acid, sinapic acid, salvianolic acid, cis- and trans-p-coumaric acid, hydroxyeucomic acid, eucomic acid, caffeoylquinic acid, anddicaffeoylquinic acid are among the free and esterified phenolic chemicals found in faba beans. The total phenolic content of several kinds of faba bean pod extract ranged from 4.8 to 13 mg gallic acid equivalent (GAE)/g. The presence of phenolic chemicals in faba bean sections varies. The overall phenolic content of the whole faba bean is 2.9 mg

GAE/g, compared to a substantially higher quantity (22.5 mg GAE/g) in the seed coat. Faba beans contain flavonoids, which are bioactive chemicals with anti-inflammatory and anti-diabetic activities. The whole faba bean seeds have just 1.8 mg Trolox equivalent (TE)/g antioxidant activity, however the seed coat has a substantially higher antioxidant activity (22.9 mg TE/g) (Dhull et al., 2021).

Polymeric flavonoids can be found in pea, faba bean, and lentil. Antioxidant, anti-diabetic, anti-carcinogenic, and anti-inflammatory properties are all present in polymeric flavonoids. They also help to improve serum lipoproteins and promote vascular health.

Phytosterols are also recognised to have a number of health-promoting properties. Phytosterols lower cholesterol levels by reducing cholesterol absorption in the intestinal lumen via cholesterol micellar solubility inhibition. Pulses, corn, and certain plant oils are common sources of phytosterols in the diet. Plant sterols may reduce immune cells' inflammatory activity and hence prevent immunological disorders. They have anti-cancer, anti-inflammatory, anti-oxidant, and immunological modulating properties. Many metabolic pathways are influenced by phytosterols. They play a crucial part in pulses'hypocholesterolaemic actions. Hyperlipidemia is linked to the onset of a number of chronic illnesses. Phytosterols play a vital function in lowering the risk of cardiovascular disease in persons who eat pulses as a diet by lowering fat absorption at the gut level (Singh et al., 2016).

13.5.1 L-Dopa: A Neurotransmitter

The faba bean stores a lot of L-Dopa in its many sections. L-Dopa is a precursor of dopamine that is being utilised to treat Parkinson's disease and hormonal imbalances. L-Dopa is an amino acid that can be extracted naturally from a variety of legumes and other crops such as bananas (Musa spp.). L-Dopa is made in the mammalian body and brain from the amino acid L-tyrosine. Earlier research suggested that L-Dopa is an essential precursor for catecholamines, a group of neurotransmitters that includes dopamine, noradrenaline, and adrenaline. Synthetic L-Dopa is commonly used to treat parkinson's disease patients. Synthesized L-Dopa is costly, and it can cause nausea, vomiting, low blood pressure, drowsiness, and restlessness, among other things. To avoid potential negative effects, it is recommended that natural sources of L-Dopa be consumed.

The yearly global demand for L-Dopa is projected to be around 250 tonnes, with a market value of around $101 billion. To circumvent adverse effects and the high cost of synthetic L-Dopa synthesis, it seems fair to cultivate crops rich in natural L-Dopa. In terms of L-Dopa content, faba bean comes in second behind velvet bean (*Mucuna Pruriens* L.). However, the amount of L-Dopa in faba beans is affected by genotypes, ambient conditions, growth stage, and organs. L-Dopa content varies widely among faba bean genotypes, with L-Dopa found in flowers from 197 cultivars, seedlings from 32 cultivars, and seeds from 52 cultivars with the green seed coat. There was a substantial difference in L-Dopa content between six faba bean lines with different bloom colours (Etemadi et al., 2019).

L-Dopa is distributed unevenly throughout the faba bean, and different organs acquire L-Dopa at varying rates. However, many previous studies have focused on the amount of L-Dopa in seeds, with little attention paid to the amount of L-Dopa in other parts of the plant.

In general, the concentration of L-Dopa in various faba bean organs peaks during the early phases of growth. However, because L-Dopa yield is a function of plant biomass and concentration, the largest L-Dopa yield can be obtained at later phases of growth when biomass is at its peak. The availability of nitrogen and phosphorus to faba bean plants may affect L-Dopa production. Deficiencies in N and P had a direct impact on phenylpropanoids accumulation.

Despite the fact that the faba bean is an N-fixing plant, the impact of supplementary N fertilisation on L-Dopa concentration is unknown. The amount of accumulated L-Dopa has no effect on the level of N stress. Because fresh faba beans are not always available in all regions, Parkinson's patients who rely on a fresh natural source of L-Dopa should have conserved a large quantity of plants for use. As a result, plants that are naturally high in L-Dopa can be processed in a variety of ways, including chopped frozen tissues or dried powdered plant components. Processing plant parts, on the other hand, may have a detrimental impact on L-Dopa concentration. Cooking and soaking in alkaline solutions can degrade L-Dopa in legumes. Cooking, but not roasting, degraded L-Dopa in velvet beans. The L-Dopa content of faba bean leaves and seeds is affected by various processing processes. Content can be influenced by different processing method in such manner: Fresh material > frozen > oven-dried > air dried (2 days) > air dried (4 days) > air dried (7 days) > boiled (Etemadi et al., 2018b).

13.5.2 Vicine and Covicine

When the β-glucosidic bond between glucose and the hydroxyl group at C-5 on the pyrimidine ring is hydrolyzed, two glucosidic aminopyrimidine derivatives, V and C, form the redox aglycones divicine (D) (2, 6-diamino-4,5-dihydroxypyrimidine) and isouramil (I) (6-amino-2,4,5-trihydroxypyrimidine). Faba beans are high in ascorbate and have varied levels of L-DOPA glucoside. Young seeds have extremely high quantities of V and C, as well as high levels of ascorbate. G6PD-deficient people do not appear to be harmed by L-DOPA. The beta-glucosidase enzyme found in faba bean seeds can break the beta glucosidic link between V and C. Its activity is low in immature seeds, increases in ripe seeds, and then decreases in older seeds. The faba bean beta-glucosidase converts non-toxic V and C into toxic D and I in G6PD-deficient individuals. Cooking, seed drying, and acid, such as hydrochloric acid, at amounts similar to those found in normal adult gastric juice, inactivate this enzyme. As a result, both dried and cooked beans are safe to eat. Because their stomach juice is less acidic and the beta-glucosidase in the beans is not inactivated, G6PD-deficient little children and the elderly are at risk. D and I are rapidly absorbed and superstoichiometrically oxidise glutathione present in millimolar concentration in the RBC when combined with ascorbic acid. GSH is a critical intracellular reductant that preserves a significant number of thiol groups in reduced form in enzymes and other proteins. When GSH is oxidised, RBC loses numerous vital functions: they become stiff, certain essential membrane proteins clump, and important enzymes become inactive. As a result, RBC are changed into senescent RBC, which are recognized as non-self cells by the immune system's macrophages and are quickly removed. In a healthy RBC, oxidised GSH is rapidly regenerated by a metabolic cycle in which G6PD plays a key role. Large amounts of fresh faba beans are safe to consume by healthy people.

However, because the regeneration of oxidized GSH in G6PD-deficient RBCs is extraordinarily sluggish, D/I become toxic and are thus often regarded as the primary cause of favism. In G6PD-deficient subjects, D and I freed from consumed faba beans cause an essentially irreversible oxidation of GSH and, as a result, a series of alterations that eventually result in macrophages rapidly and massively removing significant numbers of RBC (Crépon et al., 2010).

13.5.3 Phenolic and Flavanoid Componds

The seeds of faba bean contain 115.21 mg gallic acid equivalent per g extract and 47.34 mg quercetin equivalent per g extract total phenolic content and total flavanoid content respectively.

Recovery of these compounds may vary with the use of different extraction solvents. It can be stated that the highest recovery can be obtained using methanol extracts while ethyl acetate can provide lowest recovery of these compounds. The extraction of phenolic compound by using ethyl acetate confirms the presence of catechin or epi-catechin whereas the extraction of phenolic compounds using methanol extracts confirms that the phenolic and flavanoid content present in the pods of faba beans are having high polarity including flavonoid glycosides and more polar aglycones (Mejri et al., 2018).

Some of the phenolic compounds which are identified using HPLC-PDA-ESI-MS/MS in the methanolic extract of the faba bean pods are mentioned here. Through their potential to lower peroxisome proliferator-activated receptors (PPAR-γ) and sterol regulatory element-binding protein (SREBP-1c) expression, kaempferol glycosides have outstanding anti-obesity and anti-diabetic properties (Zang et al., 2015). Salicylic acid, an aglycone, is touted as a powerful anti-diabetic and anti-inflammatory drug. Catechin, epicatechin, and derivatives of flavan-3-ols have been described as effective antioxidants, anti-obese, and anti-diabetic components, and their methods of action have been deciphered. They can control blood glucose levels by inhibiting α-amylase and α-glucosidase, increase β-cell regeneration, improve insulin release and resistance, and protect pancreatic islets from oxidative damage caused by hyperglycemia. The putative mechanisms include the

Table 13.1 Phenolic compounds and associated benefits

Phenolic compounds	Benefits	Reference
Apigenin	Anti-diabetic nutraceuticals with a strong protective effect on pancreatic β-cells in streptozotocininduced diabetes in animal model.	Mejri et al. (2018)
Ellagitannins bis-HHPD-glucose and Procyanidin dimer	Strong radical scavenging and potent antioxidant properties toward lipid peroxidation. Anti-inflammatory, enzyme inhibitory, anti-diabetic, anticancer and immuno-modulating activities.	Vinayagam and Xu (2015)
Flavan-3-ols including catechin, epicatechin	Antioxidant, anti-obese and anti-diabetic components	Kawser Hossain et al. (2016)
Kaempferol, Isorhamnetin, Quercetin	Antioxidant, anti- inflammatory and anti-diabetic	Mejri et al. (2018)
Verminoside	Radical scavenger,	Mejri et al. (2018)

reduction of oxidative stress, improvement of endothelial dysfunction via AChE activity, modulation of the pro-inflammatory cytokines TNF-α, interleukins (IL-1 and IL-6) and interferon gamma (IFN-γ), regulation of dyslipidemia complications, regulation of the expression of genes involved in glycometabolism, lipid metabolism, protein glycation and insulin signalling pathways, and enhancement of immunity. Flavonols and their glycosylated derivatives, such as iso-rhamnetin, quercetin, diosmetin, and kaempferol, are well-known antioxidants, anti-inflammatory, and anti-diabetic compounds. Their anti-diabetic activity is been mediated by insulin secretion activation, inhibition of β-cell apoptosis via caspase-3 activity reduction, improvement of enzymatic and non-enzymatic antioxidant status, inhibition of lipid peroxidation, improvement of renal function, suppression of hepatic lipogenesis and increase of free fatty acid uptake, and reduction of pro-inflammatory cytokines. Bis-HHPD-glucose and procyanidin dimer are ellagitannins that have excellent radical scavenging and antioxidant effects against lipid peroxidation. Anti-inflammatory, enzyme inhibitory, anti-diabetic, anti-cancer, and immunomodulatory properties are also known. The key mechanisms behind the anti-diabetic effect of anthocyans, including pelargonidin and delphinidin glycosides, are stated to be glucose homeostasis, lipid metabolism modulation, and improved viability of β-cells leading to higher insulin release (Mejri et al., 2018). (Table 13.1).

13.6 Health Benefits of Faba Beans

Legumes, like medicinal plants, are high-value nutritional products that provide a wide range of health advantages to humans. Humans eat legumes as their primary source of nutrition.

13.6.1 Diabetes

Diabetes mellitus is a metabolic condition characterised by abnormal glucose, lipid, and protein metabolism caused by a lack of insulin secretion and/or action. Diabetes, cardiovascular issues, cancer, and other diseases are all linked to oxidative stress. Oxidative stress levels were shown to be higher in patients with Type 2 diabetes mellitus (DM). Hyperglycemia increases the production of free radicals, which causes oxidative stress when they react with proteins and DNA, raising plasma insulin and lipid levels as well as cardiovascular disease risk factors. Reduced ROS-induced oxidative stress and inflammation may be a useful treatment strategy for preventing the onset of T2DM and diabetic consequences. Plant-based polyphenols have demonstrated that they can help with T2DM by reversing the metabolic pathways. The expression of genes involved in insulin secretion (e.g. Sirtuin1 (Sirt1) and glucose transporter 2 (Glut2) in b-cells, peroxisome proliferator-activated receptor-gamma (PPARc) in adipocytes, and insulin signalling mechanisms (glucose transporter 4 (Glut4) has been shown to be regulated by dietary polyphenols such as epicatechins, resveratrol, c-oryzanol and catechin. According to study, faba beans offer anti-diabetic, free radical scavenging, hypoglycemic, and antioxidant capabilities, as well as hypoglycemic and antioxidant characteristics. While patients who consume inadequate nutrition eventually develop difficulties, people who consume antioxidant-rich *V. faba* in their diet do not develop complications. Because *V. faba* contains antioxidants, it has free radical scavenging activity, which aids in the rejuvenation of pancreatic -cells and protects against the cytotoxic streptozotocin effect, which is the key to regulating diabetes mellitus. The significance of oxidative stress in diabetes and its association with the antioxidant properties of faba bean as an edible pulse could be a useful strategy for people with diabetes. Seed extract's anti-oxidant and hypoglycemic properties could be owing to a synergistic action of the phytochemical elements in it, or they could function separately. Molecular dynamics simulations reveal that phenolic chemicals interact with digestive enzymes, which could be a first step toward the development of medicines, nutraceuticals, or functional foods. Two anti-nutritional chemicals found in *V. faba*, vicine and divicine, were thought to be the fundamental factor in the anti-diabetic effect. Vicine and divicine crystallised compounds were identified and investigated for anti-diabetic efficacy in animal models. The study reveals a rapid drop in blood glucose and cholesterol levels. Insulin hormone levels, high density lipoproteins, ferritin, haemoglobin, superoxide dismutase, catalase, glutathione peroxidase, and glutathione-S–transferase were all shown to be higher. The beneficial effects of the ethanolic extract of V. faba were very strong. The above evidence supports V. faba's anti-diabetic and hypolipidemic properties. As a result, diabetic people can benefit from *V. faba* consumption (Prabhu & Devi Rajeswari, 2018).

13.6.2 Weight Management

The amount of total dietary fibre (TDF) in pulse flour is substantially greater. TDF levels in pulse flour ranged from 13.8 to 16.6 g/100 g, compared to 10.1 g/100 g in wheat flour. In fava-bean flour, TDF is greater. The Indian Council of Medical Research (ICMR) and the National Institute of Nutrition (NIN) currently recommend consuming 30 g/2000 kcal fibre (RDA,2020) per day to maintain regular bowel function, aid in weight management, and lower the risk of coronary heart disease and type 2 diabetes. In comparison to cereal flour, all pulse flours have a greater TDF concentration due to the presence of more insoluble dietary fibre (IDF). IDF is not readily soluble in water and passes undigested to the large intestine, whereas soluble fibre (SDF) is highly soluble in water and creates viscous solutions. The potential of SDF to produce viscous solutions has been shown to impede gastric emptying, reducing glucose and triglyceride absorption across the gut. Dietary fibre, such as resistant starches and oligosaccharides, that does not form viscous solutions and is passed undigested to the large intestine, increases stool bulk and reduces intestinal transit time. This keeps the bowels in good shape. IDF's significance in weight management is also attributed to its ability to add bulk to the diet, induce satiety, and prevent gastrointestinal issues due to their reduced energy density function (Millar et al., 2019).

13.6.3 Resistance Against Human Cytomegalovirus (HCMV)

Human cytomegalovirus (HCMV) is a common pathogen that causes asymptomatic and long-lasting infections in healthy persons. In the absence of an efficient immune response, such as in immunologically immature and immune-compromised persons, it can cause serious disease. As a result of the surge in organ allografting, immunosuppressive medication, and HIV-infected patients in recent decades, its influence has grown. It is also the most common infectious agent linked to birth abnormalities. Over 200 putative open reading frames (ORFs) are found in the HCMV genome, but their roles in viral replication and pathogenesis are unknown. The 1048 amino acid product of the UL32 (unique long domain 32) gene, which accounts for 20% of the virion tegument mass and closely binds with the capsid, is known as basic phosphoprotein 150 (pp150). During both latent and reactivated viral infection, HCMV pp150 is highly immunogenic and produces a significant humoral immune response in CMV-positive people. UL32 is one of the most common cytotoxic T-cell clones obtained from healthy CMV-positive donors and is an immune-dominant target of the host cellular response against CMV.

Agrobacterium tumefaciens-mediated transformation was used to introduce the pp150 gene of human cytomegalovirus into Vicia faba plants. PCR and dot-blot hybridization were used to identify three of five hygromycin-resistant *V. faba* plants as positive. Immunoblotting and inhibition of immunofluorescent assay (IFA) results revealed that pp150 soluble protein has immune function. ELISA, intracellular labelling, and flow cytometry analysis revealed that 100% of mice inoculated with pp150 transgenic V. faba seeds had HCMV pp150-specific antibody (IgG, IgA) and IFN- γ producing T cells. The transgenic V. faba plants will supply new material for the development of a food-based HCMV vaccine. Using transgenic plants to provide an oral vaccination with minimum processing and no protein purification could be a cost-effective alternative to conventional vaccine production methods. For an oral plant vaccine to be effective, the plant must be edible, easy to cultivate where the vaccine is needed, edible raw, and non-perishable. V. faba plants appear to be crop plants that meet these criteria (Prabhu & Devi Rajeswari, 2018, Yan et al., 2010).

13.6.4 Anticancer Activity

13.6.4.1 Cellular Protection by Faba Bean Extracts

The antioxidant activity of cells is measured using a cellular antioxidant activity assay (CAA). The absorption, distribution, and metabolism of antioxidant chemicals in a living cell determine the ultimate result of this assay. In compared to animal models, the CAA is a cost-effective and quick technique to learn about the antioxidant efficacy within a cell. Regardless of heat treatment, there is no significant difference in the CAA of extracts derived from both genotypes of faba beans (Nura and Rossa), as measured in mmol quercetin equivalent/g dry weight of bean. The roasted Nura beans had a greater absorption of extracts than the raw Nura beans at half maximal effective concentration. The compositional differences between the chemicals identified at 280 nm in extracts from Nura and Rossa were shown by the HPLC chromatogram in which the polymeric chemicals that predominate in extracts from both Nura and Rossa could be the cause of the 'hump' at the less polar region, although phenolic acids and flavonols were higher in the Rossa extract. Within an hour, a range of phenolic compositions were likely to contribute to the various cell absorption rates and peroxyl radical protection efficacy. It's also possible that applying heat to faba beans during roasting caused a partial oxidation of polymeric substances, which would impair absorption and have an impact on antioxidant capacity within a cell. Faba bean CAA EC50 values are slightly lower than lentil (670 μg/ml), yellow pea (780 μg/ml), and green peas (1280 μg/ml), using AGS cell (Siah et al., 2012).

13.6.4.2 Cellular Protection Against H_2O_2

H_2O_2 is a type of reactive oxygen species found in living cells. Extracts from the raw faba bean genotypes Nura and Rossa were administered at doses of 0.1–0.4 mg/ml and demonstrated dose-dependent cellular protection against H_2O_2. At doses greater than .04 mg/ml, however, the protection decreased due to the onset of antiproliferative effects, or maybe due to the pro-oxidative actions of phenolic compounds at high concentrations. The same trend was seen in extracts made from roasted Nura. Extracts from roasted Nura and Rossa were found to have protective properties at doses of 0.2 and 0.6 mg/ml, respectively (Siah et al., 2012).

13.6.4.3 Effects of Faba Bean Extracts on Proliferation and Apoptosis of Cancer Cells

The effect of extracts from the Nura and Rossa faba bean genotypes on the growth of various cancer cell lines, including AGS, HT-29, BL13, Hep G2, and one non-transformed cell line, CCD-18Co. The crude faba bean extracts, administered at concentrations ranging from 02–20 mg/ml, suppressed all of the studied human cancer cell proliferations in a dose-dependent manner, while having no effect on the non-transformed human colon CCD-18Co cells. Raw Nura extracts inhibited the growth of non-transformed colon cells, CCD-18Co, whereas raw Rossa extracts did not. Raw bean extracts from both genotypes effectively inhibited the growth of HT-29 human colon cancer cells. The proliferation of non-transformed CCD-18Co cells was unaffected by extracts from the roasted Nura and Rossa whereas the growth of human colon cancer cells, HT-29, was significantly reduced. The amount of phenolic content and antioxidant capacity appeared to be reduced when heated. Because the IC50 value shows the concentration required to prevent 50% of cell growth, a lower IC50 suggests better antiproliferative potential. On AGS cells, the IC50 values of extracts from raw Nura (.02 mg/ml) and Rossa (1.04 mg/ml) were lower than those of green pea (3.25 mg/ml), chickpea (3.23 mg/ml), and lentil (1.27 mg/ml). In comparison to the raw Rossa, extracts from the raw Nura had particularly high antiproliferative effects on AGS and Hep G2 cells.

Cancer cells avoid apoptosis, a natural cell death process. The preferred method of removing cancer cells from the human body is to induce apoptosis in them, which is a method employed in chemotherapy treatments. Food ingredients that promote cancer cell death may aid in cancer prevention. The exposure of HL-60 (human promyelocytic leukaemia cells) to crude extracts derived from the raw and roasted faba bean genotypes Nura and Rossa caused cell death, according to flow cytometric examination. With higher extract concentrations, the percentage of apoptotic cells rose. Early apoptotic events were found after 3 h of incubation. The amount of apoptotic cells rose over time, with the raw and roasted faba bean extracts inducing the highest proportion of apoptotic cells over 24 h. Furthermore, the number of necrotic cells remained quite low. This finding implies that the applied faba bean extracts induced apoptosis, which suppressed cancer cell multiplication.

The fruit of *V. faba* has been shown to have anticancer properties in colon cancer patients. The lectin found in *V. faba*, in particular, emasculates colon cancer cells with a malignant phenotype by increasing their morphological differentiation into gland-like structures. As a result, the progression of colon cancer is halted. *V. faba* protein hydrolzates have antitumor effect in animal models at modest dosages (10 mg/kg body weight).

Anti-cancer activity was shown to be stronger in the normocholesterolemic diet group than in the normocholesterolemic diet group. The bioactive chemicals in *V. faba* fruit are thought to block the activity of a subgroup of matrix metalloproteinases, which is thought to be a crucial mechanism for the anticancer activity. The metalloproteinases are known to be important in cancer growth and metastization. *V. faba* may be used as a medical supplement in the treatment of colon cancer, according to research.

13.6.4.4 Parkinson's Disease (PD)

The pathology of Parkinson's disease is primarily associated with the progressive loss or impairment of dopaminergic neuron function, which occurs as a result of chronic inflammation, oxidative stress, protein aggregate deposition within neurons, neurotransmitter depletion, abnormal ubiquitination, mitochondrial dysfunction, excitotoxicity of neurons, and disruption or damage of the blood-brain barrier (BBB). Motor symptoms such as tremor, rigidity, and difficulties coordinating physical movements are frequent in Parkinson's disease and are caused by dopamine depletion in the substantia nigra pars compacta, a region of the midbrain. As a result, motor disturbances in Parkinson's disease are treated with exogenous levodopa or L-DOPA (3,4-dihydroxy L-phenylalanine), which only provides symptomatic relief. Lifelong medication is normally recommended by physician to improve the quality of patient's life in order to treat PD, but the uses of synthetic medicines throughout life have been reported with adverse effects on hepatic and cardiac health (Rath et al., 2021).

The patients with PD can potentially have benefits in consumption of V. faba, as it is enriched with L-dopa as faba bean contains a large amount of L-Dopa in its many parts particularly in the pods and young beans (50–100 mg approximately). Marcus Guggenheim recognized L-dopa from V. faba in 1913 for the first time. Synthesis of L-dopa is from the amino acid tyrosine. L-Dopa being a precursor of dopamine is currently being used as a major ingredient in combating Parkinson's disease and hormonal imbalance. L-Dopa, is an amino acid, naturally isolated from various legumes and other crops such as banana. Faba bean is ranked after velvet bean (Mucuna Pruriens L.) in terms of L-Dopa content. The seeds of Mucuna pruriens (MP) is estimated to have 5% L-DOPA whereas Faba beans have 0.5% L-DOPA (0.07% when dried) (Rijntjes, 2019).

Despite the fact that Vicia faba formulations have not been evaluated in animal models of Parkinson's disease, there are various anecdotal accounts on their effects in humans. Three individuals with Parkinson's disease who had "on-and-off" variations were given 250 g of cooked faba beans twice a day. The authors noticed prolonged "on" times with less dyskinesia and significantly reduced time in the "off" period after one week of treatment, while one patient was able to significantly reduce his L-DOPA dosage. Patients who tried dried beans were similarly said to have experienced no therapeutic advantages. Six individuals with Parkinson's disease compared the effects of a fava bean dish (cooked or micro-waved) to the corresponding dose of L-DOPA/carbidopa and found that both the beans and the medications improved their symptoms (Verni et al., 2019).

13.6.4.5 Anti-fungal Activity

The antimicrobial activity of foodstuffs can be combined with their potential antioxidant activity to create a unique medicinal solution. Through liquid chromatography, the 15KDa trypsin inhibitor from V. faba was identified and named Egypt trypsin inhibitor (VFTI-E1), which has potent antifungal action against the fungus valsamali. Some of the chemicals identified from V. faba, such as chymotrypsin inhibitor, Chitinase, Wyerone, and Wyerone epoxide, have been shown to be effective antifungal agents.

Endophytic microbial communities colonise plant tissues and can play an important role in plant growth and health. Legumes‘root nodules are a rich source of powerful endophytes that can help manage soil-borne illnesses. These endophytic bacteria have the ability to boost plant growth through a variety of ways, both direct and indirect. Endophytes from faba bean nodules have the ability to create siderophores and auxin, as well as the expression of genes that code for antibiotic substances such as Pyrrolnitrin (PRN) and Phenazine (PHZ). Under greenhouse conditions, Rahnella aquatilis B16C, Pseudomonas yamanorum B12, and Pseudomonas fluorescens B8P have shown to be effective in suppressing F. solani root rot in three Faba bean cultivars.Thus suggested as biocontrol agent for field application (Prabhu & Devi Rajeswari, 2018).

13.6.4.6 Inhibition of Angiotensin-Converting Enzyme (ACE), A-Glucosidase and Lipase

ACE is an important blood pressure regulator that causes vasoconstriction, which causes blood pressure to rise. Inhibition of ACE activity has the potential to reduce the occurrence of hypertension by preventing ACE from raising blood pressure. Roasted and raw beans have shown inhibition of angiotensin-converting enzyme (ACE) and this mainly due to formation of proanthocyanidin–enzyme complex (Siah et al., 2012).

The enzymes a-glucosidase and lipase, which are responsible for sugar and lipid digestion, respectively, are key enzymes in the digestive tract. Inhibition of a-glucosidase activity may decrease starch digestion and sugar absorption, resulting in a decreased postprandial hyperglycaemic response, but inhibition of lipase activity may decrease fat uptake, resulting in weight maintenance. All of the enzymes mentioned above are inhibited by raw and roasted faba bean extracts. The reason contributing for this inhibition is that, in faba beans presence of condensed tannins (proanthocyanidins) are prone to building protein complexes (Siah et al., 2012). Procyanidinand prodelphinidin-type flavan-3-ol subunits were the main proanthocyanidins of faba beans (Singh et al., 2016).

13.6.5 Anti-inflammatory Activity and Anti Acetyl-Cholinesterase (Anti AChE) Activity

Inhibition of pro-inflammatory mediators (arachidonic acid metabolising enzymes, cyclooxygenase, and lipoxygenase suppression) and the ability of phenolic compounds to scavenge radicals such as flavonoids and condensed tannins, possibly explain the phenomenon of having in-vitro anti-inflammatory action of faba beans. Faba beans can also inhibit the denaturation of protein thus contributing to anti -inflammatory action of the beans.

Faba bean pods can be used to isolate AChE inhibitors that are beneficial in the treatment of Alzheimer's disease, senile dementia, ataxia, and Parkinson's disease. Because faba beans have strong antioxidant, anti-inflammatory, anti-AChE, and moderate antibacterial characteristics, they could be used as a good source of bioactive compounds with functional and health-promoting effects. The anti-diabetic, hepato-protective, reno-protective, and repro-protective activities of the methanol extract of the faba beans (highest yield and strongest bioactivity) could be beneficial for a variety of oxidant- and/or inflammatory-related disorders, and the antioxidant properties associated with the anti-inflammatory activity could be beneficial for a variety of oxidant- and/or inflammatory-related disorders (Mejri et al., 2018). (Table 13.2).

13.7 Anti-nutritional Factors in Faba Beans

The mature seeds of faba beans contain a number of antinutrients. Phytates, vicine, convicine, saponins, lectins, oligosaccharides (raffinose, stachyose), condensed tannins, and trypsin and protease inhibitors are a few examples (Labba et al., 2021). The antinutritional chemicals vicine and convicine found in faba beans are known to cause haemolytic anaemia (called favism). One of the main reasons for the limited use of faba beans is favism. The presence of protease inhibitors, which are known to impair protein digestibility and promote pancreatic hypertrophy, is linked to the digestibility of legume-based proteins. Trypsin inhibitors in faba bean are found to be lower than other legume crops such as soybean, chickpea, and lentil. Because of phytate–mineral–protein complexes, phytic acid found in faba beans has been shown to reduce mineral bioavailability and modify protein absorption (Khazaei et al., 2021). Due to chelating characteristics of phytate, it considered to be responsible for reduction in the bioavailability of divalent cations.

Table 13.2 Health benefits of faba beans

Health benefits	Components responsible for health benefits	References
Anti- cancer activity	Inhibition of metalloproteinases activity due to presence of phenolic compounds	Lima et al. (2016)
Anti -diabetic activity	Vicine and divicine, α-glucosidase inhibition, epicatechins, resveratrol, c-oryzanol and catechin	Husen (2012), Prabhu & Devi Rajeswari (2018)
Anti- diabetic and Hypolipidemic	Insulin hormone levels, high density lipoproteins, ferritin, haemoglobin, superoxide dismutase, catalase, glutathione peroxidase, and glutathione-S–transferase	Prabhu & Devi Rajeswari (2018)
Helps in Alzheimer's disease, senile dementia, ataxia, and Parkinson's disease	Inhibition of AChE	Mejri et al. (2018)
Anti- microbial activity	Flavonols, flavan-3-ols, gallotannins and ellagitannins	Mejri et al. (2018)
Anti-fungal activity	15KDa trypsin inhibitor, Chymotrypsin inhibitor, Chitinase, Wyerone, and Wyerone epoxide	Prabhu & Devi Rajeswari (2018)
Anti- inflammatory activity	Inhibition of protein denaturation	
Bio indicator to determine the iron bioavailability in humans	V. faba treated with phytase	Luo et al. (2012)
Chemo preventive properties and anti-cancer agent	Inhibition of topoisomerases by polyphenolic compounds	Tselepi et al. (2011)
Fights colon cancer	Lectin	Prabhu & Devi Rajeswari (2018)
Hypertension prevention	Inhibition of angiotensin-converting enzyme (ACE) due to formation of proanthocyanidin–enzyme complex	Siah et al. (2012)
Medication for a cough	Cooked faba beans	Khare (2007)
Prevents Parkinson's disease	L- DOPA	Prabhu & Devi Rajeswari (2018)
Resistance against human cytomegalovirus (HCMV)	Phosphorotein (pp-150)	Prabhu & Devi Rajeswari (2018)
Weight management	Total dietary fibre, lipase inhibition	Millar et al. (2019)

13.7.1 Favism

Faba bean consumption has been linked to the development of favism. The Mediterranean region has the highest prevalence of favism illness. The disease's causative agents (vicine, divicine, convicine, alkaloids, and aglycones) are thought to be generated directly from the fava bean or their digestive byproducts. Susceptible individuals have a physiologic deficit of glucose-6-phosphate dehydrogenase (G6PD), which is highly active in red blood cells and plays a vital part in the pentose monophosphate shunt pathway (Fig.13.1). Reduced glutathione is produced by NADPH, which removes free radicals that cause oxidative damage. When reduced glutathione levels are low, oxidants destroy active enzymes and functioning proteins. Individuals without G6PD are at danger of developing haemolytic anaemia as a result of oxidative stress, which is exacerbated by the consumption of faba bean proteins such as vincine, divicine, and convicine. Damage to RBC occurs as a result of this situation, limiting iron transfer.

Hemolytic anaemia with yellow jaundice (haemoglobin converted to bilirubin), weariness, and lack of energy are among the clinical signs, as are disturbed respiration and a weak and fast pulse. Traditional heat treatments (boiling or roasting) used to soften the texture have consistently demonstrated to be sufficient to denature

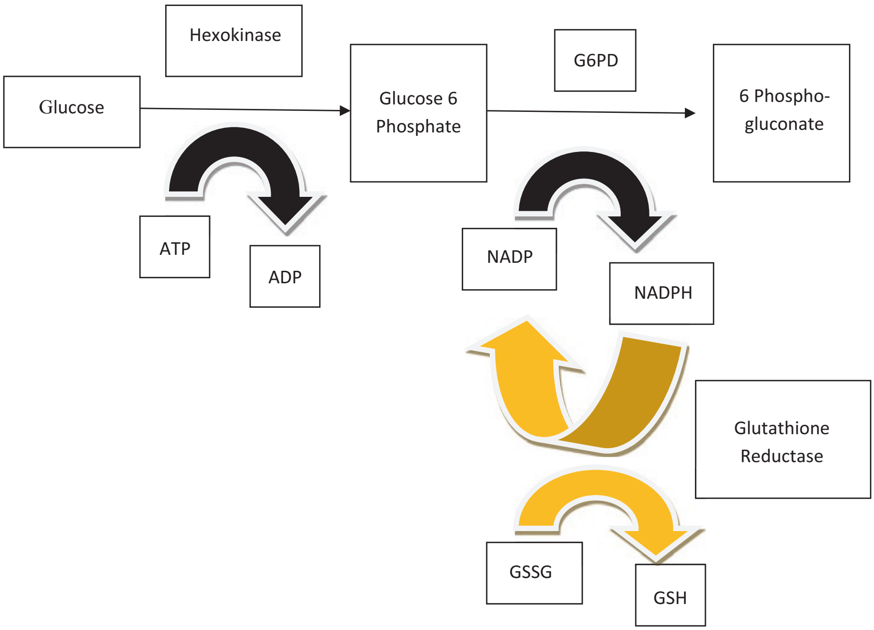

Fig. 13.1 Role of glucose-6-phosphate dehydrogenase (G6DP) enzyme in pentose phosphate pathway. Deficiency of G6PD blocks first step in the Pentose Phosphate Pathway (an important step in the synthesis of ribose 5-phosphate)

proteins and decrease alkaloids, reducing the toxicity of faba beans (Prabhu & Devi Rajeswari, 2018).

Antinutrients in faba beans are removed or minimised using a variety of processing processes. Phytate, a major antinutritional factor, was degraded by using exogenous phytase and discarding the soaking solution after treatment, and its effect on iron bioavailability was significantly reduced (39%) after soaking treatment, but a smaller reduction (10%) in iron content of faba bean was observed after additional treatment with phytase. The effects of phytase treatment and lactic acid bacteria fermentation on phytic acid reduction, as well as protein quality and digestibility of FBF, show that phytic acid is degraded by around 89% following phytase treatment. Because of the decrease in phytic acid, the protein solubility curve shifted to indicate increased solubility at low pH. After enzyme-assisted phytic acid degradation, the digestibility of faba bean proteins and the release of free amino nitrogen can be greatly improved. The effects of gamma irradiation on proximate/mineral composition are negligible; nevertheless, it considerably reduces tannin concentration while increasing in vitro protein digestibility (IVPD). Irradiation has the potential to improve the nutritional quality of faba beans by lowering antinutrients and enhancing protein digestibility in vitro (Dhull et al., 2021).

13.8 Improving Health Benefits of Faba Beans

13.8.1 Germination Enhances Health Benefits

Germination is a widespread and traditional way for increasing the nutritional value and palatability of grain legumes in human nutrition. It has been shown to boost the content and availability of dietary micronutrients, protein, and monosaccharides while lowering ANF levels. Tannins and -galactosides of the raffinose family oligosaccharides are the most prominent ANF in faba beans (RFO). RFO can produce bloating in the colon due to fermentation and increase the risk of diarrhoea due to a shift in the osmotic gradient. Tannins can decrease protein digestibility and dietary energy nutritional value.

Condensed tannins in faba beans were dramatically reduced after 24 and 72 hours of germination. After the second day of germination, RFO (raffinose, stachyose, verbascose, and ajugose), which accounted for up to 50% of sugars in ungerminated faba bean, have been significantly reduced. Increased protein utilisation has been attributable to a decrease in RFO concentration when rats being fed germinated beans.

When compared to soybeans, faba beans have lower levels of methionine and cysteine in their amino acid profile. Proteins are hydrolyzed during germination storage, increasing the proportion of polypeptides, peptides, and free amino acids.

These might be utilised to make new molecules that are made up of amino acids other from those found in the former storage proteins, changing the amino acid pattern in germinated seeds.

Folate, an essential cofactor, as donor as well as acceptor, involved in purines, pyrimidines, and amino acids synthesis, was increased significantly (>40%) in faba bean during germination.

Germination has been extensively studied as a viable processing method for obtaining nutrient-dense faba bean flour (FBF). Germination resulted in a minor drop in starch (15%), a significant reduction in phytates and α-galactosides (45% and 94%, respectively), and a significant increase in dietary fibre. The calcium concentration of germinated versus cooked samples increased by around 6%, which could be connected to the decrease in phytic acid. The reduction in hemicelluloses content, which can interfere with calcium absorption, was also credited with the enhanced bioavailability. The phytic acid acts as a phosphorus reserve, which is freed during germination by phytase action, enhancing phosphorus bioavailability. The levels of phytic acid, polyphenols, and condensed tannins decreased after 24–72 hours of germination, as did the activity of trypsin, chymotrypsin, and -amylase inhibitors (Hefni et al., 2015 & Dhull et al., 2021).

13.8.2 Soaking, Cooking, Enzymatic, and Radiation Treatments

There are a variety of approaches for reducing ANFs. Many factors influence the efficiency of the treatments, including the positioning of the ANFs in the seed. After dehulling, for example, the tannin content, which is primarily found in the hull, is easily reduced. Dehulling also helps to reduce soluble and insoluble fibres, as well as phytic acid levels. Traditional procedures like soaking and cooking have been extensively researched. Because lectins are thermosensitive, they rarely survive food preparation and have little effect on the nutritional quality of the faba bean. Soaking for 12 h at 37 °C was found to be efficient in lowering saponin and phytate levels by 29% and 4%, respectively, although cooking did not entirely remove them (Luo et al., 2009). After preheating, soaking at 10 °C reduced the amount of phytic acid by up to 51%. 43 Although combining several approaches resulted in a greater reduction of ANFs, it is worth noting that intrusive methods might also result in the loss of nutritional elements. RFOs could be removed by soaking in water or a sodium bicarbonate solution, and the removal rate was higher the longer the treatment lasted. Cooking and autoclaving had a significant impact on raffinose reduction as well. Extrusion was found to be the most effective approach for inactivating trypsin, chymotrypsin, and -amylase inhibitors (98.9%, 52.8%, and 100%, respectively), while also enhancing in vitro protein and starch digestibility. Enzymatic therapy was used to combat phytate breakdown. When the amount of phytate in faba bean flour was reduced, the mineral bioavailability of zinc and iron improved dramatically, which was obviously related to phytic acid breakdown. However, the in vitro bioavailability of minerals in the hulls was unaffected by the treatment, implying that tannins and fibre continue to play a role in chelating ions. The hydrolysis of vicine and convicine from the faba bean using fungal -glucosidases from Aspergillus oryzae and Fusarium graminearum established the potential of microrganisms in detoxifying ANFs. The concentration of phytic acid in two varieties of faba beans (BB7–S1 and SH-S2) did not vary appreciably after they were cooked. The radiation treatment had no effect on the content, but it was quite effective on the tannins. Thus increasing in vitro protein digestibility as well as nutritional attributes of faba beans (Osman et al., 2014).

13.8.3 Fermentation

Fermentation is one of the oldest food preservation technologies, capable of improving the sensory and nutritional quality of food while also altering its structural properties and extending its shelf life. Fermentation, as a pre-digestion process, plays an important role in nutrition, thanks to the microbial breakdown of complex nutrients and the release of metabolites. It can happen naturally or by the inoculation of starter cultures owing to autochthonous or contaminating microbiota (moulds, bacteria, and yeasts). Because the microbiota of the raw components, the environment, and the process conditions all play a role in spontaneous fermentation, the quality of the final product cannot be controlled or standardized (Beena Divya et al., 2012). LAB have been widely used as starters among the microorganisms most commonly associated with food processing because they are considered safe and, when chosen based on the right physiological and metabolic features, they allow for the achievement of unique technological, sensory, nutritional, and functional goals. Two faba bean cultivars, V. faba major and minor, were used to make type I sourdoughs using the back-slopping method (typically used for wheat flour), which involves a spontaneous fermentation followed by daily replenishment of the fermented dough with flour and water. *Pediococcus pentosaceus*, *Leuconostoc mesenteroides*, and *Weissella koreensis* were the LABs with the highest frequency of incidence in both cultivars. Some strains of *P. pentosaceus* were later discovered to have high inhibitory effect against two gastrointestinal pathogens, *Escherichia coli* and *Listeria monocytogenes*.

Differences in microbiological and biochemical composition were discovered between the two sourdoughs, owing to the V. faba minor cultivar's increased hull fraction content. The minor variety has a higher content of condensed tannins and dietary fibres due to the presence of hulls. However, once sourdoughs achieved a stable state, fermentation was able to reduce tannin levels by 30%. During growth, stachyose and verbascose levels dropped significantly, whereas raffinose, produced from the hydrolysis of the other raffinose family oligosaccharides (RFOs), accumulated modestly, most likely due to the presence of Pediococcus spp., which are incapable of digesting it. Thus fermentation is known to reduce phytic acid content in some legumes and it can decrease up to 90% of vicine and convicine (Verni et al., 2019).

13.9 Conclusions

People currently suffer a slew of health issues that can be avoided or managed by increasing their intake of nutritional meals high in helpful bioactive elements. Pulses are an important part of many people's diet around the globe. Pulses are the dried seeds of legumes including beans, peas, chickpeas, and lentils that are low in fat. Pulses contains substantial amount of bioactive elements such as polyphenols, phytosterols, resistant starch, oligosaccharides and dietary fibre, which are advantageous in the management and prevention of chronic diseases. Pulses have a low glycemic index with high antioxidants and nutritional fibre. Pulses can help to prevent or cure diabetes, heart disease, obesity and certain types of cancer. The impact of phytosterols, resistant starch and dietary fibres in the hypocholesterolemic action of pulses cannot be overstated. Pulses can help to promote heart health and reduce blood cholesterol when consumed on a regular basis. The faba bean is a versatile crop that can be grown for both nutritional and therapeutic purposes. The seeds, pods, and leaves of the faba bean are high in protein and practically every nutrient needed by humans. Medicinal plants like V.faba have the potential to play an important role because there are a large number of medicinal plant species available worldwide, which could revolutionise therapeutic drug treatments. V. faba is an overlooked food crop that deserves further study. Carbohydrates, proteins, lipids, and other micronutrients are abundant in V. faba's. It also contains anti-nutritional chemicals such vicine and covicine, which have been linked to favism. Various procedures such as dehulling, soaking, cooking, autoclaving, germination, fermentation, extrusion or heat treatment, enzymatic treatment and genetic alterations can be used to reduce these anti-nutritional elements make it more acceptable as a nutrient-rich ingredient in various cuisines. V. faba is biologically rich in antioxidants and has been shown to be effective in the treatment of ailments such as colon cancer and diabetes mellitus. It possesses antifungal properties as well as resistance to human cytomegalovirus (HCMV). As a result, V. faba is regarded as a key crop due to its dietary, medicinal and agronomic properties. Faba beans as a legume, are a good source of lysine-rich protein as well as a variety of vital elements. L-DOPA, a precursor of dopamine is also found in faba beans and it can be employed as a bioactive molecule for Parkinson's disease treatment. Faba beans are widely consumed in many parts of the world, with India having the highest per capita consumption. Following various processing, faba beans have the potential to replace animal-derived proteins in a variety of protein-rich products, which matches well with shifting consumer trends and existing ecological needs. The crude phenolic extracts obtained from raw and roasted faba beans had potential health-beneficial properties, such as potent antioxidant activities (based on both reagent- and cell-based assays), chemopreventative effects (through induction of cancer cell apoptosis), and protection against reactive oxygen species. Furthermore in-vitro studies revealed that these extracts inhibited ACE, a-glucosidase and lipase enzymes. Different types of cancer cells were inhibited in a dose-dependent manner by faba bean extracts. Because of their high protein content, faba bean seeds are ideally suited to poultry diet. Tannins and Vicine and convicine (VC) have been greatly reduced in faba bean seeds according to recent genetic advancements. The energy value and protein digestibility of faba bean for pigs and poultry are increased by removing the tannins from the seeds. By removing VC, the energy value of faba bean in broiler chickens is increased, and the possibility of using faba bean in laying hen diets is increased. Aside from protein and calories, the effects of a faba bean-enriched diet in humans have been shown, with a considerable reduction in plasma LDL-cholesterol levels. One of the causes for the growing desire for healthier, plant-based foods is a growing knowledge of the health concerns connected with animal protein consumption. Because of its established hypocholesterolemic properties, bile acid–binding capacity, and therapeutic impact of L-DOPA, the fababean has a lot of potential as a functional food. Faba beans, however, have been underutilised for decades despite their good impact on human health and the agroecosystem. The existence of ANFs, which interfere with nutrition absorption and can occasionally create pathologic diseases, is the main explanation for this. Nonetheless a wide range of strategies for reducing ANF have been found to be beneficial. Some of the proposed solutions, such as germination and fermentation, resulted in efficient and cost-effective methods for reducing and in some cases completely eliminating ANFs. The use of faba beans in cereal-based food formulae, whether raw or processed, has been explored for many years. It was primarily responsible for enhancing the protein level of the composite product and balancing the amino acid composition when introduced as raw flour. The addition of germinated or fermented faba-bean flour to bread, pasta, and extruded snacks improved the nutritional, functional, and technological attributes of the products.

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Chapter 14
Disease Management of Faba Beans

Vishal Manjunatha, Disha Bhattacharjee, and Clara Flores

14.1 Introduction

Faba bean (*Vicia faba* L.) is one of the most important and oldest food legumes grown by man (Cubero, 1974). Faba bean origin dates to 6250 BC in the prehistoric period, with seeds being found in Jericho (McVicar et al., 2013). Faba bean is now widespread in Europe, North Africa, Central Asia, China, South America, the USA, Canada, and Australia. The crop is mainly grown in East Asia, North Africa, Southern Europe, and the Nile Valley during winter and spring, occupying around 2.44 million hectares with an annual production of 4.4 million tons (FAOSTAT, 2008). The five top producers are China, Ethiopia, Australia, France, and the United Kingdom accounting for more than 75% of world production, with China alone producing 34% of all faba beans as of 2013 (FAOSTAT, 2014). From its origin in the Near East, the crop has spread worldwidend led to various adaptations for different agronomic traits (Cubero, 1974).

Faba beans are a multipurpose crop used as a source of protein in the human diet, as fodder and forage crop for animals. It is an important and -appreciated pulse crop in the Middle East, northern Europe, Mediterranea China, Australia, and North Africa (Duc, 1997). Faba beans are harvested when immature and used for consumption. The dried seeds are cooked, canned or frozen, whereas the mature seeds are roasted and eaten as snacks or used as an ingredient in various food preparations such as falafel, meat extenders or skim-milk replacers (Singh et al., 2013). When faba beans are used for animal feed, seeds with low-tannin, low vicine+convicine

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and low-trypsin inhibitor contents are preferred (Vilariño et al., 2009). Faba beans also find application as an alternative protein source to soybean for livestock in Europe, as good quality silage, as straw and a cash crop in Egypt and Sudan and for manure production (McVicar et al., 2013; Singh et al., 2013; Smith et al., 2013). Further, it plays a key role in the biological nitrogen fixation process and adds up to 40% organic nitrogen into the soil (Singh et al., 2012). However, faba bean acreage declined from 5 million tons in the 1960s to 4 million tons in the 2000s (Singh et al., 2013). The main reasons for this decline and low yields are the various abiotic and biotic stresses. Yield losses in faba beans due to abiotic stresses include factors such as heat, drought, frost, and salinity.

The faba bean is grown widely under a range of climatic conditions from temperate to subtropical, making it a host of many biotic stresses such as insect pests, fungal and bacterial pathogens, viruses, and parasites. Some of the most common fungal, bacterial, viral, and parasitic diseases, their causative agents, and symptoms are summarized in Table 14.1. The fungal diseases mentioned include anthracnose, chocolate spot, *Sclerotinia* stem rot, rust, Ascochyta blight, Pythium root, seed rot and damping off, seedling blight, Alternaria leaf spot and Cercospora leaf spot diseases. The bacterial diseases discussed include brown spot, common blight, and halo blight. Further, viral diseases of the bean yellow mosaic virus and parasitic diseases of stem nematode and broom rape are reviewed.

Although each of these diseases is devastating, when two or more diseases act on the plant simultaneously, their combined effect is more catastrophic and yields a greater loss. Besides yield losses, the disease also affects the quality parameters of faba bean, thereby inducing economic losses for farmers. Some common fungal, bacterial, viral, and parasitic diseases in faba beans are discussed in the current chapter. The symptoms, causative agent, disease life cycle, and disease management strategies are evaluated for each disease.

14.2 Major Fungal Diseases

14.2.1 Anthracnose

Anthracnose of faba bean is a major disease worldwide, causing economic losses approaching 100% under favorable disease development. In Northeastern India, the disease usually appears in the second or third week of June and reaches the maximum damaging stage from the beginning of August to mid-September (Singh et al., 2012). Anthracnose, first described from plant specimens obtained in Germany in 1875, has, since then, been reported in the USA, European countries, Canada, and Latin America, not only in *Vicia faba* but across most bean species and legumes (Mohammed, 2013b; Walker, 1957).

Table 14.1 Diseases in faba beans

Disease type	Name	Causative agent's	Major symptoms
Fungal	Anthracnose	*Colletotrichum lindemuthianum* [(Sacc. & Magnus) Lams.–Scrib]	Senescence of the seeds
	Chocolate spot	*Botrytis fabae* and *Botrytis cinerea*	Small chocolate spots on the leaves, stem, flower, and pod tissues
	Sclerotinia stem rot	*Sclerotinia sclerotium*	Drenched abrasions at the confluence in stem
	Rust	*Uromyces fabae*	Rusty red small powdery lesions densely cover the surface
	Ascochyta blight	*Ascochyta fabae Speg*.	Lesions appear on leaves, stem and pods
	Pythium root and seed rot	*Fusarium solani*, *Rhizoctonia solani*, *Sclerotium rolfsii*, *Fusarium spp.* and *Pythium spp.*	Seeds stall germination, become pulpy, squashy, brown, shrivel up and finally fragment
	Seedling blight	*R. solani*	Seed and root rot, seedling damping-off and canker in the hypocotyl in pre and post emergence start showing on the host
	Alternaria leaf spot	*Alternaria spp.*	Dark brown to blackish spots with irregular rings and serrated margins
	Cercospora leaf spot	*Cercospora spp.*	Dark brown spots with irregular and tenuous rings
Bacterial	Brown spot	*Pseudomonas syringae* pv. *syringae*	Small, brown, water-soaked lesions on the plant's leaves
	Common blight	*Xanthomonas campestris*	Small, angular, light green translucent lesions on the plant's leaves
	Halo blight	*Pseudomonas syringae* pv. *phaseolicola*	Lesions on the plant's leaves begin as small, water-soaked brown spots surrounded by a wide halo of green or yellow tissue
Viral	Yellow mosaic	Bean yellow mosaic virus	Irregularly shaped yellow spots in the background of the leaflets
Parasites	Stem nematode	*Ditylenchus dipsaci*	Swelling and deformation of the stem with lesions which turn reddish-brown to black as the plant matures
	Broomrape	*Orobanche* and *Phelipanche*	Attachment of parasitic plants that are pale yellow to reddish-brown color with swollen and tuberous stem covered flowers

14.2.1.1 Symptoms

The fungus is often present around the seeds, leading to senescence for the majority of the seeds before germination. Seedlings outgrown from contaminated seeds often have dark brown to lightly burnt umber-colored spots on the seed coats and present as recessed lesions with pink masses of spores on the cotyledons and stems (Fig. 14.1). The anthracnose fungus will also infect the stem, manifesting as dark brown eyespots which develop lengthwise along the stems. Humid conditions can cause numerous lesions, which, in turn, cincture and debilitate the stem to the point where it becomes flimsy (Singh et al., 2012).

14.2.1.2 Causative Agent

The causative agent for this disease is *Colletotrichum lindemuthianum* [(Sacc. & Magnus) Lams.–Scrib], which is considered a hemibiotrophic fungus. The causative agent has a concatenated biotrophic- and necrotrophic-infection process to pervade and colonize, involving the transition from asymptomatic intracellular primary hyphae to destructive slender, capilliform, secondary hyphae referred to as the biotrophynecrotrophy switch, which is indispensable for disease development. An extracellular matrix does not surround the secondary hyphae. Chitin is the only component shared by secondary hyphae and other fungal cell types (Perfect et al., 2001). The sexual stage is uncommon in nature.

14.2.1.3 Disease Life Cycle

Colletotrichum lindemuthianum employs a complex life cycle of differentiated stages that let the fungus survive and bestows remarkable resistance to various environmental conditions. When reproduction in *C. lindemuthianum* is undergoing an asexual cycle, the spores are produced and immersed in water soluble mucilage (O'Connell et al., 1996). Being a hemibiotroph, fungal spore follows a biphasic lifestyle, one as a saprophyte and one as a biotroph. Using extracellular lytic enzymes, the fungus grows in any inorganic carbon source in the saprophytic lifestyle. As a biotroph, the fungus is prone to feed off of living plants.

Fig. 14.1 Symptoms of Anthracnose on bean plants. Seedlings from infected seeds have dark brown to black sunken lesions on the (**a**). cotyledons and (**b**). stems. (**c**). Leaves have dark brown lesions along the leaf veins. (Source: McGrath, 2021)

C. lindemuthianum, seemingly, does not form specialized structures such as haustorium, as seen in some other strict biotrophs (Green et al., 1995; O'Connell, 1987). The pathogen avoids or subdues the initiation of the plant defense responses, such as switching the "hypersensibility reaction" on or synthesizing and depositing cell wall callose (Heath & Skalamera, 1997).

14.2.1.4 Disease Management

Prevention is the best way to manage bean anthracnose introduced to production farmland by infected seeds or by machinery during cultivation or harvesting by eradicating the pathogen numbers in the seed production field (McGee, 1995). Seeds produced under wet and humid conditions and seeds produced from previously infected fields are not sowed because often, they harbor the fungus inside their seed coat (Sicard et al., 1997). Infested bean debris should be removed from the soil after harvest to reduce winter survival, so spores can't spread during the wet season (Mohammed, 2013b). Ensuring that the cleaning and the bagging stations in previously anthracnose-infected areas are cleaned and disinfected using a 10% bleach solution, followed by chlorine dioxide and chloroxylenol between shipments and the shipments are isolated (Buruchara et al., 2010).

Cultivation practices such as 2-year crop rotation with non-target plants like cereals and solanaceous crops, are recommended to minimize the chance of spore survival, thus, reducing the development of bean anthracnose mainly by reducing of initial infection that arises from the initial inoculum (Buruchara et al., 2010). Other cultural methods include sowing at the recommended planting dates, as cool conditions favor anthracnose development, and scouting the fields weekly for anthracnose symptoms so that seeds from infected plants are not harvested (Batureine, 2009).

Seed treatment and field spray significantly improved seedling emergence and reduced the incidence of broad bean anthracnose. Benlate, Ziram, Vitavax, Ferbam, and lime sulphur, in the order listed, are effective for foliar sprays. Bavistin, Vitavax, and Agrosan GN are recommended for seed treatment. In field trails, seed treatment with thiram 75 WP, carbendazim 50WP, carbendazim + thiram, mancozeb75WP, triadimenol 15DS, and metsulfovax 20 WP at 2.5 g/kg seed gives good control of seed borne infection, the best-being carbendazim and carbendazim and carbendazim+ thiram (Sindhan & Bose, 1981). Seed treatment followed by 2–3 sprays of mancozeb @ 0.25% at 10–15 days interval after the first appearance of symptoms; effectively manage the disease resulting manifold increase in yield of faba bean crop (Mohammed, 2013a).

14.2.2 Chocolate Spot

Chocolate spot is a commercially cataclysmic disease across the temperate belt that limits broad bean production, especially in South Tigray, Western Canada, Australia, and Egypt (Fleury, 2016; Morsy, 2000; Wubshet & Chala, 2021). It causes an estimated 5–20% loss in annual faba bean production, but losses as high as 50% have been reported in Egypt (Sahar et al., 2011).

14.2.2.1 Symptoms

The symptoms of the disease reflect the name with small chocolate spots on the leaves, stem, flower, and pod tissues. The chocolate-colored lesions start small, expanding under moisture, eventually merging,leading to the browning of the whole leaf (Fig. 14.2). Two stages of the disease have been generally observed. The disease does produce small sclerotia bodies similar to *Sclerotinia sclerotium* (white mold causing *Sclerotinia* stem rot) (Fleury, 2016). These sclerotia bodies can be found inside the stems of badly diseased plants. Additionally, chocolate spot kills flowers and stems. Under favorable conditions, the disease spread quickly causes severe defoliation, flower droop, stem collapse, tissue necrosis, and plant senescence. Pod infection can cause seed staining thereby leading to massive yield losses (Singh et al., 2012).

14.2.2.2 Causative Agents

Chocolate spot of faba bean, caused by *Botrytis fabae* and *Botrytis cinerea*, can be seed-borne. The pathogen sporulates abundantly during the aggressive stage on blackened tissue only. *B. fabae* is often confused with *B. cinerea* on faba bean. *Botrytis* spp. are ascomycete fungi, classified within family: *sclerotiniaceae*, which

Fig. 14.2 Symptoms of chocolate spot disease manifesting as chocolate-colored spots on faba bean leaves. (Source: Fanning, 2020a)

incorporates the other main plant pathogens *B. cinerea* and *S. sclerotiorum* (Lee et al., 2020). *B. cinerea* is a necrotroph that terminates host cells by activating cell senescence and a hypersensitivity response (Veloso & van Kan, 2018) instead of *S. sclerotiorum* which is a hemibiotroph.

14.2.2.3 Disease Life Cycle

Botrytis spp. can overwinter as sclerotia in the soil, crop debris, and seeds. Conidiospores can be disseminated by wind and rain sprinkle within crops over the pasture. Dampness resting upon the plant surface is essential for germination and infection. The optimum setup is at 90% humidity and temperatures between 15 to 22 °C (Singh et al., 2012). Harvest reductions usually result from flower sepsis, causing them to fall without forming pods. Phosphorus or potassium deficiency, waterlogging, leaves damaged by bug contagion or bruising from excessive burdens reduce crop vigor, making plants more vulnerable to the development of chocolate spot.

14.2.2.4 Disease Management

Various control options to lessen commercial faba bean losses due to chocolate spot such as the chemicals (fungicides), biological, use of resistant genotypes, induced resistant and modified cultural practices (Sahar et al., 2011). The recommended administrative options for *B. fabae* are the implementation of chlorothalonil or mancozeb fungicides and late planting in Ethiopia (Sahile et al., 2008). The use of low seeding rates and choosing a recommended plant date to avoid extended periods of clammy conditions (Wilson, 1937), removal of infected plant debris from the field that probably harbor hyphae or sclerotia of *B. fabae* (Hanounik & Hawtin, 1982; Harrison, 1979), rotating the faba bean crop with non-target crops such as cereals to diminish sclerotial proliferation and chances of primary infection (Harrison, 1979), use of clean, blemish-free seeds and wide row spacing can play a key role in reducing disease severity and spread.

14.2.3 Sclerotinia *Stem Rot*

Even though *Sclerotinia* stem rot occurs worldwide and has a very wide host scope, attacking >350 plant species belonging to more than 60 families (most belonging to family Leguminosae), in faba beans the fungus was first isolated in an infected faba bean plant at Larisa, Greece (Lithourgidis, 2004). The damage caused in the faba bean may vary depending upon the weather condition, host susceptibility and nature of the infection.

14.2.3.1 Symptoms

The earliest symptoms on plants can be observed 10–22 h after artificial inoculation with mycelium, according to experiments designed to identify the mode of penetration and time of incubation for the fungus on faba bean plants (Lithourgidis et al., 1991). The drenched abrasions, particularly at confluence, can advance swiftly along and encircling the stem above and underneath the infected nodes, causing the contaminated stem to turn soft and grey-white in color. The bruising strap the stem, ceasing vascular transport, resulting in diseased stems to become bleached and straggling, and plant tissues aloft the lesion wither and expires (Derbyshire & Denton-Giles, 2016; Grau et al., 2004; Willbur et al., 2018). Infected leaves drop and may advance down the canopy, thus, spreading the infection to neighboring plants in the field.

14.2.3.2 Causative Agent

The disease is incited by fungus *Sclerotinia sclerotium*. The hyphae are closely separated, 9–18um broad, inter, and intracellular. The sclerotia are pinkish white when young, becoming darkly pigmented at maturity and varied in magnitude and form, flattened, elongated or roughly spherical, 2–12 mm in diameter. Each sclerotium develops 2–5 columnar stripes on germination (Singh et al., 2012). *Sclerotinia* which is a necrotrophic fungus. When not infecting plants, the fungus spends >90% of its life as sclerotia, its major resting stage. Sclerotia are the hard, melanized survival forms, impregnable to desiccation, and may act as food reserves (Young & Werner, 2012). *Sclerotinia* reproduce carpogenically by producing small apothecia containing sexual spores called ascospores, released and disseminated by the wind.

14.2.3.3 Disease Life Cycle

Sclerotia fabricated within infected stems can be disseminated and may contaminate seed lots, after picking, via equipment or be harvested with the seed. Favorable weather conditions for infection tend to concur with a fully developed crop awning supported by crisp, muggy, shaded conditions in soils, infection by *Sclerotinia sclerotiorum* can intermittently spread across a pasture, and plants attacked are generally infected during flowering, which, in turn, vitalizes the development of apothecia and the liberation of ascospores (Willbur et al., 2018). Haze, condensation, and fog, being sources of moisture, help disease evolution. The vegetative hyphae extend over stem surface and enter through the stomata to initiate invasion. This is followed by the colonization phase, involving the maturation and bifurcation of subcuticular hyphae (Liang & Rollins, 2018). Subcuticular hyphae may be more important in defense suppression in the host and infection initiation, whereas divergent hyphae are more essential in starting cell senescence and cell wall degeneration (Liang & Rollins, 2018).

14.2.3.4 Disease Management

No solitary treatment can completely control *Sclerotinia* stem rot. Integrated management helps reduce the loss of yield. Very limited genetically resistant cultivars are available for faba bean crops against the disease. To reduce ascospore manufacture and release, cultural practices including crop rotation, wider row spacing, lower seeding rates, and reducing plant density help. Controlled canopy management by increasing air flow and decreasing humidity in the canopy help stifle fungal infections. Stubble management such as using irrigation or burning crop residues to minimize viable sclerotia persistence between seasons has demonstrated effectiveness. In addition to cultural control, there are many fungicides such as anilinopyrimidines, methyl benzimidazole carbamates (MBCs), dicarboxamides, and others (Derbyshire & Denton-Giles, 2016; Peltier et al., 2012) are commercially available to arrest crop losses.

14.2.4 Rust

Rust is one of the major diseases of *V. faba* in Northern Africa and the northern parts of the Australian grain belt (northern New South Wales and southern Queensland). Around 20% yield reduction is expected when rust transpires at the time of pod filling (Sillero et al., 2011), even though early rust epidemics can spawn up to 70% loss of the yield (Rashid & Bernier, 1991; Yi, 1986). Losses up to 30% were approximated wherever the disease occurred at the seedling stage.

14.2.4.1 Symptoms

Rust symptoms are first seen on leaves as rusty red small powdery lesion densely covering the surface and later developing on the stems (Fig. 14.3). The aecial stage of the rust produces canary yellow pustules on leaves early in the season, which are soon replaced by Aecia, followed by the more common uredinia, the buff-colored pustules surrounded by a neutral halo, on leaves and stems (Singh et al., 2012). The pustules accommodate large numbers of spores which the wind can disseminate to seed further infections.

14.2.4.2 Causative Agent

The causative agent for rust is *Uromyces fabae*, which displays all five fungal spore forms. Metabasidium, which assembles four haploid basidiospores with different mating types are formed. After the basidiospores are ejected from the metabasidium, they may land on a leaf, germinate, and generate infection structures. Pycnia are produced containing pycniospores and receptive hyphae. Pycniospores, in turn,

Fig. 14.3 Yellow, raised pustules representing Rust infection on leaves. (Source: Fanning, 2020b)

produce aeciospores that germinate and form infectious morphologies from which uredia are formed. Urediospores, produced by uredia, are single-celled with spines on the surface and are fabricated in colossal proportions, eventually dispersed over large distances due to wind (Fig. 14.4) (Gutierrez & Torres, 2021). Teliospores and pycniospores cannot infect plant hosts, whereas basidiospores, aeciospores, and urediospores do (Voegele, 2006).

14.2.4.3 Disease Life Cycle

After rust spores from infected stubble are blown onto new crops by the wind, given the fulfillment of germination requirements (adequate water, optimal temperature, and light exposure), the spores will germinate on almost any surface. The cytoplasm of the outgrowing spore occupies the germ tube as the forming germ tube convolutes across the surface. Upon receiving further signals, differentiation of the appressorium initiates and it concurs with the discernment of various lytic enzymes. Appressorium differentiation produces a septum cutting off the germ tube and further develops a penetration hyphae at the base of the appressorium. A haustorial mother cell, which is formed from a substomatal vesicle originating from the hyphae, differentiates on contact with a mesophyll cell and is segregated from the infection hypha by a septum. After cytoplasm occupies the haustorial mother cell, all former structures become empty. A haustorium forms from the mother cell with a thin nape (Heath & Skalamera, 1997). The emergence of the haustorium breaches the host cell wall and the swelling haustorium infest the host cell plasma membrane, starting the infection.

Fig. 14.4 *Ascochyta fabae* caused blight in *Vicia faba*. (Modified from Source: Bayer, 2021)

14.2.4.4 Disease Management

Cultural implementations in the manner that apt crop rotation with non-target crop, elimination and burning of crop debris, suitable plant spacing, and removal of weeds help reduce the inoculum or avoid the disease and future infections. The use of clean, contaminant-free seed and field sanitation to destroy the crop debris is very important for reducing losses caused by faba bean rust. Control measures need to be taken before the disease becomes established to minimize crop losses. Several fungicides such as mancozeb (0.2%), bayleton (0.05%) and calixin (0.2%) give satisfactory control of faba bean rust. The disease occurs mostly late in the season, so chemical control may be expensive then. However, when rust occurs with chocolate spot or *Ascochyta* in the same field, sprayings of mancozeb or chlorothalonil and copper products are beneficial in controlling the disease (Mansour et al., 1975).

14.2.5 Aschochyta Blight

Ascochyta blight, another major foliar necrotrophic fungal disease, ranks among one of the main constraints of faba bean production. Due widespread nature of the infection especially during mild and wet weather conditions, it leads to yield losses ranging between 30% and 90% (Gutierrez & Torres, 2021). Ascochyta spot diseases of broad beans have been recorded at different times in many places, but the first few records were in 1899 in England, Argentina (Beaumont, 1950) and New Zealand (Hampton, 1980).

14.2.5.1 Symptoms

The infection indications materialize on the aerial parts of the plant: the leaves, stems, and pods, but can also spread to the seed (Gutierrez & Torres, 2021; Lawsawadsiri, 1974). Lesions appear circular, brown in color, pale in the center, as seen in Fig. 14.4. Under favorable conditions, the lesions will enlarge, become irregular, and fuse to cover most of the leaf surface (Singh et al., 2012). Within the lesions, numerous pycnidia can be observed at later stages of the infection, while the leaf tissue starts necrotizing around the lesions.

Stem lesions are less abundant and are sunken deep into the host tissue. The lesions on the stem are more elongated and darker than the leaf lesions, also usually covered in scattered pycnidia. Widespread infection in the stem weakens the stem of the plant, which is easily broken in windier conditions.

Pod lesions are circular/oval, dark brown, and deeply sunken. Well-developed lesions can penetrate the pod and infect developing seeds, making them discolored and shrunken. In its early stage, infection stains the pod yellow and forces the pod to abort before seeds are set. Later stage infections can have mycelium penetration of both the pod and the seed. Infected seeds have a dark brown stained seed coat. Broad bean seed that has greater than 25% seed coat discoloration can contract the emergence of seed by 30 per cent, downgrading the value of the crop (Lawsawadsiri, 1974; Singh et al., 2012).

14.2.5.2 Causative Agent

Ascochyta fabae Speg. is the causative agent of the Aschochyta blight. *A. fabae* is an extremely variable pathogen, it is described to have multiple biotypes with differences in their cultural phenotypes such as mycelial growth rate, sporulation, and size of conidia. On malt agar, *A. fabae* develops as circular colonies with peripheral band of white aerial hyphae of various widths. The mycelium spreads from the center and pycnidia are abundant. The optimum temperature for mycelium growth is around 20–25 °C, with an optimum pH of 6.8. Pycnidiospores, produced from the pycnidia on the stem, pods, and leaves, are oblong and 1–3 septate with an optimum germination temperature between 22–25 °C. *Didymella fabae* is the sexual teleomorph of *A. fabae*.

14.2.5.3 Disease Life Cycle

The pathogen lives as pycnidia on diseased plants and seed debris left in the field. However, badly affected seeds do not germinate although they can serve as a substrate for the growth of the fungus under suitable conditions. Once the spores spread from the seeds into plants, the primary inoculum multiplies on hypocotyl, epicotyl and near the stem base. It then spreads to aerial parts after producing germ tubes. The appressoria that grow from these germ tubes, penetrate, and occupy the lumen of the epidermal cells of faba bean plant, especially the leaves and stem. Hyphae of the pathogen disrupt the host tissue, and lesions begin to form, with mycelium around the edges and pycnidia in the center.

Cool and wet weather are the favorable conditions for the spread of the disease. Seed-borne infection in seeds stored at room temperature declined from 70% in May (after crop harvest) to 4% in October and to 3% in December (the next crop season) (Vishunavat et al., 1985). The spores present on the seed surface lost viability in October. In the field, the spread of the pathogen occurs through conidia disseminated by raindrop splashes in windy weather, by insect, and by contact between leaves and the movement of animals through the field.

14.2.5.4 Disease Management

Methods to control the blight include integrated chemical interventions, field sanitation to destroy crop debris, crop rotation, suitable spacing, and proper seed placement to help avoid the disease. Pathogen is externally and internally seed-borne; therefore, the only satisfactory preventive measure that can be implemented is to use clean seed harvested from healthy crops. Seed treatment, an important control measure in the absence of resistant varieties, can be done with copper sulphate, thiram, benomyl or calixin M (Bernier, 1990). Use of resistant cultivars offers a cheap and effective control measure. Several cultivar lines among the ICARDA germplasm have been found to be resistant to the blight in Syria, Canada, England, and Sweden (Hanounik, 1989).

14.2.6 Pythium Root, Seed Rot and Damping off

This disease affects the seed, seedlings, and roots of faba bean. Losses depend on soil moisture, temperature, and other factors. Black root rot caused by *Pythium* spp. is another paramount disease of broad beans. Up to 45% crop loss may occur under severe infection conditions during favorable conditions due to this disease (Mitiku, 2017).

14.2.6.1 Symptoms

In pre-emergence damping-off, seeds stall germination, become pulpy, squashy, brown, shrivel up, and finally fragment (Fig. 14.5). They may eradicate even before the hypocotyl has ruptured the seed coat, leading to seed rot. When the radicle and plumule emerge out of the seed, they undergo outright rotting. The disease is often not detected since this happens under the soil surface.

Post-emergence damping is often observed due to the toppling over the infected seedling. Post-emergence seedlings are usually attacked at the roots and peduncles at or, sometimes, underneath the soil. The infected area becomes moisture logged, discolored, and collapses soon after (Belete et al., 2013). The infection causes the beginning part of the seedling peduncle to soften and be much attenuated than the uninfected parts, which in turn causes the seedling to collapse. The fungus continues invading the perished seedling, leading to withering and death. The damping-off oomycete may eliminate radicles or generate the formation of contusions on the roots and stem of the older plants (Singh et al., 2012).

14.2.6.2 Causative Agents

Multiple species of *Pythium* spp. cause pre- and post-emergence damping off. Multiple pathogens such as *Fusarium solani*, *Rhizoctonia solani*, *Sclerotium rolfsii*, *Fusarium* spp. and *Pythium* spp. are responsible for causing considerable commercial losses due to root rot (Belete et al., 2013), *Pythium* spp. being the main genesis of the *Pythium* seed and root rot. *Pythium* spp. is ubiquitous, present on most topography, ranging from tropical to Arctic and Antarctic regions. They exist as either saprophytes, parasites or pathogens in soil and water and on infected hosts such as plants, other fungi, insects, algae, marine, terrestrial animals, and human beings (Miao et al., 2020).

Pythium spp. is a weak saprophyte and a poor parasite. It can infect only the juvenile or succulent organ of plant tissues which are devoid of secondary thickening. Mature tissues that have developed secondary thickening become resistant to its attack. At the start of the infection, *Pythium* spp. produces an unpigmented, quickly growing mycelium, which gives rise to sporangia, that will germinate directly to generate more than one germtubes. At the periphery of the hyphae, a vesicle is

Fig. 14.5 Symptoms of root rot on broad beans. (Source: Kikkert et al., 2011)

formed. More than 100 zoospores are produced in this vesicle, released in the water present on the host surface or in soil. In addition to zoospores, the mycelium also produces oogonia and antheridia. The fertilization tube produced by the antheridium enters the oogonium. The nuclei of the antheridium budge via the tube in the direction of the nuclei of the oogonium, fertilizing and forming a zygote. The zygote forms a thick-walled oospore, which are resistant to unfavorable environmental conditions and serves as the survival and resting stage of the fungus (Singh et al., 2012).

14.2.6.3 Disease Life Cycle

Saprophytic mycelium of *Pythium* spp. directly penetrates the seed or seedling tissues of the host plant. Oomycete secreted pectinolytic enzymes dissolve the pectins that bind cells together, leading to tissue maceration. The oomycetes grow between and through the cells. As a result of tissue collapse, the infected seeds and saplings die and alter to a rotten aggregation, primarily comprising oomycetes and specialized polysaccharides (suberin and lignin), which the infecting fungus cannot break-down. The collapsed tissues cannot support the seedling, leading to the death of the host. The infection on a well-developed seedling with thick and reinforced cells may stop the advancement of the oomycete and only small abrasions develop. Invasion of older radicles is generally restricted to the cortex, whereas younger, fleshier roots may be infected with lesions a few centimeters long (Singh et al., 2012).

14.2.6.4 Disease Management

The most effective measure against Pythium rot, root rot, and damping off are the use of chemical and/or biological seed protectants to keep away the pre-emergence phase and to adopt sanitary precautions in the nursery to check the appearance of post-emergence damping off. Seed treatment with fungicides provides good control of pre-emergence damping off. Spraying the seedlings with the fungicides used above helps ward off *Pythium* spp. The common seed protectants are thiram, captan, and some systemic fungicides such as metalaxyl (Singh et al., 2012).

14.2.7 Seedling Blight

Seedling blight occurs throughout the world, and losses in yield are as high as 19% in faba beans (Chang et al., 2014).

14.2.7.1 Symptoms

Symptoms start to occur 3 weeks after planting when the damage to the host occurs and the characteristic symptoms of the disease, namely, seed and root rot, seedling damping-off and canker in the hypocotyl in pre and post-emergence, start showing on the host (Assunção et al., 2011). Lesions also present on the leaf sheath is first ellipsoid or ovoid, greenish-gray. The centre of the spots becomes white with brown or purplish margin depending on the host variety. Outer leaves may fall, plants look yellow and may ultimately wilt. Diseased young plant show red coloration to the pith and girdling of stem may cause death. Minute brown sclerotia may develop on these lesions (Singh et al., 2012).

14.2.7.2 Causative Agent

Mycelial cell of the most important species, *R. solani*, holds multinucleate isolates divided into 14 anastomosis groups, considered to be isolated, non-breeding communities (Tewoldemedhin et al., 2006). The highly environmentally resistant pathogen can survive as hyphae on the infested crop debris, as sclerotia, in the soil, and as thick-walled hyphae that function as chlamydospores. The mycelium, which is achromatic when young but turns amber or beige with age, consists of elongated cells. Mycelia are the foremost form of dissemination and infection. They produce branches that extend around the right angle to the chief hypha, which are somewhat compressed at the junction. The only characteristic available to identify a *Rhizoctonia* spp. infected root rot is the distinguishing branching of the fungus. No asexual spores are produced, but misshapen, pervious, brown to black sclerotia can be formed (Gossen et al., 2016).

14.2.7.3 Disease Life Cycle

The incidence and severity of seedling blight depend on cropping history and environmental conditions. Late seeding into warm soils and deep seeding reduced seedling emergence as hyphae spread is strongly favored at higher temperatures. The pathogen once established in field remains even under adverse environmental conditions. All pathogens that cause seedling blight across all bean hosts follow a familiar disease cycle. The pathogen proliferates in the seedling roots and infects the seedlings nearby via mycelium. New sclerotia are produced at the end of the season, thus continuing the cycle (Fig. 14.6). The fungus can easily spread through contaminated water, soil, or tools (Gossen et al., 2016).

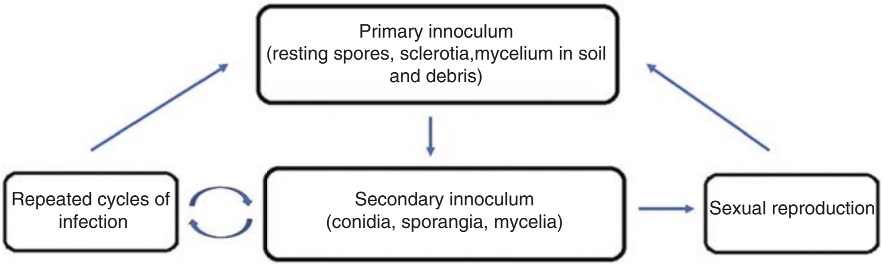

Fig. 14.6 A generalized life cycle for the seedling blight caused by *Rhizoctonia* spp. (Adapted and modified from source: Gossen et al., 2016)

14.2.7.4 Disease Management

Given the resistant nature of Rhizoctonia diseases, the management of seedling blight has always been a challenge. Keeping weed hosts at a minimum and maintaining proper sanitation of the crops near the faba bean field is essential. Disease free seeds planted on well-drained, raised beds to encourage a reduction in disease. Other cultural practices such as wide spacing, good aeration of the soil, steam sterilization of seed beds in a greenhouse etc. can help reduce incidences of a widespread outbreak. Biological controls are still in trial-and-error stages. Periodic treatments with comprehensive fungicides generally improve seedling founding and yield (Gossen et al., 2016; Singh et al., 2012).

14.3 Minor Fungal Diseases

14.3.1 Alternaria Leaf Spot Disease

Alternaria leaf spot disease is a persistent disease of faba beans during the growing season, leading to lower crop yield. Species of *Alternaria* range from saprophytes to endophytes and can infect different groups of plants. In particular, the species *Alternaria alternata* poses a serious risk to horticultural plants worldwide. Climate change, airborne spreading of spores, and an increasingly globalized market of seeds have facilitated the spread of this pathogen (Matić et al., 2020).

14.3.1.1 Symptoms

Symptoms begin as dark brown to blackish spots with irregular rings and serrated margins (Fig. 14.7). In later stages of the disease, these spots coalesce, and large foliage areas become necrotic. Leaves become tattered and significant defoliation of the plant can occur. Lesions can also appear on other plant parts, including stems and pods. Lesions have a target-like appearance due to the formation of concentric brown rings with dark edges.

14.3.1.2 Causative Agent

Alternaria leaf spot, a minor fungal disease, is caused by the fungus *Alternaria*. Species of *Alternaria* overwinter as spores that persist in plant debris or seeds. The conidia are dark, multicellular, long, and easily detached. Conidia may then be disseminated via air currents to infect new plants. *Alternaria* species can live as either saprophytes or endophytes. Depending on their physiological and morphological stage, they produce host-specific and non-host-specific toxins (Meena et al., 2017).

14.3.1.3 Disease Life Cycle

Older leaves on the plant are usually infected first. Once infected, the disease typically progresses upward. Infected leaves can turn yellow and dry and begin to fall off. Further progression of the disease can result in an almost complete defoliation of the plant as lesions coalesce from margin to center. Different isolates of *Alternaria tenuissima* have exhibited varied pathogenicity; however, *Alternaria* is usually a secondary pathogen that invades already wounded or diseased plants (Rahman et al., 2002). Spores can enter through plant wounds and the life cycle of the disease begins again.

14.3.1.4 Disease Management

Management of this disease includes using certified disease-free seeds and appropriate fungicides. Removing and burning infected plant debris and crop rotation also help to reduce the spread of inoculum to subsequent plants. Fungicides

Fig. 14.7 Alternaria leaf spot disease infecting faba bean foliage. (Source: Alternaria leaf spot, 2020)

containing chlorothalonil and carbendazim, used to manage major fungal diseases, are also effective at controlling Alternaria leaf spots. Additionally, adequate fertilization with nitrogen can reduce infection rates.

14.3.2 *Cercospora Leaf Spot Disease*

While a minor fungal disease, Cercospora leaf spot can still yield significant crop damage and is relatively common where faba beans are produced. Yield loss is especially true in wet growing seasons where temperature and humidity conditions are ideal for this pathogen.

14.3.2.1 Symptoms

Cercospora leaf spot disease begins as dark brown spots with irregular and tenuous rings (Fig. 14.8). Conidiophores of *Cercospora* are olive-brown in the plant's fascicles and stroma (Coca-Morante & Mamani-Álvarez, 2012). *Cercospora's* ideal temperature and humidity conditions are between 25 and 35 C and 90–95% humidity. Temperatures under 15 C are not favorable. Lesions begin as light gray to tan, surrounded by a brown or purple border. With the progression of the disease, lesions begin to merge, and leaves can wither and die. Pseudostromata form as tiny black dots in the substomatal cavities within the lesions. These pseudostromata produce conidiophores, and once numerous conidia are produced, lesions will appear fuzzy. The spores can move via wind and rain to infect other plants and can survive in crop debris.

14.3.2.2 Causative Agent

Cercospora leaf spot is caused by the fungus *Cercospora*. Conidiophores of this pathogen are dark brown to black and become paler when traveling away from the base. Additionally, they are unbranched, typically septate, and can be straight or curved. Certain species of *Cercospora* can produce a photoactivated toxin, cercosporin.

14.3.2.3 Disease Life Cycle

Spores dormant in infected plant debris and soil can infect wounded plants. Lesions typically begin to form on the lower leaves of seedlings. The disease will then begin to upward, especially under ideal temperature and humidity conditions. Conidia are released from infected plants, and spores are disseminated by wind and rain (Kimber et al., 2016). These spores can infect new host plants, and the process begins again.

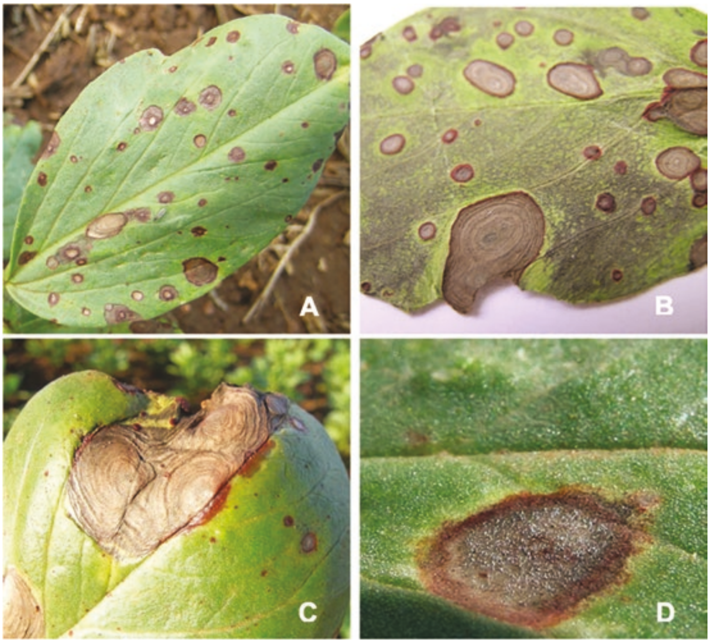

Fig. 14.8 Symptoms of Cercospora leaf spot on faba bean: (**a**), Leaf lesions. (**b**). Partially dried faba bean leaf exhibiting distinct zonate lesions. (**c**), Coalesced lesions. (**d**), Sporulating leaf lesion. (Source: Kimber, 2011)

14.3.2.4 Disease Management

Management of this pathogen includes applying fungicides containing the active ingredients chlorothalonil and myclobutanil. Common fungicides containing these active ingredients are OrthoMax Garden Disease Control and Immunox. Additionally, removal of infected plant debris and crop rotation every 3 years is recommended. The use of pathogen-free seeds will also help to manage dispersal and disease.

14.4 Bacterial Diseases

Three bacterial diseases infect faba beans: bacterial brown spot, common blight, and halo blight. Symptoms of each bacterial disease appear differently in the plant, but disease life cycle and management are similar across all three bacterial diseases.

14.4.1 Brown Spot

Of the bacterial diseases, the bacterial brown spot is the most economically damaging to faba beans and occurs globally where the beans are grown. When the infection becomes severe, most of the plant surface becomes destroyed, leading to low crop yields.

14.4.1.1 Symptoms

Symptoms begin as small, brown, water-soaked lesions on the plant's leaves (Fig. 14.9). As the disease progresses, these spots merge, creating larger lesions on plant foliage. Progression of these lesions leads to necrosis of the leaf and can cause significant defoliation of the plant. A light-yellow border will develop around the areas of necrosis. Necrotic centers can fall, giving leaves a tattered appearance.

14.4.1.2 Causative Agent

The bacterium Pseudomonas syringae pv causes bacterial brown spot. *Syringae*, a Gram-negative, rod-shaped organism with polar flagella. *P. syringae* can survive in the soil for up to 18 months under dry conditions. The pathogen can also survive on weed hosts.

14.4.1.3 Disease Life Cycle

Infecting bacteria can enter the plant through the hydathode and stomata (natural plant openings) or wounds inflicted by several injury factors, including wind tears, insect and animal damage, hail, and cultivation damage. Once inside the plant, *P. syringae* can move throughout via vascular bundles allowing the bacteria to invade stems, leaves, pods, and seeds. Ideal growth conditions for the bacterial brown spot are humid weather and temperatures of 28–32 C. This disease can also affect the plant's seeds leading to seed abortion, meaning the seeds will not mature. The disease can be spread in several ways: infected seeds, from plant to plant, or field to field. Dissemination of the bacteria can occur via high winds, splashing rains, irrigation, animals and insects, or mechanical transmission from field machinery and other human-driven practices.

Fig. 14.9 Small, brown necrotic lesions characteristic of early bacterial brown spot infection. (Source: Harveson, 2009)

14.4.1.4 Disease Management

To manage bacterial brown spot certified pathogen-free seeds should be used. However, obtaining pathogen-free seeds can be especially difficult for some countries and farms that lack the economic means. Agronomic means of abating the spread of this pathogen include removing plants and debris that have been identified as infected and sanitizing the infected area thoroughly. Deep field plowing has also been useful for removing infected debris that lies less superficial to the surface (Singh et al., 2012). Rotating crops every 2–3 years to plants that do not host bacterial brown spots will help reduce spread. Fixed copper compound sprays can also be applied to plants preemptively after the emergence of seedlings or at the first sign of disease. Additionally, the antibiotic streptomycin has been implemented to treat infected plants. However, alternative options are being screened for their effectiveness against bacterial pathogens. One alternative to antibiotics and other foliar sprays is screening seeds for disease resistance.

14.4.2 Common Blight

Common bacterial blight (CBB) is found on all six continents and has been recorded to result in a yield loss of 30–70% in susceptible cultivars worldwide. Common blight is of particular concern in the United States, Mexico, Columbia, Brazil, Iran, Argentina, Zambia, Uganda, Zimbabwe, and South Africa (Mengesha & Yetayew, 2018). The disease affects plants' seeds and foliage, which is a major cause of yield losses seen in infected crops. In severe cases of CBB where seeds have become infected, the marketability of seeds is greatly decreased, leading to economic losses (Marquez et al., 2007).

14.4.2.1 Symptoms

Symptoms of common blight begin as small, angular, light green translucent lesions on the plant's leaves (Fig. 14.10). With the progression of the disease, these lesions will start to merge. The centers of these lesions will turn brown and be surrounded by a yellow border. Leaves will become tattered, appear sun-scorched, and be more easily damaged by winds and heavy rains. Infected pods will develop small water-soaked lesions. These lesions will continue to develop until they are reddish-brown, and further progression of the disease can result in shriveled pods. Infected seeds may die, fail to germinate, or germinate infected plants.

14.4.2.2 Causative Agent

Common blight is caused by *Xanthomonas campestris* pathovar *phasoeoli*, a Gram-negative, rod-shaped bacterium. Different strains of *X. campestris* pv. *phaseoli* have been documented, with strains from the New World being highly pathogenic to Andean and Middle American beans (Mkandawire et al., 2004). *X. campestris* also produces the compound xanthan, a viscous extracellular polysaccharide. Because of the nature of xanthan, *X. campestris* has been commercially adapted to produce xanthan gum via fermentation to be used as a thickener in food and non-food industries (Tao et al., 2012).

Fig. 14.10 Common bacterial blight causing severe damage to bean foliage. Lesions on leaves have coalesced, causing large, blighted sections. (Source: Bean diseases, 2021)

14.4.2.3 Disease Life Cycle

CBB is typically a foliar disease, although the bacterium can infect stems, pods, and seeds. The bacterium typically infects the plant through natural and artificial openings. Natural openings include the stomata and hydathodes, while artificial openings are wounds created in the plant from heavy winds, insect grazing, and mechanical injury from animals and humans. This pathogen survives internally in the seed and externally in plant debris or as an epiphyte on other host plants and weeds. The primary source of new contamination is from *X. campestris* carried in infected seeds, which can lie dormant under the seed coat for years (Akhavan et al., 2013). Secondary spread occurs from overhead irrigation, contaminated machinery, wind-blown rains, and animals.

14.4.2.4 Disease Management

Pathogen-free seed should be used when planting faba bean crops. Additionally, cultural practices can minimize pathogen spread, including removing and burning infected plants and plant debris. Rotating crops every few years can also help with the spread of CBB. In addition to copper compound sprays, Bordeaux mixture and cupric hydroxide can also successfully manage disease spread. Planting crop resistant to CBB is also recommended.

14.4.3 Halo Blight

Halo blight, a damaging seed-borne disease, is found globally and can cause significant yield and seed quality loss. Pod and seed quality can become significantly diminished with severe disease cases, causing almost complete loss of plants (Bozkurt & Soylu, 2011). In regions with especially favorable growth conditions of halo blight, economic losses can be profound.

14.4.3.1 Symptoms

Lesions on the plant's leaves begin as small, water-soaked brown spots surrounded by a wide halo of green or yellow tissue (Fig. 14.11). When temperatures reach 23 °C or above halos, tend to disappear and spots turn reddish-brown. Disease progression can lead to systemic chlorosis, particularly at 18–23 °C, plants experiencing systemic infection lack halos. Infected pods have dark green, water-soaked greasy lesions. After 7–10 days of infection, bacteria begin to leak from sub-stomatal cavities and lesions will appear greasy.

Fig. 14.11 Halo blight in bean foliage with large yellow border (halo) surrounding a relatively small necrotic center. (Source: Halo blight, 2009)

14.4.3.2 Causative Agent

Pseudomonas syringae pv. *phaseolicola* is the etiological agent causing halo blight in faba beans. A toxin of the infecting *Pseudomonas* bacteria causes the chlorosis seen with the progression of the disease. *P. syringae* is an aerobic, Gram-negative, motile, rod-shaped bacterium. The pathogen can survive within the plant host and as an epiphyte and prefers higher moisture conditions and cool temperatures (Arnold et al., 2011).

14.4.3.3 Disease Life Cycle

Infected seeds are the primary source of contamination. The pathogen may lie dormant under the seeds coating for up to 4 years, and severe outbreaks of the disease can occur with as little as one infected seed in 16,000. *P. syringae* infects through natural openings in the plant, including the stomata. The pathogen can also enter the plant through wounds created by wind-driven debris, machinery damage, or plants and animals. Upon invasion of the plant, *P. syringae* will occupy the leaf apoplastic space. Once in this space, *P. syringae* uses a type III secretion system to inject cells with effector proteins that interfere with the plant's immune system (Cooper et al., 2020). The pathogen can also survive in plant debris and be carried via overhead irrigation and wind-driven rains to infect surrounding plants.

14.4.3.4 Disease Management

Certified pathogen-free seed should be used, when possible, to help prevent the spread of halo blight. Foliage sprays containing fixed copper compound sprays can be applied to seedlings at the first sign of disease. It is recommended that plants infected with halo blight be sprayed every 7–10 days with a copper-containing copper fungicide (Singh et al., 2012). Crop rotation, deep plowing, and removal and sanitation of infected plants and debris can also mitigate disease spread.

14.5 Viral Disease

Faba beans are highly susceptible to viral diseases causing a significant decline in productivity worldwide (Elbadry et al., 2006).

14.5.1 Yellow Mosaic

Bean yellow mosaic virus (BYMV) is the most prevalent and economically significant plant virus causing mosaics and necrosis (Derks et al., 1980). BYMV was first described in 1925 in the United States and Netherlands, infecting French beans, and is now distributed worldwide (Trebicki, 2020).

14.5.1.1 Symptoms

BYMV is characterized by irregularly shaped yellow spots in the background of the leaflets (Fig. 14.12) (Singh et al., 2012). The infected areas of the leaf develop vein yellowing with a greenish or yellowish mosaic vein-banding with line patterns (Trebicki, 2020). The yellowing of leaves is due to reduced production of chlorophyll which gradually spreads over the entire lamina making the leaf chlorotic. Symptoms are more prominent on young leaves. Growth in younger plants is stunted, which significantly reduces pod yield. Mature plants have more pronounced discoloring, distorted leaves, downward cupping, wrinkling, drooping, and malformation of leaves and pods. Symptoms in seeds include irregular brownish to blackish coloring. Overall, these symptoms do not kill the plant but spread at great speed into the crop, decreasing overall yield (Cheng et al., 2002).

Fig. 14.12 Yellowing of leaves caused by Bean yellow mosaic virus. (Modified from source: Wells, 2020)

14.5.1.2 Causative Agent and Disease Life Cycle

BYMV belongs to the family of *Potyviridae* and genus *Potyvirus* and is widely distributed in legume growing environments (Fauquet et al., 2005) BYMV is a filamentous virus measuring 750 μm in length and 14 μm in width (Radwan et al., 2008) BYMV is an aphid-transmitted virus transmitted by more than 50 aphid species in a non-persistent manner with varying transmission efficiency (Singh et al., 2012). Some of the main vector species include *Acyrthosiphon pisum, Aphis fabae, Aphis gossypii, Brevicoryne brassicae, Rhopalosiphum maidis and Myzus persicae* (Trebicki, 2020). The viral transmission occurs within seconds of virus-carrying aphids feeding on the crops, spreading the virus effectively within a field, resulting high rates of infection. In addition, the virus has numerous isolated strains and a wide host range which is due to mutations in the viral genome enabling viral proteins to interact with host transcription initiation factors from different plant species with different sequences (Nicaise et al., 2007; Wylie et al., 2008).

14.5.1.3 Disease Management

Spraying of 0.1% metasystox when the crop is a month old or after identifying a diseased plant can prevent the severity of the disease (Singh et al., 2012). Aphid populations need to be controlled to prevent the transmission of the virus. The underside of leaves can be checked for aphids, and if found they need to be treated immediately with insecticidal soap, neem oil, pyrethoids or pirimicarb (Biddle & Cattlin, 2007). Predators feeding on aphids can also be used and adjusting planting dates to minimize exposure to aphids can also be beneficial. The seeds from plants showing symptoms of viral infections should not be saved as the virus can be carried within the seed.

14.6 Parasitic Diseases

The most common plant parasites seen in faba beans include stem nematode and broom rape.

14.6.1 Stem Nematode

The stem nematode *Ditylenchus dipsaci* is one of the most devastating seed and soilborne plant parasitic pathogen of faba beans seen often in temperate regions of the world (Hanounik, 1983). Stem nematode was first described on broad beans in Algeria wherein the causative agent was larger than previously recorded species and hence called the 'giant race' (Maupas & Debray, 1896). In experimental plots in Syria, 67.8% yield losses have been noted from stem nematode (Hanounik, 1983). Three different races of the nematode have been seen worldwide, including oat, lucerne,nd clover races (Vanstone & Russell, 2013). The oat race infects oat, faba bean and pea.

14.6.1.1 Symptoms

Stem nematode symptoms in faba bean are only seen in seedlings (Vanstone & Russell, 2013). The symptoms usually occur in patches, but the entire crop gets affected in case of heavy infections. *D. dipsaci* causes poor germination, emergence, establishment, and malformed plants. As plant matures, swelling and deformation of the stem result in stunted growth and premature plant death. Patches of lesions are seen on the stem, which turns reddish-brown and increases in length, advancing to the edge of an internode. The stem eventually turns black, dies from the base, and stops at a leaf. Leaf and petiole necrosis, malformation, curling of leaves, and water-soak spots are also common under heavy infections but are often confused with herbicide damage (Asaad et al., Accessed March 2022). Infected seeds and newly formed pods are darker, distorted, and smaller in size, with speckles on the surface and fewer seed heads. (Fig. 14.13).

14.6.1.2 Causative Agent and Disease Life Cycle

Ditylenchus dipsaci nematode is 1.0–1.3 mm in length and 30 mm in diameter (Singh et al., 2012). The nematode penetrates plants from soil, hay, straw, weeds, infested plant material, or seeds. The female lays 200–500 eggs during a season from which six generations can develop under optimum conditions and temperature range of 15–20 °C (Courtney, 1952). The survival fourth juvenile stage of *Ditylenchus dipsaci* withstands sub-zero conditions and temperatures of 55 °C; decades of desiccation and can be isolated from completely dry plant material

Fig. 14.13 Stem nematode causes leaf and petiole necrosis with reddish brown streaks on the stem. (Source: Grain Legume Handbook, 2008)

(Sturhan & Brzeski, 2020). The nematodes multiply rapidly on susceptible plants under cold, wet conditions increasing the numbers due to which symptoms become prominent on plants.

Several biological races of *D. dipsaci* have been reported with varying host preferences. *D. dipsaci* is known to attack over 450 different plant species in more than ten biological races some of which have a limited host-range (Asaad et al., Accessed March 2022). The 'giant' race tends to be the most damaging race causing severe symptoms and giving rise to infested seed which enables the nematode to spread to new sites.

14.6.1.3 Disease Management

Several methods are currently used to reduce the presence and destroy *D. dipsaci* nematode. Infections can be prevented by ensuring the use of nematode-free seeds (Hooper, 1991). Infested seeds can be disinfected by treating with hot water for 1 hour at 46 °C, with a nematicide in a gas-tight container, or with 0.5% formaldehyde solution (Singh et al., 2012). Proper sanitation in fields is crucial in preventing the spread of nematodes since they survive and reproduce in infected plant material and debris (Asaad et al., Accessed March 2022). All infected plants and weeds should be removed and destroyed, and farm tools should be cleaned of potentially contaminated soil before use. Fumigation of the soil by preplant row treatment or soon after planting with appropriate nematicides helps prevent the spread of the disease (Stoddard et al., 2010). Methyl bromide can also be used against free-living larvae of *D. dipsaci* (Powell, 1974).

Further, D. dipsaci are highly host-specific, so losses due to D. dipsaci can be reduced by 3-year crop rotation with resistant crop, deprivinghe nematodes of a suitable host and starves the population (Stoddard et al., 2010). The time of planting a susceptible host crop can limit the severity of nematode damage and hence, planting during cooler temperatures and lower humidity suppresses reproduction and infestation rates.

14.6.2 Broomrape

Broomrapes are obligate parasitic plants belonging to the Orobanchaceae family and include genera *Orobanche* and *Phelipanche* which attach to the host roots and are completely dependent on the host due to lack of chlorophyll (Maalouf et al., 2011). Broomrapes are widely spread along the Mediterranean basin and induce yield losses of 7–80% based on infestation levels (Gressel et al., 2004). This root parasite is one of the most important limiting factors of faba bean production (Cubero, 1983).

14.6.2.1 Causative Agent and Symptoms

Broomrapes are small parasitic herbaceous plants, 15–50 cm tall, and are similar to fungi and nematodes infecting roots (Singh et al., 2012). They have a pale yellow to reddish-brown color swollen and tuberous stem covered by small, brown scale-like leaves. The upper half-length of the stem is occupied by numerous orchid-like flowers arising singly and arranged in spikes along the stem (Fig. 14.14). Each flower produces ovoid seed pods about 5–8 mm containing several hundred seeds.

Broomrapes affect faba beans in small patches affecting the growth of plants to various extents depending on the time of infection. *O. crenata* is the most widely spread parasite in the Mediterranean region and West Asia, while *O. feotida* is found in the western Mediterranean region, mainly Beja, Tunisia, andorocco (Rubiales et al., 2006). *Broomrapes of Orobanche* and *Phelipanche* spp. survive by absorbing carbohydrates from the phloem and water and minerals from the xylem of the host, ultimately killing them (Maalouf et al., 2011). Broomrape infestations cause an extensive reduction in crop yield and adversely affect crop quality.

14.6.2.2 Disease Life Cycle

*Broomrapes,*arasites, need to attach and penetrate the host root tissue to establish a connection with phloem for nutrient absorption and xylem for water within a few days of germination (Whitney, 1978). Then, they grow, reproduce, and persist in the soil as dormant seeds.

Fig. 14.14 *Orobanche foetida* parasitizing faba bean plant. (Source: de Vries et al., June 2018)

The seeds germinate only in the presence of chemical stimuli (growth regulators) from root exudates of a host plant in proximity. The seeds remain viable in their dormant state for more than 10 years awaiting specific germination requirements. The seeds produce radicle upon germination, which attaches to the root of the host plant producing a cup like structure called an appressorium. A mass of undifferentiated cells from the appressorium penetrate the host into the xylem and phloem, connecting the host and the parasite. After which, the parasite develops a stem and secondary roots that grow outward, connectingith other host roots (Singh et al., 2012).

14.6.2.3 Disease Management

Control strategies such as hand weeding, herbicide applications, late sowing, soil solarization, and crop rotations can be incorporated to reduce *Orobanche* and *Phelipanche* spp. Intercropping with cereals reduces the intensity of broomrapes as allelochemicals released by cereals roots is suggested to inhibit broomrapes seed germination (Fernandez-Aparicio et al., 2007). Spraying the soil with 25% copper sulphate solution and fumigating soil with methyl bromide has been shown to destroy the parasite (Singh et al., 2012). Also, herbicides such as glyphosates, imidazolinones, and sulfonylureas applications at specific crop growth stagesave been effective in controlling broomrape (Pérez-de-Luque et al., 2010).

Since broomrape infection and pathogenesis takes place underground, damage to the crop occurs prior to the emergence of the parasite and diagnosis of infection. The most desirable control strategy is the use of resistant cultivars (Sillero et al., 2010). Breeding for broomrape resistance cultivars is the most economical and feasible method to control the disease.

14.7 Summary

Faba bean (*Vicia faba* L.) is a rich dietary protein source for animal and human consumption. It is one of the most globally important cash crops adapting to climate change and plays a significant role in atmospheric nitrogen fixation, enhancing soil fertility. However, the various fungal, bacterial, viral, and parasitic diseases in faba beans have always been a limiting factor in the production of faba beans, causing yield losses and blemishing quality of the grain. Thus, disease management strategies are essential for the successful cultivation of faba beans. To prevent yield losses, these diseases need to be effectively controlled. However, management decisions and seasonal conditions play a significant role in disease outbreaks and grain yield. Famers need to implement an integrated approach to disease management to produce a profitable crop. Some of these diseases maybe minimized by crop rotation, seed testing for diseases, seed treatment, strategic use of foliar fungicides, careful paddock selection, choosing varietals that are disease resistant and weed control. Considering an integrated approach with preventive measures and biological treatments and development and dissemination of disease and pests management strategies will help achieve this goal.

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