Chapter 9
Re-emergence of Pseudocereals as Superfoods for Food Security and Human Health: Current Progress and Future Prospects

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Abstract Unlike cereals which are monocotyledons, pseudocereals are dicotyledonous plants and are known as pseudocereals because of the similarity of their grains with cereals. They were traditionally used in different civilizations and played a very prominent role in their food, medicine, and rituals. These grains are highly nutritious and are also medicinal since they have abundant nutrients and health-promoting phytochemicals. They are rich in high-quality proteins and essential amino acids. Unlike cereals, pseudocereals ensure the supply of various micro and macronutrients as well. They are considered as "superfood for the future" due to their high nutritional value. Their consumption had undergone massive decline due to negligence by the modern generations. But over the last few years, people have shown greater interest in the consumption of these nutritionally rich grains, and there is an increased acceptance of pseudocereals in the present times. The advancements in nutritional profiling technologies has shown their nutritional superiority over cereals. The major pseudocereals are amaranth, buckwheat, chia, and quinoa. These grains are gluten-free which makes their consumption safer for gluten-intolerant people. Genetic works on pseudocereals confirm that these plants are highly beneficial in improving health and are genetically very diverse which makes them capable to survive in a wide geographical range and tolerate various stresses. This chapter discusses the origin, distribution and taxonomy of the main pseudocerals with their nutritional composition. It further discusses the traditional, medicinal and nutritional importance of the pseudocereals in the context of climate change. A comparison of its nutritional components with the cereals provides understanding of the nutritional richness of the pseudocereals. The last two sections are devoted to the genetics and genomics of pseudocereals and their role in climate resilience.

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9.1 Introduction

Pseudocereals are a group of plants that are similar to cereals in their seed, grain structure, palatability, starch content and cooking characteristics but differ in the sense that they are dicotyledons (Morales et al. 2020). Most of the starchy grains of pseudocereals are smaller than the size of cereals but both are consumed in similar manner (Henrion et al. 2020). Pseudocereals are considered as the crop of twenty-first century due to their excellent nutritional quality (Pirzadah and Malik 2020). They have a higher lipid content than cereals and contain 75% unsaturated fatty acids, which can be used in the human diet in place of saturated and *trans* fat (Haros and Schonlechner 2017). These food crops which were once popular in ancient times as part of the diet of different populations and became less noticed due to the domination of cereals in the food pattern of the world population during twentieth century, hence they are called "sub-exploited food" (Morales et al. 2020). Pseudocereal nutrition is either comparable or superior to cereals, which makes them preferable to be used as a substitute for cereals. Nowadays, the the global attention towards pseudocereals have increased due to their nutritional qualities, agronomic properties, potential to diversify the natural resources and environmental adaptabiity (Carrasco and Soto 2010). The Latin American countries depend on the pseudocereals as their staple food crop and countries such as Russia and China are great producers of pseudocereal such as buckwheat (Morales et al. 2020). Amaranth and Quinoa were selected as the best vegetable food for people by The National Academy of Sciences (NAS) research. Also, they were selected as food in astronaut diet during space travels by the National Aeronautics and Space Administration (NASA; Morales et al. 2020). Another important fact about pseudocereals is that they are gluten-free, hence they are safe to be used by celiac-diseased patients who are reactant to the gluten in food items like wheat. The intake of gluten by the celiac patients causes damage to the mucosal wall of the small intestine, that results in conditions such as reduced absorption of nutrients and indigestion. Therefore gluten-free pseudocereals will be a relief for the celiac patients (Thakur et al. 2021). Besides that, various bioactive compounds present in pseudocereals provide a wide range of health benefits for the consumers apart from nutrition, hence they are also called "functional food" (Morales et al. 2020). The pseudocereals are enriched with various phenolic and flavonoid compounds such as vanillic acid, ferulic acid, quercetin and kaempferol which provides protection from chronic diseases such as cardiovascular disease, cancer, diabetes and hypertension (Thakur et al. 2021). Therefore, the inclusion of pseudocereals in people's diets is beneficial to both celiac patients and consumers suffering from various lifestyle related disorders.

The current global conditions also demand to diversify the diet of consumers with climate resilient, nutritionally superior and health beneficial food crops (Cheng et al. 2015). In this fast growing world, where the population is estimated to reach about

9 billion by 2050, depending only upon major cereals such as rice, maize and wheat alone for the availability of nutrients may not be good. Due to the dominance of limited number of food crops in the diet, the world is not able to mitigate the challenges of climate change and malnutrition (Cheng et al. 2015). The presence of high carbohydrate content in the grains, cereals are used for the 60% of calorie intake by the developing countries and 30% by the developed countries (Olugbire et al. 2021). At the same time, it was recorded that, the 11% of total global population is severely affected with malnutrition and 17% are suffering from hidden hunger or micro nutrient deficiency (Grote et al. 2021) which indicate the inability of major cereals to ensure food security. Additionally, produtivity of cereals has reduced significantly due to climate change and increased incidence of pathogens. Abbas (2022) documented that, the yeild of major cereals like rice, wheat, maize, barley and jowar were declined in a period of 2009-2019 due to the rise in temperature. This kind of research point towards the necessity to diversify the food systems with climate resilient and nutritionally superior crops. The popularization of inclusion of pseudocereals in the people's diets can solve the problem to a certain extent, and currently various countries are following this as discussed above. The tolerance of pseudocereals against abiotic stresses like drought, temperature, salinity, and heavy metal stress has already been proved which suggest their climate resilience (Pirzadah and Malik 2020). Besides that, they are capable of surviving and being productive even in marginal lands (Das 2016a). This also makes pseudocereals more relevant since urbanization has produced many marginal lands. The cereals do not have potential to grow in marginal lands due to their higher nutrient requirement for growth, but the capability of pseudocereals to survive under minimum nutrients can help them grow efficiently (Rodríguez et al. 2020). This may be another reason why pseudocereals are considered as "past food for future people" (Morales et al. 2020). The major pseudocereals that can be used to diversify our food menu with the assurance of availability of macro and micronutrients are grain amaranth, buckwheat, chia, and quinoa (Arslan-Tontul et al. 2022). All these crops are significant in their characteristic nutrient composition and presence of bioactive compounds. Table 9.1 represents the information about the taxonomy, origin, and distribution of these pseudocereals.

These pseudocereals are also useful in industrial and nutraceutical fields. Chia is very popular as an ingredient in skin care products (Huber et al. 2020). The high omega-3 fatty acid content in chia is a potential ingredient for maintaining and improving skin hydration (Ullah et al. 2016). Thus re-emergence of pseudocereals is a relevant topic to be discussed to ensure food security for the future generation and as a potential raw material in various nutraceutical industries.

Table 9.1 Taxonomy, origin, and distribution of pseudocereals

Pseudocereal	Family	Common name	Origin	Distribution
Amaranthus cruentus L.	Amaranthaceae	African spinach, Red amaranth, Purple amaranth (Ogwu 2020)	Southern Guatemala, South of Mexico, and Central America (Singh 2017)	Africa, America, Mesoamerica, North-western Argentina, East, Southeast and South Asia (Singh 2017)
Amaranthus hypochondriacus L.	Amaranthaceae	Prince's feather and amaranth (Ogwu 2020)	Northern Mexico (Singh 2017)	Africa, America, Mesoamerica, north-western Argentina, East, Southeast and South Asia (Singh 2017)
Amaranthus caudatus L.	Amaranthaceae	Red amaranth, Flower amaranth, Pendant amaranth (Ogwu 2020)	Andes (Singh 2017)	Africa, America, Mesoamerica, north-western Argentina, East, Southeast and South Asia (Singh 2017)
Chenopodium quinoa Willd.	Amaranthaceae	Quinoa	Andean region of South America (Jaikishun et al. 2019)	Bolivia, Peru, Ecuador, Colombia, Argentina, Chile (Jaikishun et al. 2019)
Salvia mexicana L.	Lamiaceae	Chia, Chian, Salba (Sosa-Baldivia et al. 2018)	México (Sosa-Baldivia et al. 2018)	Asia, Africa, North America, South America, Europe (Bhargava et al. 2006)
Fagopyrum esculentum Moench and *Fagopyrum tataricum* Gaertn.	Polygonaceae	Common Buckwheat (Rana et al. 2012), Sweet buckwheat (Norbu and Roder 2003), Tartary Buckwheat (Rana et al. 2012), bitter buckwheat (Norbu and Roder 2003)	Southern China (Zhou et al. 2018)	China, Korea, Japan, Tibet, Bhutan, Nepal, India, Poland, Europe, England, Ukraine, Russia (Suvorova and Zhou 2018)

9.2 History and Naming of the Pseudocereals

9.2.1 Amaranth

Amaranth, being popular as a leafy vegetable, has only gained very less significance in its grain use. These grains are highly nutritious and are abundant in various amino acids. The mostly used grain amaranth species are *Amaranthus caudatus*, *Amaranthus cruentus*, and *Amaranthus hypochondriacus* (Ogwu 2020). The name amaranth means immortal, everlasting, or non-wilting according to Greeks (Mlakar et al. 2009). Amaranth is known by various common names in different parts of the world. Some of them are listed below (Table 9.2):

9.2.2 Quinoa

Quinoa has been known by various local names in Andean regions. In Ecuador and Peru, they were known as kiuna and parca. In Bolivia, they were popular as supha, jopa, jupha, jiura, aara, ccallapi, and vocali. In Chile, it is "quinhua" and in Colombia, it is "suba" and "pasca" (Tahmasebi and Firuzkoohi 2017). In the Inca tradition, it is considered as "chisaya mama" (Tanwar et al. 2019) or "the mother grain", with holy status gifted to God (Vega-Gálvez et al. 2010).

Table 9.2 Common name of Amaranth in various countries

Country	Common name	Reference
Aztec civilization (present Mexico)	Huahtli	Myers (1996)
India	Rajgira ("king seed"), Ramdana ("seed sent by God"), Keerai	Singh (2017)
Nepal	Marcha, Nana, Pilim, Latav	Singh (2017)
China	Een choy, Yin choy, In-tsai, Hsien tsai, Xian cai	Rastogi and Shukla (2013)
Sri Lanka	Thampala	Rastogi and Shukla (2013)
Vietnam	Yan yang	Rastogi and Shukla (2013)
Bolivia	Coimi, Millmi	Rastogi and Shukla (2013)
Ecuador	Sangoracha, Alaco	Rastogi and Shukla (2013)

9.2.3 Chia

Many inconsistencies have occurred in the scientific and common nomenclature of chia. These inconsistencies in its name was one of the reasons for the decline in its production. Initially, chia was known as Chian in Nahua, a Mexican language which meant “oily” due to their high oil content (Sosa-Baldivia et al. 2018) and as “strength” in the Mayan ancestral language since they were used as a high-energy food in Yucatan (Akinfenwa et al. 2020). Mexican people used this term as a collective term to address all species belonging to the genus *Salvia*.

Carl Linnaeus assigned *Salvia hispanica* as the standardized name for the chia plants in 1753, which means “a Spanish plant to cure or save” in English, that lead to the assumption of origin of the plant in Spain and Italy. After 1832, the Spanish Language Academy finalized to switch over the common name from Chian to Chia. According to Spanish practice, they considered a single name for crops or plants which can be grouped with similar characteristics and functions, which intensified the misconception about naming as other plants also got the name chia by the Spanish people. During the mid-18s, Pablo De la Llave proposed to change the binomial name of chia to *Salvia chian*; thus highlighting its Mexican origin (De la Llave 1833). In 2006, through the marketing strategy of a Peru based company named Agrisalba SA, the chia production was increased rapidly by the claim that white chia (Salba) seeds are nutritionally superior than black mexican cultivar chia seeds. Even though it was later found that there was no such difference in the nutrient composition of the white Salba and black Chia, the name had gained wide popularity by that time through their marketing strategies. Chia seeds are also popular as ‘Salba’ (Salbachia (n.d.); Anacleto et al. 2018). But later on, to restore its Mexican identity, a major event in the history of the nomenclature of Chia took place on March 23, 2012 by naming the plant as *Salvia mexicana* as an acknowledgment of its geographical origin in Mexico (IPNI, 2012). This binomial naming corrected the English meaning of Chia from “a Spanish plant to cure or save” to “a Mexican plant to cure or save” (Sosa-Baldivia et al. 2018).

9.2.4 Buckwheat

Fagopyrum belongs to the family Polygonaceae. The genus name *Fagopyrum* has undergone many modifications by various botanists. In 1753, Linnaeus established *Polygonum* Linn by including *Fagopyrum* in *Polygonum*; without separating it as a genus under *Polygonum*. Finally, based on the morphological, palynological, and cytological studies, Graham and Wood (1965) and Hedberg (1946) came to the conclusion that *Fagopyrum* showed differences from *Polygonum* in their morphology, palynology, and cytology; and hence should be considered as a separate genus. Thus the genus name accepted now is *Fagopyrum* Miller. The term buckwheat can be considered as a collective term for the two widely cultivated and palatable

Table 9.3 Various vernacular names of buckwheat (Zhou et al. 2018)

Country	Vernacular names
India	Ogal
Nepal	Mite phapar
Bhutan	Jare
Russia	Grecicha kul'turnaja
Ukraine	Grechka
Poland	Gryka, Tatarka gryka, or Poganka
Czech Republic and Slovakia	Pohanka
Sweden	Bovete
Denmark	Boghvede
Finland	Tattari
Slovenia	Ajda, Hajdina, or Idina
Bosnia	Heljda
Serbia	Heljda
Montenegro	Heljda
Croatia	Heljda
French	Sarrasin, Blé noir, Renoue'e, Bouquette
Breton	Gwinizh-du
Italy	Fagopiro, Grano saraceno, Sarasin, Faggina
Germany	Buchweizen or Heidekorn
Korea	Maemil
Japan	Soba
Mandarin	Tian qiao mai
Mandarin (tartary buckwheat)	Ku qiao mai

variants of *Fagopyrum* i.e., common buckwheat (*F. esculentum* Moench) and tartary buckwheat (*F. tataricum* Gaertn) (Luthar et al. 2021; Sytar et al. 2016). Buckwheat have plenty of vernacular names in various parts of the world (Zhou et al. 2018). Table 9.3 lists out the various vernacular names of buckwheat.

9.3 The Traditional Importance of Pseudocereals

Ancient people in various parts of the world used these pseudocereals for several food and medicinal preparations (Rana et al. 2012; Adhikary et al. 2020). These small grains were also very important religiously in different countries (Adhikary et al. 2020). The religious, medicinal and popular culinary preparations from pseudocereals indicate the strong link of the grains with the day-to-day life of ancient people. These grains thus indicate the culture and history of many civilizations like the Inca and the Aztec. In the ancient Aztec and Inca civilizations, grain amaranth was an important crop with religious importance (Sauer 1950). They mixed amaranth seeds with honey which is consumed during some religious ceremonies (Sauer

1950, 1955). They are consumed by soaking in milk after fasting (Sauer 1955) and are used to prepare laddoos which upholds their importance in Hindu culture (Adhikary et al. 2020). Badagas people of Nilgiri hills used to offer puffed amaranth seeds on the Badagas funeral pyre (Adhikary et al. 2020). In Nigeria, amaranth was used in multiple ways traditionally and superstitiously (Ogwu 2020). Hot amaranth soup with fish is a popular food served as a post-delivery care to improve the health of the mother (Ogwu 2020). They were used as both animal and human food. Various local medicines were made from dried amaranth seeds (Ogwu 2020).

Quinoa grains had sacred importance in ancient Inca culture (Bastidas et al. 2016). Since they considered quinoa as the "mother of grains", these small seeds were very significant in religious, economic, and medicinal aspects (Bastidas et al. 2016). Archeological remains from hearths, burials, storage structures, and human digestive tracts confirm this fact (López et al. 2011). The residue of threshed quinoa seeds is burned and the ash along with cocoa leaves was chewed (Bonifacio 2003). A traditional South American beer called *Chicha* is made by adding quinoa and water, along with sugar and cinnamon if needed (Cutler and Cardenas 1947). Various salads and soups were prepared and consumed by South American people (Ludena Urquizo et al. 2017). Chia seeds were considered as a holy ingredient in Aztec civilization (Cahill 2003). In the ancient Mayan civilization, chia seeds were the staple diet for warriors since these small seeds provided a lot of energy (Scapin et al. 2016). In Mexico, a drink with chia seeds was consumed by runners known as Iskiates which helped them to cover a longer distance with the aid of a high energy supply from chia seeds (Scapin et al. 2016). Thus chia seeds were very important in the past and due to their medicinal importance, they were used in meals, drinks, and as pressed oil (Pal and Raj 2020). Chia seed oil was also a component of varnishes, cosmetics, and paints. The glossy finish of hand-made Mexican vessels was due to the use of chia seed oil in the paint (Cahill 2003).

Buckwheat is a major ingredient in various Bhutanese recipes (Norbu and Roder 2003). They prepare pancake-like *khuli*, noodles-like *puta*, fire-roasted pancakes called *Teyzey*, a form of unleavened circular bread called *Keptang* etc. and in Eastern Bhutan, a special dish called *Kontongs* was served during festivals (Norbu and Roder 2003). Sweet buckwheat dough sprinkled with a spoon of chilli powder and a drink called *Roth chang* was served on the 21st day of death as a symbol of mourning (Norbu and Roder 2003). In India, when cereals and pulses are not consumed during fasting, buckwheat and dishes prepared from buckwheat flour are consumed by people (Rana et al. 2012). Table 9.4 give details about various traditional uses of pseudocereals in different countries.

Even though, they had been widely used in the past, their popularity considerably decreased over the time due to various reasons. The monocropping techniques introduced by the agribusiness companies caused the production and consumption of only limited food items, especially cereals like rice, wheat, and maize. This not only homogenized the cultivation pattern but also our food habits. A decrease in amaranth cultivation can be viewed under this development of the monocropping style (De Shield 2015). A high degree of seed shattering, long maturity time, and

Table 9.4 Traditional uses of pseudocereals in different countries

Pseudocereal	Country/ Region	Traditional use/preparation	Reference(s)
Amaranth	Mexico	Zoale, a ceremonial paste made from grains was fed to the slaves before they were sacrificed to the God	Adhikary et al. (2020)
	Alegria	Used in the preparation of a confectionary	Adhikary et al. (2020)
	Nigeria	Red inflorescence is used for preparing a traditional drink for stomach aches	Ogwu (2020)
	Nepal, India and Pakistan	Popped seeds are used to make laddoos which are of religious importance in Hinduism	Adhikary et al. (2020)
Quinoa	South American Countries	Used to prepare salads, soups, porridges and fried patties	Ludena Urquizo et al. (2017)
		Seeds are used to make Chicha, seed flour is used to make tortillas and bread	Cutler and Cardenas (1947) and Nelson (1968)
		Used in the preparation of a sacred drink-*Mudai*	Bastidas et al. (2016)
Chia	Aztec empire	Flour from the seeds known as Chianpinolli was used in various Aztec beverages known as Chianatoles	Valdivia-López and Tecante (2015)
	Mexico	Beverage preparation such as "Agua de Chia" or "Chia fresca"	Cahill (2003)
		Chia seeds along with citrus fruits and water was consumed by Iskiates	Pal and Raj (2020)
Buckwheat	Bhutan	Used for preparation of *khuli, putta, teyzeye*, *Keptang* and *kongtong* For making a distilled alcohol-*ara*	Norbu and Roder (2003)
	Tang region of Bhutan	Cooked sweet buckwheat dough served on the 21st day after death followed by serving a drink called *roth chang*	Norbu and Roder (2003)
	Chumey region of Bhutan	Phob–biscuit-like preparation served during rituals	Norbu and Roder (2003)
	India	For preparing chillare (a kind of unleavened bread) and ghanti (a kind of local wine) Flour, namely "kuttu ka atta" is used as food during fasting	Rana et al. (2012)

lower yield when compared to other cereals added to the decline in the production of amaranth grain (Das 2016b). A principle cause for the decline in chia cultivation in Mexico was the Spanish colonization; Spaniards banned chia cultivation due to its wide use in Mexican rituals and the crop was replaced by other crops like wheat, barley, and sugarcane (Sosa-Baldivia et al. 2018). New food crops then became staple foods which neglected the traditional crops like chia and chia cultivation was thereafter limited only to the mountain ranges of Mexico where Spanish rule was limited (Sosa-Baldivia et al. 2018). The significance of buckwheat production mainly diminished because of the fact that their production per acre was considerably low than other cereals since they showed less response to the fertilizers and difficulty in developing hybrid varieties due to a self-incompatibility issue (Léder 2009). Another potential reason for the decline in buckwheat production might be its allergy-causing effects (Norbäck and Wieslander 2021). Exposure to buckwheat as food, during processing, and using buckwheat post-production materials like its husk in pillows lead to IgE-mediated allergy which causes severe allergic responses and anaphylaxis (Norbäck and Wieslander 2021). Even in the case of the decrease in quinoa cultivation and consumption, Spanish colonies had their negative impacts (Valencia-Chamorro 2003). They considered quinoa as a "Non-Christian" grain and hence prohibited it and introduced other cereals and thus cultivation of quinoa got confined only to communal lands called "aynokas" (Angeli et al. 2020). From these indications, it is clear that multiple factors affected the decrease in the cultivation and thereby the consumption of these pseudocereals.

9.4 Re-emergence of Pseudocereals as Superfoods

9.4.1 Nutritional Importance (Compared with Cereals)

Being rich in nutritional contents, pseudocereals are known as the "grains of twenty-first century" (Martínez-Villaluenga et al. 2020). Compared to cereals, pseudocereals are equal or rather superior in nutritional composition. These superfoods ensure to provide higher energy when consumed than rice, wheat or maize. Among the pseudocereals, chia provides the highest amount of energy (486 kcal; USDA 2018), which is far above the most popular cereals that we use.

Carbohydrate constitute the major nutrient fraction in pseudocereals, making up about 60–80% of their dry weight (Martínez-Villaluenga et al. 2020). It was found that these pseudocereals also ensure to provide a high amount of resistant starch which regulates the blood glucose and lipid level, reduce obesity, and improves intestinal biota (Skrabanja et al. 1998; Zhou et al. 2019). Dietary fiber is another important component that helps in proper digestion and bowel health (Heredia et al. 2002). Pseudocereals are rich in dietary fiber and satisfy the recommended level of daily dietary fibre intake (Jones 2014).

In the case of protein content, pseudocereals are the best source of high-quality protein which is comparable to cow milk (Bekkering and Tian 2019). They are made of 2S albumin, 11S and 7S globulin, which is superior to the protein provided by cereals (Pirzadah and Malik 2020). Since plant-based protein is gaining more acceptance in the present time due to its environmental sustainability and ensuring food security in a more cost-effective way, pseudocereals are on top of the list to meet the increasing demand for plant-based protein (Alonso-Miravalles and

O'Mahony 2018). An abundance of essential amino acids like methionine, phenylalanine, lysine, and isoleucine also make them preferable than cereals to be included in the day-to-day diet (Motta et al. 2019). This is not only applicable to the essential amino acid content but also to the total content of non-essential amino acids. Thus pseudocereals are an excellent source of protein in our diet which ensures proper growth and development as well as healing and repair of damaged cells in our body.

Total lipid content in pseudocereals is another reason why we should switch over to pseudocereals rather than solely relying upon conventional cereals. It should be noted that pseudocereals are safer to use since the major fraction of this lipid are unsaturated fatty acids and only a minor fraction is made up of saturated fatty acids (Martínez-Villaluenga et al. 2020). Therefore consumption of pseudocereals does not or only minimally cause health risks like atherosclerosis, cholesterol, obesity, diabetes or blood pressure (Kromhout and de Goede 2014; Simopoulos 2008).

Vitamins and minerals in the pseudocereals are also quite surprising due to their high content. This helps consumers to develop good health and well-being. Vitamin B content in various pseudocereals is either higher or comparable to that of the most consuming cereals (USDA 2005). They are also a promising source of vitamin E (tocopherol) which acts as an antioxidant in our body (Pirzadah and Malik 2020). The common cereals that we mostly depend upon only supply a minimal amount of tocopherol. In the case of mineral content, the whole pseudocereal grain is a rich source of various minerals, since they are primarily located in the bran (Martínez-Villaluenga et al. 2020). Therefore, they ensure a potential supply of minerals like magnesium, potassium, calcium, phosphorus, and iron. Table 9.5 provides nutritional composition of the pseudocerals in comparison with the cereals such as maize, wheat and rice. It is clear that pseudocerals are enriched with many important nutrients when compared with the cereals.

9.4.2 Medicinal Importance

9.4.2.1 Gluten-Free Foods

Gluten is a form of protein, made up of prolamin and glutelin fraction (El Khoury et al. 2018) which is mostly seen in cereals such as wheat, barley, and rye. The gluten content in the food improves the overall viscoelastic properties which are highly preferred during baking and other processes in the food industry (Giménez-Bastida et al. 2015). In some individuals, gluten generates some immune responses, causing inflammation in the intestine, this disease is termed as celiac disease (CD; Olivares et al. 2011). This is a genetic disorder and also overlaps with the other autoimmune diseases (Lundin and Wijmenga 2015) and the patients cannot consume gluten rich diets (Catassi and Fasano 2008). When ingested, the celiac disease susceptible people develop symptoms like abdominal pain, osteoporosis, neurological problems, anemia and irritable bowel syndrome (Green 2005). Gluten content in food may also cause health issues like dermatitis herpetiformis (DH), non-coeliac gluten

Table 9.5 The nutritional composition of cereals and pseudocereals

Nutritional content	Maize	Wheat	Rice	Amaranth	Buckwheat	Chia	Quinoa
Energy (kcal)	365	346	345	378	343	486	368
Carbohydrate (g)	74.3	71.2	78.2	63.1–70	63.1–82.1	42.12	48.5–77
Dietary fiber (g)	7.5	12.5	4.5	2.7–17.3	17.8	34.4	7–26.5
Total protein (%)	9.4	6.8	11.8	13.1–21.5	5.7–14.2	16.54	9.1–16.7
Essential amino acids (g/100 g)							
Isoleucine	3.6	3	4.1	2.7–4.2	1.1–4.1	0.801	0.8–7.4
Leucine	12.4	6.3	8.6	4.2–6.9	2.2–7.6	1.371	2.3–9.4
Lysine	2.7	2.3	4.1	4.8–8	4.2–8.6	0.97	2.4–7.8
Methionine	1.9	1.2	2.4	1.6–4.6	0.5–2.5	0.588	0.3–9.1
Phenylalanine	4.8	4.6	5.2	3.7–4.7	1.3–7.2	1.016	3–4.7
Threonine	3.7	2.4	4	3.3–5	3.9–4	0.709	2.1–8.9
Tryptophan	0.9	2.4	1.4	0.9–1.8	1.83	0.436	0.6–1.9
Valine	5.6	3.6	5.8	3.9–5	2.3–6.1	0.95	0.8–6.1
Non-essential amino acids (g/100 g)							
Alanine	7.81	3	0.57	3.5–6.2	4.6–9.6	1.044	3.2–5.7
Arginine	4.99	5.1	0.88	8.7–15.6	10.5–11.3	2.143	6.9–13.6
Aspartic acid	7.87	4.4	0.87	7.3–10.7	7.6–16.6	1.689	8
Cysteine	1.55	2.3	0.19	2.1–3.6	0.8–3.5	0.407	0.1–2.7
Glutamic acid	19.23	33	1.81	14.4–17.7	23.2–24.4	3.5	13.2
Glycine	4.39	3.8	0.46	6.7–15.2	6.2–13.2	0.943	2.2–6.1
Histidine	2.9	2.1	0.23	1.9–3.8	1.8–4.9	0.531	1.4–5.4
Proline	10.03	8.6	0.48	2.82–4.6	2.6–8.8	0.776	2.3–5.5
Serine	5.38	4.3	0.49	4.9–9.3	3.2–8.6	1.049	3.4–5.7
Tyrosine	3.76	3.5	0.53	3.3–3.7	0.6–4.9	0.536	2.5–3.7
Total lipid (g)	4.7	2.5	1.5	6.7	3.4	30.7	6.07
Vitamins (mg/100 g)							
Thiamine	0.4	0.5	0.06	0.01–0.1	0.1–3.3	0.62	0.3–0.4
Riboflavin	0.2	0.2	0.06	0.04–0.41	0.06–10.6	0.17	0.3–0.4
Niacin	3.6	5.5	1.9	<0.01–8.04	2.1–18	8.83	1.1–1.5
Tocopherol	0.49	0.06	0.11	15.4	9.5–16.4	0.5	24.7
Minerals (mg/100 g)							
Magnesium	127	138	65	254–266	390	335	207–502
Calcium	7	30	10	175–206	46.5–50.4	631	27.5–148.7
Phosphorus	210	298	160	441–455	330–395.3	860	140–530
Iron	2.7	3.5	0.7	12.17.4	11.8–14.9	7.72	1.1–16.7
Manganese	1.9	2.3	0.5	4	1.2–1.8	26.92	Not reported
Potassium	287	284	268	290–434	450	407	656–1475
Zinc	2.3	2.7	1.3	3.7–5.2	2.1–2.4	4.58	0.8–4.8
Sodium	15.9	0.6	–	0.6	-	16	11–31
Copper	0.14	7	2	0.77	0.9–1.6	13.88	1–9.5

$References for this table are given below for the respective crop

Maize	Pirzadah and Malik (2020), McKevith (2004), Bekkering and Tian (2019), Jood et al. (1995), Murdia et al. (2016)

(continued)

Table 9.5 (continued)

$References for this table are given below for the respective crop	
Wheat	Pirzadah and Malik (2020), McKevith (2004), Jancurová et al. (2009), Bekkering and Tian (2019), Ranhotra et al. (1996)
Rice	Pirzadah and Malik (2020), Jancurová et al. (2009), Bekkering and Tian (2019), Santos et al. (2013)
Amaranth	Martínez-Villaluenga et al. (2020), Boukid et al. (2018)
Buckwheat	Martínez-Villaluenga et al. (2020), Boukid et al. (2018)
Chia	Suri et al. (2016), Kulkarni et al. (2020)
Quinoa	Martínez-Villaluenga et al. (2020), Ranhotra et al. (1993)

sensitivity (NCGS), and gluten ataxia (GA) (El Khoury et al. 2018). The most recommended way to prevent the risks of these diseases is to switch over to gluten-free products (Green et al. 2015).

Even though gluten-free foods such as whole grain bread, cornflakes, bun, and whole grain cookie provide sufficient energy (Missbach et al. 2015), the protein, vitamin, mineral, and dietary fiber (El Khoury et al. 2018) supplied by these food items are limited (Missbach et al. 2015). The improper absorption due to the immune response activated by the CD patients leads to the deficiency of iron, folic acid, minerals like copper and zinc, and fat-soluble vitamins like vitamins A, D, E, and K (Caeiro et al. 2022). This causes nutritional deficiency to some extent in the affected ones.

One of the best way to ensure gluten-free food rich in protein and dietary fibres is to consume pseudocereals. It is also perhaps the best way to maintain a gluten-free diet in a more economical way. Normally used gluten-free food items like whole grain bread and cornflakes are more expensive than their gluten-containing forms (Panagiotou and Kontogianni 2017). Thus pseudocereals can be used in the daily diet of CD and other gluten-intolerant patients to lead a healthy life. The comparatively cheaper price of pseudocereals with no compromise in nutritional availability greatly helps to reduce the financial burden for CD patients. Since the protein in amaranth and quinoa as well as fibre in buckwheat are easily digestible and readily absorbed, they ensure proper absorption of nutrients contained in it (Caeiro et al. 2022). Amaranth flour was found to be used efficiently in making gluten-free bread in the study conducted by Gambus et al. (2002). The formulation of amaranth flour fortified with iron was a success, elevating the nutritional composition. Using flour of amaranth, buckwheat, and quinoa as a replacement for potato starch in baking bread not only increases protein, fibre, mineral, and tocopherol content but also improves the bread volume and produced softer crumbs (Alvarez-Jubete et al. 2010). Tarhana is a traditional Turkish fermented food normally prepared from cereals (Ozdemir et al. 2007). Use of quinoa instead of conventional rice flour or potato starch in the production of tarhana resulted in elevation of the crude protein and fat content in the tarhana and the mineral content was also high in tarhana made of quinoa flour with a notable increase in the concentration of K, Ca, Mg, and Fe (Demir 2014). Moreover, use of quinoa flour in tarhana preparation also improved the taste, odour, consistency, and acceptability of soups made from it (Demir 2014). Bread made of buckwheat flour showed inferior baking quality; but was high in protein, minerals like Cu and Mg, fatty acids like oleic and linoleic acids, folate, and antioxidant content (Giménez-Bastida et al. 2015). The bread made from buckwheat flour showed higher volume and softer crumbs. To overcome the poor baking quality of buckwheat flour, Renzetti et al. (2008) used microbial transglutaminase during bread preparation which resulted in increasing its baking qualities. Chia, when used as seed rather than flour, was found to be more acceptable by consumers and using 15% chia in bread baking does not change the overall acceptability of the bread and was also better in nutrient availability (Steffolani et al. 2014).

9.4.2.2 Prebiotics/Probiotics in Pseudocereals for Maintaining Gut Health

Prebiotics are non-digestible compounds that modulate the activity of the gut microbiota, through its metabolism by microorganisms in the gut, thereby providing beneficial physiological effects on the host (Bindels et al. 2015). These compounds are not fully metabolized, but induce the target metabolic processes in the host and thus confer health benefits (Markowiak and Śliżewska 2018). The term probiotics was originated from the Greek words “pro” and “bios” which means “for life” (Markowiak and Śliżewska 2018). According to the definition provided by FAO and WHO in 2002, probiotics are “live strains of strictly selected microorganisms which when administered in adequate amounts, confer a health benefit on the host” (FAO 2002). It may include one or more beneficial microbial strains which once reaching the intestine maintain the overall balance there. *Lactobacillus* strains, *Saccharomyces cerevisiae*, *Bacillus subtilis*, and *Aspergillus oryzae* are commonly used as probiotics (Choudhari et al. 2008). *L. rhamnosus* GR-1, a probiotic bacteria, was found to have the ability to support the immune system (Hemsworth et al. 2012). *L. rhamnosus* GR-1 can be trustfully used to improve overall immunity and quality of the life of HIV patients as they cause no issues related to the gastrointestinal tract (Hemsworth et al. 2012). Pseudocereals are now being evaluated as a very good source of prebiotics and probiotics (Ugural and Akyol 2022). When fermented, the nutritional values of pseudocereals are enhanced and this fermentation also benefits the supply of prebiotics or probiotics. Upon lactic acid fermentation, protein availability is enhanced and the growth of pathogenic bacteria is inhibited (Ugural and Akyol 2022). The richness of various nutrients in amaranth act as a key factor for the nourishment of various essential bacteria and the fermentation process benefits this bacterial growth in the gut (Ugural and Akyol 2022). In-vitro studies show that the fermentation of grain amaranth improved their antioxidant, metal chelating capacity, and protein digestibility (Olawoye and Gbadamosi 2017). Amaranth flour when fermented with *Lactobacillus rhamnosus* GG maintained its stability for 8 hours at 37°C and remained for 2 weeks in a range of 10^8–10^9 CFU/mL after storage and no fall in the level of starch, protein, and lipid was found after fermentation (Matejčeková et al. 2015). This suggests that fermented amaranth products can be developed which are beneficial for the consumers. The prebiotic activity may be present in amaranth, and studies are being progressed in this field (Ugural and Akyol 2022). The fermentation process in quinoa not only enhanced the beneficial riboflavin and folate level but also reduced the level of anti-nutritional compounds in it (Carrizo et al. 2016). The prebiotic and probiotic activities in quinoa are authenticated by another study by Ludena Urquizo et al. (2017). Of the various formulations tested, fructooligosaccharide (prebiotic), *Lactobacillus casei* Lc-01 (probiotic), fructooligosaccharide and *L. casei* Lc-01 (synbiotic), and formulations prepared from the extract of soy (70%) and quinoa (30%), the synbiotic association was found to be more beneficial for the gut microbiota (Ugural and Akyol 2022). The most researched probiotic bacteria to be present in fermented buckwheat is *L. rhamnosus* GG since buckwheat was a very suitable substrate for their growth and activity. They were able to survive in the acidic environment for even 3 days after consumption in the stomach and intestine (Lam et al. 2007). They play a vital role in improving the natural immune system and maintaining a healthy digestive system (Collado et al. 2007). *L. rhamnosus* GG also protects the body from pathogenic bacteria in the stomach and also helps in calming down various symptoms of atopic dermatitis, gastrointestinal disorders, and cow's milk allergy (Collado et al. 2007). Protein from tartary buckwheat was found to be beneficial in the growth and activity of prebiotic bacteria like *L. casei* LC2W and *Bifidobacterium longum* BD400 (Zhou et al. 2015). Thus the consumption of these pseudocereals not only ensure an ample supply of nutrients but also the complete health of a person including proper digestion and improved immunity. In the modern scenario where the consumers depend on fast food items, the presence of prebiotic and probiotic bacteria in our body will be at their minimum population; which will put our state of health in danger. Fibre-rich foods like pseudocereals may help us to overcome the issues that are probable to be developed due to frequent fast food consumption.

9.4.2.3 Bioactive Compounds

Bioactive compounds are non-nutrient compounds that have a profound role in improving human health (Martínez-Villaluenga et al. 2020). They may be either essential compounds like vitamins or non-essential like polyphenols (Biesalski et al. 2009). The presence of these bioactive compounds in pseudocereals makes them a functional food, which improves health more than the mere availability of nutrients to survive (Morales et al. 2020). Various pseudocereals are rich in different bioactive compounds. The major classes of bioactive compounds found in pseudocereals are saponins, phenolic compounds, polysaccharides, phytoecdysteroids, phytosterols, betalains, bioactive proteins, and peptides (Martínez-Villaluenga et al. 2020).

Saponin is the major bioactive compound in quinoa, which is the reason for its bitter taste (Gómez-Caravaca et al. 2011). Bioactive phenolic compounds include phenolic acids like vanillic acid, ferulic acid, gallic acid, salicylic acid, caffeic acid, and protocatechualdehyde; flavonoids like flavanols, flavones, flavanones, anthocyanins, isoflavonoids, and flavonols. Buckwheat is the richest source of phenolic compounds among the pseudocereals (Liu et al. 2019). The polysaccharides from quinoa show immune enhancing properties, thus they have the potential to be used in pharmaceutical preparations (Fan et al. 2019). Phytosterols are a plant homologous compounds of cholesterol in animals and are present in a relatively higher quantity in amaranth (Martínez-Villaluenga et al. 2020). The most important fact about phytoecdysteroids is that its presence in pseudocereals is exclusive to the bran of quinoa (Kumpun et al. 2011). In general, phytoecdysteriods are secondary metabolites that protect the plant from attack by nematodes and insects (Martínez-Villaluenga et al. 2020). Another interesting bioactive compound in quinoa is betalains, which is a nitrogen-containing aromatic indole derivative of tyrosine. Betalain extract is an approved natural colorant by the European Union (additive E-162) and the Food and Drug Administration (FDA) in food and pharmaceutical products (Martínez-Villaluenga et al. 2020). Bioactive peptides are the amino acid sequences that are inactive in their precursor protein structure but get biologically active when they are hydrolyzed in-vivo or in-vitro (Morales et al. 2020). Rutin is an important bioactive compound belonging to the class of flavonols in buckwheat and it is responsible for various therapeutic effects like anti-inflammatory, protection from UV radiation, anti-diabetic etc. (Koja et al. 2018). Table 9.6 shows the various bioactive compounds in different pseudocereals and their health benefits.

9.5 Pseudocereals as Climate-Smart Crops

Yet another interesting fact about these pseudocereals is that they can withstand climatic variations and stress conditions under which the major staple cereals may not be able to survive. Pseudocereals are hence able to grow in marginal lands with minimal nutrient availability with no compromise in their nutritional value (Pirzadah and Malik 2020). Quinoa can withstand a wide temperature range from −8 °C to 35 °C (Jacobsen et al. 2005). Zhou et al. (2018) revealed the genes responsible for ion sequestration, ABA homeostasis and signaling which make quinoa tolerant to abiotic stress. This team of researchers also proposed a model for salt accumulation in the salt bladder (Rodríguez et al. 2020). The pseudocereals show high photosynthetic diversity, which makes them capable of growing in various geographic and climatic conditions (Pirzadah and Malik 2020). Thus pseudocereal cultivation is effortless since they are climate-resilient and can be grown on any marginal land. In the present condition of increasing population and urbanization, the cultivation of pseudocereals is the best way to tackle poverty and malnutrition among the people in the near generation.

Table 9.6 Bioactive compounds in pseudocereals and their health benefits

Pseudocereal	Bioactive compounds	Health benefits	Reference
Amaranth	Squalene	Hypocholesterolemic, anti-cancerous, cardioprotective	Adhikary et al. (2020)
	Phytosterols	Hypocholesterolemic	Ogrodowska et al. (2014)
Buckwheat	Flavanols—rutin and quercetin	Anti-tumour, anti-oxidant, anti-inflammatory, anti-bacterial, anti-fungal, anti-diabetic, immunoregulatory, neuroregulatory, anti-atherosclerosis, hypotensive, gastroprotective	Huda et al. (2021), Kwon et al. (2018)
		Anti-tumour, anti-oxidant, anti-inflammatory, anti-bacterial, anti-fungal, anti-diabetic, immunoregulatory, neuroregulatory, anti-atherosclerosis	Huda et al. (2021)
	Flavones—orientin, vitexin, homoorientin, and isovitexin	Anti-inflammatory, anti-neoplastic	Huda et al. (2021)
	Flavanones—hesperidin	Anti-inflammatory, anti-viral	Huda et al. (2021)
	Flavanols—catechins and epicatechins	Anti-oxidant, anti-bacterial, anti-neoplastic, anti-ageing	Huda et al. (2021)
	Anthocyanin	Cardioprotective	Huda et al. (2021) and Kwon et al. (2018)
	Proanthocyanidin	Anti-tumour, anti-cancer	Huda et al. (2021)
	Stilbenes—resveratrol	Anti-cancer	Huda et al. (2021)
	Phenolic acids—Protocatechaldehyde, vanillic acid, caffeic acids, salicylic acid, gallic acid	Anti-oxidant, cardioprotective, anti-neoplastic	Martínez-Villaluenga et al. (2020) and Huda et al. (2021)
	Tannins	Anti-tumour, anti-oxidant	Huda et al. (2021)
	Polysaccharides	Anti-tumour, anti-oxidant, anti-inflammatory, hepatoprotective, hypolipidemic, immunoregulatory, anti-diabetic, neuroprotective	Huda et al. (2021)
Chia	Sterols	Hypocholesterolemic	Ashura et al. (2021)
	Quercetin	Antioxidant, anti-inflammatory, antibacterial, antiviral, anti-hepatotoxic, hypocholesterolemic, vasodilation, blood thinning	Ashura et al. (2021)

(continued)

Table 9.6 (continued)

Pseudocereal	Bioactive compounds	Health benefits	Reference
	Caffeic acid	Hypoglycemic, activity, anti-oxidant activity, anti-cancer, memory protective, anti-hypertensive, neuroprotective	Ashura et al. (2021)
	Gallic acid	Antileukemic, anti-oxidant, anti-cancer, anti-neoplastic, anti-inflammatory, anti-diabetic	Ashura et al. (2021)
	Myricetin	Anti-bacterial, anti-gonadotrophic activity	Ashura et al. (2021)
	Kaempferol	Antioxidant, anti-diabetic, anti-cancer, cardioprotective, anti-inflammatory, anxiolytic, neuroprotective, analgesic, anti-allergic, anti-diabetic	Ashura et al. (2021)
Quinoa	Saponins	Anti-microbial, analgesic antioxidant, anti-inflammatory, cytotoxic, diuretic, hypocholesterolemic, hypoglycemic, anti-thrombotic, neuroprotective	Hernández-Ledesma (2019)
	Phytosterols	Anti-inflammatory, anti-cancer, anti-oxidant, hypocholesterolemic	Hernández-Ledesma (2019)
	Phytoecdysteroids	Anti-obesity, anti-osteoporotic, wound healing properties, anti-diabetic	Hernández-Ledesma (2019) and Vilcacundo and Hernández-Ledesma (2017)
	Phenolic compounds—phenolic acids, flavonoids, coumarins, lignans, quinine, phenols, phenylpropanoids, stilbenoids, xanthones	Anti-oxidant, anti-cancer, anti-inflammatory, anti-obesity, anti-diabetic, hypoglycemic, anti-diabetic	Hernández-Ledesma (2019)
	Polysaccharides	Anti-inflammatory, anti-cancer, lipid oxidation inhibitory agents, interleukins activators	Hernández-Ledesma (2019)
	Betalains	Anti-cancer, anti-lipidemic, anti-oxidant, antimicrobial	Hernández-Ledesma (2019)
	Bioactive proteins and peptides	Hypocholesterolemic, anti-diabetic, chemopreventive, anti-oxidant, anti-hypertensive	Hernández-Ledesma (2019)

9.6 Genetics and Genomics of Pseudocereals

One of the reasons for the negligence towards pseudocereals is the presence of anti-nutritional compounds which either cause low digestion of nutrients or make consumption difficult due to the characteristic taste and smell. Modern molecular methods can be used to find a way to overcome these limitations of pseudocereals (Yabe and Iwata 2020). Even though much research works has been done to know the evolutionary history and population structure of these plants, only very little genetic research work has been done on the genetic improvement of pseudocereal plants. This is due to the small and complex flowers of these plants which makes their handling during work difficult (Rodríguez et al. 2020). The wide scope of this topic opens the way to the development of a novel food habit in the world that ensures food security and proper nutrition. Genetic studies on the genes that are responsible for the climate resilience of pseudocereals also will benefit the development of new plant varieties which give the best yield with least requirements. The high content of essential amino acid lysine in amaranth was inferred to be due to the elevated expression of the *dihydrodipicolinate synthase* (*DHDPS*) gene in seeds and the presence of the *aspartate kinase 1 gene* (*AK1*) (Rodríguez et al. 2020). Stress-responsive transcriptome analysis of *Amaranthus hypochondriacus* by Délano-Frier et al. (2011) led to the understanding of the genes and their tolerance mechanism against various stress conditions. Genes involved in betalain biosynthesis, *cytochrome P450* (*CYP76AD1*) and *4,5-DOPA dioxygenase extradiol 1* (*DODA1*) were found using the physical and genetic maps by Lightfoot et al. (2017). A study on starch biosynthesis at a molecular level was done in *A. cruetens* by Park et al. (2017). It was already known that the amylose part of starch was produced by the granule-bound starch synthase (GBSS) encoded by the *Waxy* gene. Two isoforms of this gene viz. *CrGBSSI* in the perisperm and *CrGBSSIb* in the pericarp tissues of amaranth grains were found. The *CrGBSSI* gene is mainly expressed during the mid-late developmental stages of endosperm development whereas the *CrGBSSIb* gene expression was higher during initial developmental stages which implies that this enzyme may have a prominent role in the metabolism of amylose in pericarp starch (Park et al. 2017). The amylopectin part was coded by *soluble starch synthase* (*SSS*), starch branching enzyme, and starch debranching enzyme (Martin and Smith 1995). Park et al. (2012) revealed that the expression of *soluble starch synthase I* (*SSSI*) gene was high at the seed development stage. This expression pattern in amaranth indicates that the protein was essential for proper seed development (Park et al. 2012). This gene, even though expressed in a variety of tissues, showed a higher expression during the time of leaf development. The SSSI protein in grain amaranth was found to have three conserved regions common to all known starch synthases and *E. coli* glycogen synthase, which ultimately led to the conclusion that SSSI was detected in this study encoded a functional starch synthase enzyme. The SSSI gene showed a high degree of nucleotide polymorphism which may be beneficial in studying allele genealogies (Park et al. 2012). The transcriptome, gemone and physical map assembly of grain amaranth was performed by Clouse et al. (2016). A genome size of 377 Mb, a de novo transcriptome assembly with 66370 contigs from abiotic stress library and different tissues and a physical map of size 340 Mb generated in the BioNano Genomics platform by the study group. The molecular mechanism behind lysine richness of amaranth grain was unravelled by Sunil et al. (2014) through their genomics and transcriptomics study. They have annotated the genes involved in the lysine biosynthesis pathway of the plant through the comparative genomics and gene expression studies.

The shattering character of buckwheat was found using an AFLP marker and a linkage map was thus constructed around the *Shattering1* (*sht1)* gene locus by Matsui et al. (2004). Many research works were done for knowing the gene regulatory mechanism on the floral structure, salt tolerance, and aluminum toxicity in buckwheat. Whole-genome sequencing technologies like Illumina HiSeq 2000 were beneficial in deriving information about the genes involved in flavonoid biosynthesis, 2S albumin-type allergens biosynthesis, granule-bound starch synthases (GBSSs) etc. Identification of genes involved in the biosynthesis of rutin, one of the potent bioactive compounds in buckwheat, will definitely be helpful in the production of novel antioxidant compounds (Rodríguez et al. 2020). Two genes, *FtMYB16* and *FtMATE1* regulate the rutin biosynthesis with the former interacting with *Ftimportin-α1* mediates rutin biosynthesis and the later coding for the transporter of isoquercetin for the accumulation of rutin (Li et al. 2019). In another study by Koja et al. (2018), it was found that a recombinant *flavonol 3-O-glucoside 6″-O-rhamnosyltransferase* (*FeF3G6″ RhaT*) catalyzes the biosynthesis of rutin in the concerned rutin accumulating organs. *Flavonol 3-O-glucosyltransferase* (*F3GT*) first converts quercetin into isoquercetin which is then converted to rutin by *F3G6″ RhaT* (Koja et al. 2018). *MADS* genes, that control tissue and organ development, reproduction, and seed cracking were found to be relevant in the case of buckwheat since the fruit is very difficult to dehull. The study of cell walls showed that the presence of lignin, hemicellulose, cellulose, and pectin were the factors affecting fruit cracking. The easily cracking tartary buckwheat, rice-tartary had lower lignin, hemicellulose, and cellulase level but lower pectin level compared to the common tartary buckwheat. This trend in the rice-tartary favours easy dehulling and fruit cracking. Of the three potential targets of *SHP* genes in tartary buckwheat *MADS* gene family, expression of *FtpinG0009028100.01* and *FtpinG0009028000.01* was higher in easy cracking variety. *FtpinG0009028000.01* is the potential target for studying various aspects of dehulling characters of tartary buckwheat, which in the future may benefit developing novel varieties of consumer-friendly tartary buckwheat (Liu et al. 2019).

The chromosome number of quinoa was found to be $2n = 4x = 36$ (Stevens et al. 2006). The drought and salinity resistance of quinoa were studied by many researchers through transcriptome analysis. High lysine content was found due to the high expression of the gene encoding aspartokinase that converts aspartate to lysine. A high copy number of genes encoding the enzymes for vitamin B6 and dihydrofolate biosynthesis was found to be the reason for the higher availability of vitamin B and vitamin E in quinoa. *Triterpene saponin biosynthesis activating regulator-like* 2 (*TSARL2*) genes were found to be responsible for the saponin biosynthesis in quinoa seeds, which is an important bioactive compound. Also, its higher expression may cause a higher accumulation of saponin which imparts a bitter taste and certain anti-nutritional effects (Rodríguez et al. 2020). In a study done by Xiao-lin et al. (2022), 13 *Sucrose non-fermenting 1 (SNF1)-associated protein kinase 2* (*SnRK*$_2$) genes that encode proteins with complete serine/threonine protein kinase catalytic domains were found and named *CqSnRK*$_{2.1}$-*CqSnRK*$_{2.13}$. The *SnRK*$_2$ protein consists of protein kinase which helps a plant to withstand abiotic stress conditions like drought, salinity, and low temperature. The increased expression of *CqSnR*K$_{2.2}$, *CqSnRK*$_{2.11}$, and *CqSnRK*$_{2.12}$ in quinoa under drought treatment indicates the ability of quinoa to withstand drought conditions. Elevated expression of these genes was found to cause stomatal closure through the ABA signaling pathway which makes quinoa drought-resistant (Xiao-lin et al. 2022). The transcriptome sequencing of quinoa seedlings after salinity stress treatment revealed the molecular regulation involved in salt stress through the differential expression analysis. They documented that the genes coding for glucan endonuclease, glutathione S-transferase, phosphate transporter, beta-galactosidase, trichome birefringence-like protein, cytochrome P450 etc. were differently expressed (Ma et al. 2021). Many years before, the role of *Salt Overly Sensitive 1* (*SOS1*) in salinity tolerance mechanism of quinoa was analysed by Maughan et al. (2009) via genomic sequencing, expression analysis, fluorescent in-situ hybridisation and phylogenetic investigation, which was the first report on the salinity tolerance genes of Amaranthaceae family.

By using Illumina HiSeq 2500 and PacBio RSII, a draft genome of quinoa was assembled with a size of 1.1 Gb by Yasui et al. (2016a) and accordingly, Quinoa Genome DataBase was developed (QGDB; http://quinoa.kazusa.or.jp/). They also sequenced the genome of buckwheat using Illumina HiSeq 2000 and drafted data of 1.17 Gb size. Buckwheat Genome DataBase (BGDB; http://buckwheat.kazusa.or.jp) thus has about 35,816 annotated genes (Yasui et al. 2016b). This shows that, very limited genetic and genomic information of the pseudocereals is available. This suggests the dire need to do genetic and genomic studies on these pseudocereals to dissect their beneficial traits and to further improve them for greater food security and greater resilience. Further studies must focus on the genetics and genomics of the pseudocereals.

9.7 Challenges in Using Pseudocereals

Some compounds in pseudocereals were found to be anti-nutritional and harmful to human health. Excessive intake of them may cause serious health issues. Saponins in quinoa are anti-nutrient when consumed above the recommended limit, they cause hemolytic properties causing the release of hemoglobin due to the increased permeability of erythrocytes (Martínez-Villaluenga et al. 2020). They were also found to show membranolytic and fungi toxic activities (Melini and Melini 2021). Tannins present in pseudocereals were found to cause damage to the intestinal mucosa and thereby hinder mineral absorption. Their characteristic astringent smell also reduces their consumption (Melini and Melini 2021). Phytates also negatively affect mineral bioavailability by forming phytate complexes with Fe^{2+}, Zn^{2+}, Ca^{2+}, etc. (Melini and Melini 2021). The presence of trypsin inhibitors is also considered as anti-nutritional factor since they interfere with the action of trypsin in the intestine and thereby affect protein digestion (Satheesh and Fanta 2018). Oxalate present in amaranth, buckwheat, and quinoa cause susceptibility to secondary hyperoxaluria that ultimately leads to calcium oxalate stone formation (Jancurová et al. 2009). The presence of such anti-nutritional compounds thus becomes a reason for the reduced consumption and production of these pseudocereals. However, modern genetic tools can be used to silence the genes that govern the biosynthesis and accumulation of such antinutrients in the plants. These technologies can be used to reduce the contents of harmful compounds in the pseudocereals.

9.8 Conclusions and Future Prospects

Pseudocereals open a wide opportunity in the agricultural, pharmaceutical, and research field. Instead of limiting ourselves to hand-countable cereals, it is better to diversify our food menu by including these pseudocereals. This will not only help us improve our health and ensure the sufficient availability of nutrients but also increase the biodiversity of our nature. A new era with widespread cultivation of pseudocereals even in local lands should be a goal of the nations who fear food crisis in the future. Their importance ranging from the supply of various nutrients to unique bioactive compounds that improve the overall health of a person indicates how they can be effectively brought into the diet of the modern generation where the concept of leading a healthy life is a progressing trend. Cultivation of these grains will also be profitable since they demand only very less nutrients and maintenance. They are also a promising crop in producing gluten-free food products with the supply of all essential nutrients. Hence, they are important for CD patients in leading healthier lives in a more financially supportive way. Since only very limited works has been done in the field of genetic improvement of these pseudocereals, wide opportunities are being opened up before us to explore. Genetic improvement may be also helpful in overcoming the limitations that are being faced during its cultivation and also to reduce the anti-nutritional compounds in it. Maximum utilization of these grains will help to overcome the nutritional deficiency problems. Proper utilization of marginal lands for the cultivation of pseudocereals is thus economically beneficial. Pseudocereals thus are relevant in economic, social, nutrition, ecological, and functional aspects. A proper action plan for its public acceptance through awareness programs on its nutritional importance and scopes in its cultivation may help to diversify our food habits in a more healthier and economical way.

Being highly rich in nutrients and climate-smart crops, there is a wide scope for a large-scale acceptance of pseudocereals. Until now, only very little work has been done in the genetic improvement of pseudocereals. One of the major limitations of these pseudocereals is their small size and shattering of grains, which makes them less preferred by farmers to cultivate. Hence studies and work which would help to overcome these issues will benefit us to ensure a world without food scarcity and malnutrition. Knowledge about these nutritious pseudocereals is very limited since these grains were not a member of our food habits for nearly two or three generations. In India, where the population is increasing exponentially and the cultivable land is converted for non agricultural purposes, there would be a need soon where even marginal land should be converted into productive land to meet the food needs of people. Pseudocereals are thus important since they can be grown in marginal land with very limited nutrient availability and labour effort. As an important functional food, genetic improvement of pseudocereals plays a very important role which can enhance the bioactive compounds present in them. Using modern genome sequencing, gene modification and gene editing methods, many beneficial traits can be incorporated into the pseudocereals. Genes responsible for the biosynthesis and accumulation of of bioactive compounds and nutrients can be transformed into suitable vectors and their culturing thus helps in the large-scale production of improved crops. More studies are needed to improve the pseudocereals but focus should also be placed on the awareness programs to popularise the consumption of pseudocereals to tackle poverty, malnutrition, and hidden hunger.

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