Adzuki Bean

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Introduction

The adzuki bean (*Vigna angularis*) is a legume crop, mostly bushy and upright, typically 1–2 ft. in height. The adzuki bean belongs to the Fabaceae family; it is commonly known as adzuki bean, red bean, and red mung bean. The wild forms of adzuki bean are supposed to be originated in Japan for over 6000 years ago, whereas the cultivated varieties were developed 4000 years ago. It is widely grown in the Yangtze River valley in China (FAO 2007). It occupies second rank after soybean among dry bean crop in Japan. These beans are also stated to be used as a soil improvement crop and animal feed crop (FAO 2007).

The bean has mainly straw-coloured pods, but sometimes black- or brown-coloured pods have also been reported. It is cylindrical in shape, 6–12 cm in length, and 5 mm in diameter. Each pod contains approximately 5–12 seeds and constitutes half of the total weight of the pods. The seed has a variation in the colour from maroon, straw, brown, and black. The skin of the bean is tough, whereas the cotyledon is normally smooth. The seed coat of the bean is red in colour and contains polyphenols, flavonol glycosides, and catechins (Ariga and Asao 1981; Hori et al. 2009; Yoshida et al. 2005).

At present, various varieties of adzuki bean are cultivated in more than 30 countries which include Korea, New Zealand, India, Taiwan, Thailand, and the Philippines. The variation in the features is dependent on the cultivar type, time of growing, time of harvesting, and climatic conditions (Gohara et al. 2016).

In Japan, there are approximately 60 types of adzuki bean grown and traded; the seed size ranges from 5 to 8 mm in length and 3–5 mm in width (Chilukuri and Swanson 1991). The seeds can be allocated into two types—small size (regular) is

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A. Manickavasagan, P. Thirunathan (eds.), *Pulses*,
https://doi.org/10.1007/978-3-030-41376-7_1

greater than 4.2 to less than 4.8 mm in length, known as Erimo type, and large size is greater than 4.8 mm in length, named as Dainagon.

Overview of Production, Export, and Import

Adzuki bean is grown in a place with annual precipitation in between 530 and 1730 mm and temperature range of 7.8–27.8 °C. The preferable soil pH is 5.0–7.5 (Duke 1981). The major adzuki bean producers are Japan, China, Taiwan, and South Korea. According to Sacks (1977), adzuki bean is the sixth largest grown pulses in Japan. The bean is cultivated in an area of 670,000, 120,000, 30,000, and 20,000 ha, in China, Japan, Korean peninsula, and Taiwan, respectively (Rubatzky and Yamaguchi 1997). In the United States, the bean is grown in a very limited quantity; the sole purpose is for the production of seeds and to be exported to Japan.

As such, there is not much production database available for adzuki bean. Japan imports the bean from China, Taiwan, the United States, Thailand, and Canada; it produces 100,000 tons/year and further consumes 140,000 tons/year. In the oriental market, the seed and seed flour are a commodity of high economic value (PlantUse English Contributors 2015).

The major area of adzuki bean production in Japan is Hokkaido, and the yield varies according to the duration of growing season and weather conditions. In China, the major areas are Wuqing County, Hebei Province, Jilin Province, Tai Lai County of Heilongjiang Province, north of the Huaihe River, and near Qinling. The areas in Taiwan include Pingtung and Kaohsiung provinces. In South Korea, it is the fourth vital legumes grown in terms of area and production. In the United States, it is supposed to be introduced in the year 1854 by the Perry Expedition. The United States uses it as a fodder crop (Hoshikawa 1985; Sacks 1977).

Chemical and Nutritional Qualities

The adzuki bean is a vital source of proteins, minerals, carbohydrates, fibres, and vitamins (Tjahjadi et al. 1988). It is rich in polyphenols, catechins, and chlorogenic acid (Yoshida et al. 1996, Ariga and Hamano 1990; Ariga 1988). Adzuki bean has few antinutritional factors like phytates, α-galactosides, and trypsin inhibitors whose quantity relies on the different cultivars of the crop.

The chemical composition of adzuki bean greatly varies in accordance with the variety of the crop. The nutrient contents of adzuki bean (Tables 1 and 2), i.e. the content of carbohydrates, proteins, lipids, vitamins, and minerals, are very much related to other legumes. The protein content varies with the seed size (Kato et al. 2000). The key storage proteins of adzuki bean are glycoproteins (Sakakibara et al. 1979). It has been reported that the amylose/amylopectin ratio of adzuki bean is 34.9/65.1 and 27.9/72.1, respectively (Biliaderis et al. 1980; Su and Chang 1995).

Table 1 Adzuki bean nutrition profile: (*Vigna angularis*) per 100 g (Source: USDA National Nutrient data base 2019)

Principle	Nutrient value
Energy	329 Kcal
Carbohydrates	62.90 g
Protein	19.87 g
Total fat	0.53 g
Cholesterol	0 mg
Dietary fibre	12.7 g
Vitamins	
Folates	622 μg
Niacin	2.630 mg
Pantothenic acid	1.471 mg
Pyridoxine	0.351 mg
Riboflavin	0.220 mg
Thiamin	0.455 mg
Vitamin A	17 IU
Vitamin C	0 mg
Electrolytes	
Sodium	5 mg
Potassium	1254 mg
Minerals	
Calcium	66 mg
Copper	1.094 μg
Iron	4.98 mg
Magnesium	127 mg
Manganese	1.730 mg
Phosphorus	381 mg
Selenium	3.1 μg
Zinc	5.04 mg

The starch obtained from adzuki bean has properties similar to corn starch in terms of colour, swelling power, solubility, amylose content, and gel strength. The shape of starch granules was found to be smooth, round, oval to kidney, or irregular (Reddy et al. 2017). The viscosity of its hot paste was more than corn starch and far more than wheat starch. The adzuki bean starch is very much different from the potato starch in most of its properties other than colour and amylose content. Thus from the study, it was concluded that unmodified adzuki bean starch can be used as thickeners and water-binding agents in the place of corn and wheat starch (Tjahjadi and Breene 1984).

Like other pulses, cysteine and methionine are limiting amino acids in adzuki bean. It has 25% saturated fats and 75% unsaturated fatty acids. It has a minimum of 0.4% and a maximum of 2.1% fat content which is comparatively very less than the fat content of groundnut (40.1% fat) (Su and Chang 1995). While in the case of total lipid content of adzuki bean, it is less than 2% and is alike to other foods such

Table 2 Amino acid profile of adzuki bean (*Vigna angularis* var. Tjahjadi et al. 1988)

Amino acid	g/16 g Nitrogen
Cystine/2	2.02
Aspartic acid	11.33
Threonine	3.74
Serine	4.53
Glutamic acid	17.70
Proline	5.51
Glycine	3.74
Alanine	4.10
Valine	5.63
Methionine	1.78
Methionine and cystine	2.79
Isoleucine	5.02
Leucine	8.70
Tyrosine	3.31
Phenylalanine	6.31
Phenylalanine and tyrosine	9.62
Histidine	3.55
Lysine	8.45
Ammonia	1.71
Arginine	7.78
Tryptophan	0

as rice, rye, bean, and chickpea, with the benefit that the fat of adzuki bean has PUFA n-6/n-3 having great advantage in the human nutrition (Yoshida et al. 2010). The adzuki bean releases a distinct sweet beany aroma upon cooking. The characteristic odour of bean is due to the following chemical compounds—hydrocarbons, alcohols, acids, phenols, and many more. The principal odour compound is maltol that gives a prominent sweet caramel-like flavour (Tokitomo and Kobayashi 1988). Adzuki bean is rich source of polyphenols amounting to 370 mg per 100 g of dry bean.

Medicinal Values of Adzuki Bean

In China, the adzuki bean is used for the treatment of diseases like kidney trouble, constipation, abscesses, certain tumours, threatened miscarriage, retained placenta, and non-secretion of milk. The leaves of the bean are suitable for lowering fever, whereas the sprouted bean is used to prevent abortion that is caused by injury. The compounds present in adzuki bean lowers blood pressure, cholesterol, and triglyceride levels, which finally lead to a healthy heart. It has several other health benefits that include improved bone health to prevent the spread of cancer cells. This bean is used at a large scale in traditional China as a diuretic, an antidote, and as a medication for dropsy and beriberi (Chiang Su New Medical College 1977). The adzuki bean has powerful antioxidant, anti-inflammatory, anti-diabetic, and anti-hypercholesteraemic properties (Luo et al. 2016; Shigenori et al. 2008; Tao et al. 2011; Tomohiro et al. 2009). The investigators have also found that the 40% ethanol part of the hot water extract from the bean stops the proliferation of stomach cancer cells in humans (Itoh et al. 2002).

Post-harvest Processing

The post-harvest handling and storage is a vital phase for long-term usage of the bean with all the properties intact. The unit operations involved in the post-harvest processing of adzuki bean are represented in Fig. 1. The various processes that are being carried out after the harvesting stage of bean to maintain its quality during long-term application are summarized in this section.

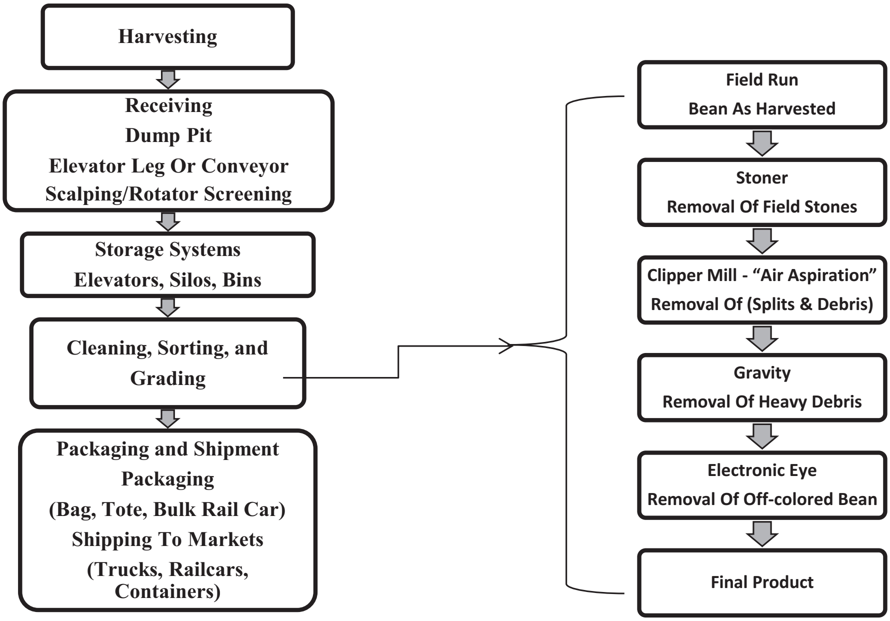

Fig. 1 Unit operations in raw adzuki bean handling and cleaning (Source—Kelly et al. 2013)

Storage

After harvesting, the bean is loaded on the trucks and then conveyed to the storage receipt elevator. It is then passed to the aspirator to remove any kind of impurities; this initial step removes foreign materials which can have spoilage in the bean during long-term storage. Most often the bean is stored in steel silos where the quality parameters are strictly monitored to retain its quality, as the weather fluctuation can have negative impact on the bean. There is a provision of continuous aeration in the silos to maintain a proper temperature balance and prevent the development of any kind of off-flavour or odour.

The adzuki bean is then transferred to the large storage silos for medium- or long-term storage before further cleaning is carried out. There is a central elevator which lifts the bean from the pits and deposits it on conveyor to be transferred into the large silos. Inside each large silo, there is bean ladder which helps in the proper flow of bean inside with sliding and circular motion and thus reducing the damage caused to the seed coats. The temperature below 18% is best for the bean before storage in the silos. The bean is then separated on the basis of size and colour before being taken for the shipment (Sacklin 1985). The bean is normally stored in silos which can be made up of wood, steel, or concrete. Among the entire concrete one is having high strength and larger capacity. It can also sustain fluctuating weather conditions which has adverse impact on the quality of bean (Roberston and Frazier 1978). Nowadays the flat storage system is gaining popularity because of the presence of free span pole building construction, where the bean is stored on a concrete floor. This system provides flexible filling and keeps an account on the seed coat damage. Proper knowledge of angle of repose is necessary for the proper filling of silos.

Moving further, the steel bins are the most commonly used storage area as it is available in a variety of shapes and sizes. It is easy to install on farms. It is made up of plates of corrugated steel bolted together to give the desired height and is closed on top with a steel structure. It has the provision of proper aeration and has conveyor belts that cause loading and unloading of bean.

The adverse storage conditions can lead to fungal spoilage, seed hydration defects, reduced digestibility, and less nutrient bioavailability. There are several defects arising from poor storage condition which are “bin burn”, “hard-shell”, and “hard-to-cook” (HTC) phenomena (Pirhayati et al. 2011; Reyes-Moreno et al. 1993). Yousif et al. (2002) found that at a high temperature preferably above 30 °C, the cooked adzuki bean has hard texture. The effect is also seen in the bean stored at a low RH of 40%. The favourable cooking quality was observed in adzuki bean stored at a temperature of 10–20 °C and 65% RH.

Handling

During conveying, the bean is transferred to the elevator, and then a known quantity of it is taken for quality analysis and to make sure the absence of any foreign particles. The most prominent effect of loading and unloading is on the seed coat of bean. The most frequent damage in bean occurs during conveyor transfer due to mechanical dropping and shattering. The poor design of bucket lifts causes damage to the seed by shearing action. The bean dropping has a detrimental consequence on the seed coat damage (Shahbazi et al. 2012). It is suggested to have less drop distance to minimize damage. The presence of bean ladders greatly diminished the seed coat damage by decreasing the free fall of the bean. A conveyor belt is comparatively better than auger conveyor in comparison to the damage caused to the bean.

Receiving and Cleaning

The bean is fed into the local elevator; it is then weighed and then transferred into a handling pit which is available at the floor of the receiving area. Now the next cleaning process is carried out; the first operation here is the application of high-velocity air to separate out any foreign material from the bean which is lighter in weight compared to bean. Moving further, the next step is removal of heavier materials which involves the application of a gravity table to remove stones and mud balls. It separates out heavier particles by vibratory motion, and on the basis of density, the bean and stones are separated out. The stone gets collected at the edge of the table. The separation on the basis of size is carried out on a sieve which divides the whole lot into oversized and undersized materials. This process of screening provides uniformity in a lot of beans and has a good economic value in the market. The next stage is the separation on the basis of colour which involves electric eyes that have a series of photoelectric cells. The bean is passed across lanes near the photoelectric cells, where a blast of air the rejects the discoloured bean. This process of colour sorting causes uniformity in the bean leading to a commodity of high economic value.

Drying

This is the process of reducing the moisture content from the bean by supplying heated air through forced convection (Afonso Júnior and Corrêa 1999). This step leads to enhanced storage life by providing physical, chemical, and microbial stability. But higher rate of moisture removal can have an adverse effect on seed quality (Almeida et al. 2009). Resende et al. (2012) reported that the drying time reduces by increasing the air temperature; the air temperature of 60 °C and 70 °C adversely affects the physiological and technological seed quality. Hence the favourable temperature for adzuki bean drying without causing any damage to the properties must not exceed 50 °C.

The process of drying also alters the physical properties of adzuki bean like an increase in sphericity and surface-volume ratio and decrease in volume, unitary volumetric contraction, surface area, and projected area (Mendes et al. 2016). The freeze-dried adzuki bean hydrolysate powder contained higher antioxidant activities as compared to ungerminated adzuki bean; also the DPPH radical scavenging activity estimated through electron spin resonance spectrometry of the freeze-dried adzuki bean was higher as compared to the colorimetric method (Sangsukiam and Duangmal 2017).

Packaging

The adzuki bean is carefully examined prior to weighing and filling into blue poly-lined cartons. The cartons are checked for the best before and production date, weight, and presence of metals, properly palletised, stretch wrapped, and then stored at a temperature of −18 °C till the time it is dispatched. Apart from this the package is also checked for the physical defects, case sealing, case coding, and print quality (Foodnet Limited 2018). The bean if not stored properly can lead to spoilage and loss in organoleptic characteristics.

Effect of Storage on Quality Factors

1. Effect on Cooking—The adzuki bean stored at high-temperature hydrate unequally during cooking which leads to irregular bean softening and finally results in the phenomenon of hard-to-cook (HTC) bean. These beans have reduced nutritional and organoleptic quality. The inappropriate storage of beans decreases the water imbibition capacity, which leads to decrease in the yield of Ann (Yousif et al. 2007).
2. Starch Quality—The fresh adzuki bean with a moisture content of 11% achieves 50% gelatinization, whereas adzuki bean stored for 1 year having a moisture content of 8% achieves 18% gelatinization. The unfavourable storage of Bloodwood and Erimo varieties at high temperature and reduced relative humidity leads to a rise in the starch gelatinization onset and peak temperature; it indicates the resistance of starch within the granules for gelatinization. Thus it causes loss of adzuki bean cooking quality (Yousif et al. 2007).
3. Texture—There was double-fold increase in the cooked adzuki bean hardness after storing at 30 °C and elevated relative humidity of 75% in comparison to the beans which were stored at 5 °C with increased relative humidity, 5 °C with reduced relative humidity of 45%, and 30 °C with reduced relative humidity. It was observed that hardness was because water was not able to enter into the cotyledon tissue of the bean and was in the free spaces of the bean that is the seed coat and the cotyledon fissure. Hence, finally it was observed that the bean uptakes water; however the cotyledons were not able to hydrate accurately (Ozawa 1978).

4. Protein Quality—The storage of bean at elevated temperature of 30 °C led to an increase in the presence of higher molecular weight proteins as estimated by size exclusion HPLC (Yousif et al. 2003). The change in the qualitative and quantitative electrophoretic protein pattern was observed in the bean stored at a high temperature of 30 °C and increased relative humidity of 85%. This change was reported to be because of the denaturation of the protein during storage period (Hussain et al. 1989). Further there was a decrease in the onset temperature and gelatinization peak temperature from the protein extracted from the bean which was stored at 40% relative humidity in contrast to those kept at a relative humidity of 65%. This shows the occurrence of destabilization in the protein at high relative humidity (Yousif et al. 2003).

Novel Processing Techniques

1. High Hydrostatic Pressure—The high hydrostatic pressure (HHP) treatment is a non-thermal method which is given distinct importance in the food industry since it reduces the cooking time without having any adverse effect on the nutritional value of the food (Bello et al. 2014). The application of HHP in adzuki bean led to a rise in the effective diffusion coefficient and decrease in the water absorption time. The value of effective diffusion coefficient of HHP-treated adzuki bean (6.7×10^{-11} m^2 s^{-1}) was found to be similar to that of various untreated grains that comprise soybean ($1.8–4.2 \times 10^{-10}$ m^2 s^{-1}), green bean ($0.8–3.6 \times 10^{-10}$ m^2 s^{-1}), brown rice (3.9×10^{-11} m^2 s^{-1}), barley (1.0×10^{-11} m^2 s^{-1}), wheat (4.0×10^{-11} m^2 s^{-1}), and amaranth (2.6×10^{-12} m^2 s^{-1}). Hence it can be said that the HHP has a significant impact on the structural modifications in the adzuki bean. This information will surely lead to a surge in the demand of adzuki bean for cooking purposes (Ueno et al. 2015).
2. Ozonation—The application of ozone in grains leads to degradation of mycotoxin and inactivation of microorganisms and helps in insect disinfestation. On the other hand, the oxidizing property of ozone causes a change in the constituent of the grain and thus has an impact on both product characteristics and process behaviour. In the case of adzuki beans, there was no significant effect of ozonation found in the hydration kinetics, phenolic compounds, and antioxidant capacity. Therefore, ozonation can be an important approach for the control of grain contaminants without affecting its quality (Santos Alexandre et al. 2018).

Product Development

In East Asia, adzuki bean is consumed in numerous ways for more than 2000 years owing to its maroon seed colour and mild flavour; it was conventionally served on the eve of celebrations such as weddings, birthdays, or New Year parties (McClary et al. 1989). It is normally made into a component of sweet soups like *zenzai* and *sarashi ame*, which is when mixed with rice called as *azuki-mochi* and *sekihan*, when mixed with sprouts called as *moyashi*. In China and Japan, the adzuki seeds are used as traditional foods like amanatto and wagashi (Gohara et al. 2016). The adzuki bean is very common ingredients of confectioneries in Eastern Asia, particularly in Japan. In this section, there is a description of some of the food and non-food applications of the adzuki bean.

Meat Extender and Fat Replacers

Owing to its high content of protein and fibre, adzuki bean has a great possibility to be used in meat product as a meat extender and fat replacer. The use of different proportions of adzuki bean flour in the place of cornflour and fat led to the production of a meatball with reduced fat and good acceptability. The adzuki bean flour has the capability to bind water, as the meatball with 100% (w/w) of the flour showed maximum cooking yield and more moisture content as compared to the meatballs with no content of flour. This replacement of cornflour and fat in meatballs with adzuki bean flour led to a reduction in the calorie count, keeping protein and carbohydrate quantity similar to the meatball without the flour. The organoleptic test for the meatballs with 25% (w/w) and 50% (w/w) of adzuki bean flour did not show any prominent variation from the meatball without flour, but they received highest overall acceptability among the panel members. Further the meatballs with 50% (w/w) replacement of cornflour with adzuki bean flour were reported to have enhanced physicochemical properties and better organoleptic properties as compared to the meatballs without adzuki bean flour (Aslinah et al. 2018).

Bakery and Confectionery Products

1. Ann—The paste made from adzuki bean is known as Ann, it is normally sweet in taste (Kato et al. 2000). The seed coat of the bean is responsible for the unique colour of the bean paste. There are two forms of adzuki bean paste, one is made by removing the seed coat called “Koshi-Ann”, and the other one is made with the seed coat called “Tsubu-Ann.” The preparation process for Koshi-Ann involves boiling of bean in freshwater, then draining the extra water further reboiling it. After that the seed coat is removed and approximately 40% of sugar is added to it. Then it is mixed properly, packaged, and stored at chilling or freezing condition. The Tsubu-Ann is made in a similar way like Koshi-Ann but with seed coat intact. The boiling step involved here causes tenderization of the seed coat and cotyledon. This process further is responsible for the distinct colour, flavour, and texture of the product that is again linked to the variety, age, and storage conditions of the adzuki bean (Yousif et al. 2007). In Japan, “Ann” is

available as peanut butter; it also comes in smooth and chunky forms with textures ranging like baked bean. In Japan, the manufacturer calls Ann as Asian chocolate because it has same role as chocolate in the western confectionery. The common use of Ann is as a filling for the snack buns, cakes, steamed dumplings, and doughnuts. The Ann, when sandwiched in between the two silver-dollar pancakes, is called as the dorayaki snack cake. The Ann is served as the main ingredient along with the sticky rice in the conventional Japanese wagashi sweet during the tea ceremony. The Ann has also found a new application in frozen desserts, where it is used as a topping for ice cream also as a flavouring agent (Ag Marketing Resource Center 2019). The bakery product that is commonly made with wheat or rice flour that has Ann filled within it is called manju. The Ann-filled glutinous rice cake is called as daifuku. The bun with Ann filling is called Anpan. Finally the baked pastry with Ann filling is called as monaka.

2. Anko—Anko is a traditional Japanese product made up of soaked and boiled adzuki bean paste; further johakuto a Japanese sugar or regular granulated sugar is added to it. It is used as an ingredient in Japanese confectionery products (Borchgrevink 2013).

Extruded Products

The use of adzuki bean flour has a beneficial effect on the commercial and nutritional quality of the Chinese steamed bread. The incorporation of extruded adzuki bean flour reduces the development time, stability time, and the farinograph quality number in the bread, whereas the water absorption and softening degree increase in the bread. The pasting properties of the product decreased with addition of the extruded adzuki bean flour. Also, this flour incorporation reduces the lightness and strengthens the hardness of the bread. The α-glucosidase inhibitory activity of the protein was enhanced in the bread by the addition of the flour. This inhibitory effect increased to 39.88% which is five times more as compared to the bread made from wheat flour (Chen et al. 2019).

Beverages

1. Adzuki-Flavoured Pepsi Drink—In 2009, Pepsi Japan released an adzuki-flavoured Pepsi drink where they blended the aroma of adzuki into the original Pepsi flavour. The product was the second seasonal drink in the year 2009, followed by the shiso-flavoured cola released in the summer. The blending of the adzuki bean flavour in the carbonated drink has a refreshing and unique tang. This product is mainly for the people in the age group of 20–30 (Japan Today 2009).

2. Probiotic Yogurt—A probiotic-based yogurt with high nutritional value and low production cost is also available; it includes skimmed milk and adzuki bean (Qing et al. 2009).
3. Granuliform Adzuki Bean Set Yogurt—In China, there is a beverage from the bean known as granuliform adzuki bean set yogurt. The optimized parameters for the preparation of yogurt are reported to be 10% of adzuki bean, 8% of milk powder, 8% of sugar, 4% of inoculums size, 4 h of fermentation time, and 42 °C of fermentation temperature (Li et al. 2011b).

Germinated Product

The sprouted adzuki bean is known as a vegetable. In China, the sprouted adzuki bean is called as Yuweiya if seeding for around 3 days and is called as Yuweimiao if seeding for around 7 days. The sprouted adzuki bean has a soft and somewhat crispy texture with an attractive fragrance (Li et al. 2011a).

Future Trends in Processing and Product Development

The problem of deep-rooted malnutrition can be cured, and overall human health can be maximized by taking into consideration the dietary quality of adzuki bean. In order to maintain the equilibrium with increasing yields and household techniques, there is a need to diversify the food production both at countrywide and domestic level (Singh and Raghuvanshi 2012). Unawareness of people is to the extent that they are not using few agricultural foods as main food despite their high nutritional quality. Adzuki bean is also one of such things that have many nutritious and medical properties but underestimated (Yao et al. 2012). Dried adzuki bean has the potent to supply few health-improving nutrients related to plant-based diets. The adzuki bean is a vital source of protein and is rich in various numbers of micronutrients, comprising potassium, magnesium, folate, iron, and zinc. Vegetarians have important role of dried bean in their diets because it contributes to some of the health benefits.

The prevailing consumer outlook on the adoption of healthy products is evident. Hence, consumers are drifting towards traditional and healthy eating habits. Adzuki bean is considered to be nutritional powerhouse as it is rich in fibre, protein, and folic acid. Adzuki bean can be used in various forms such as extract and paste. The lipid fraction of the bean proved to have anti-atherogenic, anti-thrombogenic, and hypocholesterolemic effects, whereas the ratios PUFA: SFA and n-6:n-3 was considered suitable for the proper activity of the systems in the human body. Thus there is a need to popularize this underutilized bean and more research should be undertaken to explore its full potential.

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