Ricebean

Dadasaheb D. Wadikar and Rejaul Hoque Bepary

Introduction

Ricebean [*Vigna umbellata* (Thumb.), previously *Phaseolus calcaratus*] is a nonconventional and underutilized bean and an important crop for the generation of livelihood for poor rural and tribal farmers of South and Southeast Asia. Ricebean is also known as climbing mountain bean, *mambi* bean, oriental bean, and *Beziamah* in the Assamese language (Saini and Chopra 2012). Ricebean has a rich genetic diversity and high agricultural and nutritional potential in terms of being able to grow well in comparatively poor soils in hot and humid climates and resistance to storage pests and serious diseases (Chandel et al. 1978; Singh et al. 1980). Ricebean is a native crop of South and Southeast Asia (Ohwi 1965). It is mainly grown as a crop in India, Philippines, China, Myanmar, Malaysia, Korea, Indonesia, Fiji, Sri Lanka, Mauritius, Sierra Leone, Ghana, Zaire, Tanganyika, Jamaica, Haiti, and Mexico and also to a limited extent in the West Indies, USA, Queensland (Australia), and East Africa. In India, it is cultivated mainly as a rainfed crop in the Northeastern Hills, West Bengal, Sikkim Hills, Western and Eastern Ghats Hills, Chhota-Nagpur region and parts of Odisha in the Eastern peninsular tract, Kumaon Hills (Uttarakhand), and Chamba region (Himachal Pradesh) in the Western Himalaya. About 16 different grade colours, mainly black, red, cream, violet, purple, maroon, brown, chocolate, or mottled grains with greenish, brownish, or ash grey background, are available in ricebean grains (Arora et al. 1980; Chandel et al. 1988), which indicates the grain is a rich source of bioactive compounds. In Northeast India it is grown mainly in the tribal region of Assam, Meghalaya, Manipur, Mizoram, Arunachal Pradesh, and Nagaland. It is an important crop of shifting cultivation (1.7 m ha area) or kitchen gardens (Sarma et al. 1995) for reasons of attributes such as quick maturity, freedom from major insect and disease problems, and

D. D. Wadikar (✉) · R. H. Bepary
DRDO-Defence Food Research Laboratory, Mysore, India

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producing easily cooked, good-tasting seeds. Ricebean seeds have a smooth shiny surface, are slender to oblong in shape, 6–8 mm in length, 3–5 mm in width, 3–4 mm thick; rounded at both ends and with concave, straight, or protruding hilum (de Carvalho and Vieira 1996; Bepary et al. 2018a). The proportion of cotyledon, testa, and embryo in ricebean ranges from 88% to 90%, 7% to 9%, and 0.3% to 0.5%, respectively. The world production of ricebean alone is about 1407 metric tons from an area of 1804 hectares with productivity of 2.25 q/ha. Very limited information is available on marketing of ricebean in the international trade. In the international trade of ricebean, Japan is the major importer whereas Thailand, Myanmar, China, and Madagascar are major exporting countries. In 1998–2000 about 1100 tons were exported annually. In recent years, Thailand has exported ricebean to Japan where it used in lieu of azuki bean (*Vigna angularis* (Willd.) Ohwi & Ohashi) (Tomooka et al. 2006). The proximate composition summarised in Table 1 by Bepary et al. (2016) shows that the ricebean is a carbohydrate-rich grain with about 20% protein and low levels of fat content. It has high-quality protein with all essential amino acids in a balanced manner. The starch of ricebean has the lowest glycemic index (GI) compared to other beans such as mung bean, pea, pigeon pea, soybean, and cowpea. Ricebean has higher levels of potassium, calcium, iron, and zinc with better bioavailability for calcium and zinc. The oligosaccharides (flatulence-producing saccharides such as raffinose, stachyose, verbascose, and ajugose) content in ricebean are lower than other pulses (Bepary and Wadikar 2019). The antinutritional factors such as trypsin inhibitor, α-amylase inhibitors, polyphenols, saponin, and phytic acid are greater, although tannin content is low as compared to other commonly consumed pulses. However, processing reduces these antinutrient components drastically. The hydrogen cyanide (HCN) and L-DOPA content in ricebean are lowest among the seven species of *Vigna.* Ricebean grain is rich in water-soluble vitamins (mg/100 g) such as thiamine (0.261 ± 0.164), ascorbic acid (0.903 ± 0.404), niacin (1.141 ± 0.713), pyridoxine hydrochloride (1.242 ± 1.593), pyridoxal-5-phosphate (3.353 ± 0.650), pantothenic acid (3.450 ± 2.609), folic acid (0.139 ± 0.071), and riboflavin (0.083 ± 0.038) (Bepary et al. 2019a). Ricebean bioactivities include hepato-protection, antiinflammation, anticancer, antifungal, antidiabetic, antihypertension, immunity booster, HIV-1 inhibition, and inhibition of mutagenic activities (Bepary et al. 2016). Much variation has been observed in phytic acid (%) content in ricebeans based on the reports wherein the percent of phytic acid is found to be 7.32–8.17 (Katoch 2013), 3.36 ± 0.57 (Kalidass and Mohan 2012), 2.02 ± 5.9 (Saharan et al. 2002), and 1.88–2.05 (Kaur and Kapoor 1992). The total polyphenols among the several ricebean cultivars ranged from 0.58 to 1.82 (Bepary et al. 2016). The biological value of ricebean protein is found to be 65.63 ± 1.43% with net protein utilization (NPU) of 57.31 ± 1.19% and true digestibility of 87.23 ± 0.32% (Singh et al. 1980). The ricebean grain thus has good nutritional content and wide scope for commercialisation through different processing techniques and value addition. Although postharvest management is crucial for all grains, for ricebean being traditionally grown in several parts of Southeast Asia varied postharvest practices are followed.

Table 1 Proximate composition of ricebean (g/100 g)

Author	Moisture	Carbohydrate	Protein	Fat	Crude fibre	Ash
Du et al. (2014)	9.8 ± 0.0	–	25.68 ± 1.19	1.58 ± 0.04	–	4.25 ± 0.16
Kaur et al. (2013)	–	–	19.67 ± 0.56	0.61 ± 0.36	–	4.11 ± 0.46
Katoch (2013)	–	54.22 ± 1.00	24.52 ± 0.58	2.61 ± 0.45	4.73 ± 0.49	–
Ren et al. (2012)	10.65 ± 0.70	–	25.99 ± 1.26	1.69 ± 0.09	–	3.26 ± 0.12
Pawar et al. (2012)	10.3 ± 0.07	61.6 ± 0.08	17.5 ± 0.05	0.51 ± 0.005	5.59 ± 0.06	4.5 ± 0.007
Kalidass and Mohan (2012)	5.56 ± 0.02	54.23 ± 1.60	26.12 ± 0.56	4.18 ± 0.50	4.74 ± 0.01	4.04 ± 0.04
Awasthi et al. (2011)	9.5–10.9	58.0–61.2	17.9–19.4	0.48–1.15	4.6–6.7	3.9–5.7
Buergelt et al. (2009)	10.26 ± 1.16	65.08 ± 3.49	22.53 ± 4.14	0.39 ± 0.16	4.71 ± 0.76	4.03 ± 0.49
Saharan et al. (2002)	–	61.85	18.2 ± 0.2	0.83	–	–
Saikia et al. (1999)	10.45 ± 0.13	60.41 ± 0.95	17.42 ± 0.37	0.49 ± 0.02	6.9 ± 0.55	4.33 ± 0.08
Kaur and Mehta (1993)	10.8	59.4	19.8	1.4	4.7	3.9
Kaur and Kapoor (1992)	10.41 ± 0.13	59.74 ± 0.74	17.88 ± 0.43	0.49 ± 0.04	7.09 ± 0.47	4.18 ± 0.10
Rodriguez and Mendoza (1991)	8.99 ± 0.16	58.06 ± 2.86	18.5 ± 2.53	3.76 ± 0.29	5.33 ± 1.84	5.36 ± 1.13
Revilleza et al. (1990)	8.97	59.01	16.82	3.46	4.31	7.43
Malhotra et al. (1988)	7.6 ± 0.54	62.32 ± 1.41	20.19 ± 1.78	2.98 ± 0.54	2.86 ± 0.83	4.06 ± 0.39
Chandel et al. (1988)	5.43 ± 0.32	63.76 ± 4.31	20.82 ± 2.64	1.14 ± 0.23	4.83 ± 1.88	4.01 ± 0.17
Singh et al. (1980)	–	–	17.81 ± 25.18	1.00 ± 1.60	3.3 ± 4.8	3.81 ± 4.31
Value range	***5.1–12.81***	**52.23–68.5**	**16.82–26.12**	**0.39–4.03**	**1.70–8.5**	**3.00–7.43**
Average	**9.10 ± 3.12**	**59.96 ± 2.81**	**20.78 ± 2.65**	**1.74 ± 1.42**	**5.07 ± 1.174**	**4.44 ± 1.03**

Adopted from Bepary et al. (2016)

Postharvest Processing

Postharvest operation is the integration of postharvest practices that follow the harvesting of ricebean grains. Included are judging of the maturity index, harvesting, threshing, drying, storing, processing (primary and secondary), and marketing to finally be mobilized toward the end user. Each of these practices decides the quality and safety of ricebean grains and its products and also the level of postharvest losses. Ignoring one of these practices can lead to severe consequences on quality, safety, and postharvest loss of ricebean grains. Each of these practices is discussed following.

Assessment of Maturity Index

Maturity index is the stage at which the ricebean grain can be harvested; usually, in this stage the seed reaches physiological maturity. Correct judgment of the ricebean maturity index is crucial to obtain a qualitative as well as quantitative harvest. If ricebean grains are harvested at a late or early stage of physiological maturity, grains may acquire a hard-to-cook property during the subsequent storage period (Acharya 2008). The maturity indexes of the ricebean fodder harvest are not the same as the maturity indexes of the ricebean grain harvest. Maturity indexes for ricebean grain harvest are determined by following factors: development of acceptable seed coat colour and pod colour, thousand grain weights and moisture content, increasing protein and phytic acid content, and crop duration. As these factors are dependent on variety, the nutritional status of the plant, environmental conditions, and soil fertility, it is necessary to determine the maturity index on a localized basis. Ricebean pods are very sensitive to shatter if allowed to remain on the plant for long time. Hence, ricebean needs to be harvested immediately after reaching the optimum maturity index. The generalized maturity index is considered to occur when pods turn colour from green to yellow or brown and 60% of the vine dries up. The pod shattering characteristic is common in the *Vigna* genus including ricebean. Excessive lignin deposition happens in ‘fibre-cap cells’ along the ventral suture tissue and the inner sclerenchyma tissue of the pod valves, which facilitates twisting forces in the pod wall if relative humidity of field is low, and hence pods are shattered (Rau et al. 2019). Ricebean takes 90–120 days to reach harvesting maturity, which strictly depends on the variety and the geographic and environmental conditions (Acharya 2008).

Harvesting

Harvesting of ricebean is defined as taking away the economic parts such as pods of the plant from the field when it reaches harvest maturity. Harvesting can be done either manually or by mechanical means. Methods of harvesting usually depend on the area of ricebean cultivation. Small and marginal cultivators generally harvest the grains by manual means. A commercial cultivator may use a combine harvester to harvest the grain. To reduce shattering loss, ricebean is harvested in the morning times when greater relative humidity makes the pods leathery and prevents shattering. Sowing time should be adjusted in such as a way that rainfall does not interfere with ricebean harvesting so as to prevent the development of hard-to-cook grain. Harvesting of ricebean pods is carried out by pulling out mature plants with the roots or cutting near the base of the mature plant. This harvesting practice is less labour intensive than harvesting by picking individual pods from plants. Harvesting the whole plant by cutting near its base has several advantages: reduced labour requirements, easier subsequent drying and threshing, use of the non-grain parts of the plant as fodder, less contamination of the grains with dust and soil-borne microorganisms, and land fertilization by the residual root nodules.

Pre-drying

Pre-drying is a unit operation of postharvest practices wherein harvested ricebean plants are dried to reduce moisture content for effective threshing. This practice is necessary when harvested plants have plenty of green foliage, non-uniform pod maturity, and high moisture (Lal and Verma 2007). For the maximum shattering effect of pods, the harvested plants are dried for 1–2 weeks in the sun. During the pre-drying period the harvested plants need protection from rain, dew, nocturnal humidity, and direct ground contact. Drying reduces the moisture content of pods, which facilitates twisting forces in the pod wall so that the pod shatters. Farmers dry the plants either in the backyard or on a roof top. The drying place should be free from food safety hazards. Careless drying results in contamination with physical hazards such as stone, cattle droppings, hair, and feathers.

Threshing and Cleaning

Threshing is a unique process in postharvest practices during which sound ricebean kernels are detached and separated from harvested plants. Before threshing, it is necessary to bring the moisture content to the optimal level by pre-drying. Threshing of ricebean at high moisture requires more impact force for grain detachment, creates difficulty in the removal of chaffs during winnowing, and acts as a source of pest and microbial cross-contamination (Mohan et al. 2011). Small and marginal farms thresh ricebean by beating the dried pods with bamboo or wooden sticks as soon as the pods reach the brittle stage while pre-drying (Lal and Verma 2007). In some places, threshing of ricebean is carried out by trampling cattle. A mechanical thresher can be used if a large quantity of harvested ricebean material is available. Cross-contamination with food hazards and physical damage to the grain needs to be prevented while threshing quality grains. As soon as the threshing operation is completed, the grains are cleaned to remove chaffs, very light seeds, broken grains, glumes, and other foreign materials by winnowing or dropping the grain from a bucket against the natural wind.

Drying

The moisture content of threshed ricebean grains remains high and must be lowered toward the safe level (9–12%) for grains storage. Insufficiently dried grains (if moisture exceeds 18%) is vulnerable for microbial spoilage and pest attacks and has high enzymatic activity during storage, which shortens storage life and reduces grains quality and market price (Mohan et al. 2011). Drying is considered as an important postharvest practice wherein excess moisture of the ricebean grains is removed by applying heat by natural sun radiation or from artificial hot air. Sun drying is a common drying practice followed by ricebean farmers immediately after threshing. Ricebean requires 2–3 days of sun drying to remove moisture for safe storage. Conventionally, ricebean grains are thinly spread in the home yard during the peak sunny period and stirred frequently for proper moisture removal (Paudel 2008). During the peak sunny period of the day, the relative humidity (RH) of the air remains low (below 70%) and temperature remains high, which facilitates the quick evaporation of moisture from the grains. The rate of drying is not uniform in the sun drying process because of the frequent changes in solar radiation intensity during drying days. A fast rate of drying creates cracks on grains, increases integument permeability, reduces germination percentage, and changes the seed coat colour (Scariot et al. 2017). Sun drying in a home yard is not a safe practice because it increases risk of contamination by microbial and physical hazards as well as pest infestation. The efficiency of the solar drying practice of ricebean can be increased by introduction of a small handheld moisture meter to monitor moisture, a hygrometer to monitor air relative humidity (RH), and a tarpaulin to prevent contamination. Ricebean grains that are harvested in the monsoon season have poor grain quality and short storage life because of the low solar radiation and high grain moisture (Joshi et al. 2008). This problem can be overcome by using artificial dryers with temperature control devices. In an artificial dryer, blowing hot air continuously transfers the heat and moisture away from grain surface. The efficiency of artificial dryer depends on dryer type as well as drying purpose. Drying at high temperature of high moisture ricebean grains should avoided to prevent severe damage to the grain.

Storage

Food and nutritional security from food grains, including ricebean, is only possible if the grains are stored properly. Ricebean grains are stored at different levels of the food chain for different purposes. Most Southeast Asian farmers store ricebean grains either for home consumption or as seed for future cultivation. Other storage purposes are handled by marketing agencies and processors. Ricebean can be stored for 3–4 years under cool and dry conditions. As other pulses, ricebean is more difficult to store than cereal grains because slight variations in the storage conditions cause drastic changes in physicochemical properties, seed colour, insect infestation, and microbial spoilage, with development of hard-to-cook seed. These changes ultimately influence the final quality of the processed grains. Six factors that determine the qualitative and quantitative changes of ricebean grains in storage are temperature, relative humidity, oxygen, light, moisture content of grain, and ricebean variety. In combination, these factors have severe effects causing postharvest loss. Grain moisture content is one of the prime factors that affect grain quality. Cotyledon and testa cracking was observed in canned beans prepared from grains stored at low moisture. Grains storage at high initial moisture is vulnerable for off-flavour and off-colour development, with reduced hydration capacity, increased cooking time, and the encouragement of microbial growth and pest infestation (Uebersax and Muhammad 2013). A moisture content of 5–14% is considered as safe storage when the grains are stored at a temperature range between above freezing point and below 30 °C. Within in this moisture range, the storage life is doubled with 1% decreases in moisture content (Lal and Verma 2007). The surrounding relative humidity of the storage system can change the moisture level of the grains during storage as the grain has a tendency to reach equilibrium moisture content. Grains storage at high initial moisture (above 18%) and high relative humidity (above 70%) promote the growth of moulds, including aflatoxin-producing mould, and pest infestation by bruchids. Most of the cultivars of ricebean are resistant to bruchids (*Callosobruchus* spp.) pest infestation, with a few exceptions (Somta et al. 2006). The yellow seeded variety of ricebean is slightly susceptible to bruchid pests, so it is necessary to maintain the grain at low moisture during storage. At the farm level, ricebean is stored in wooden and earthen pods for 1 year (Paudel 2008). These traditional storage systems are being rendered damp resistant and airtight by using indigenous technical knowledge. Ricebean grains harvested from northern sloping lands is susceptible to storage pest attacks. Marketing agencies and processors pack the ricebean in gunny bags stored in a well-ventilated godown.

Soaking

Ricebean soaking is a vital pre-processing unit operation that is usually carried out before cooking, germination, dehulling, and fermentation. The rate of water absorption capacity is the deciding factor for soaking time that depends on the anatomic features of the seeds, soaking medium, soaking conditions, and grain moisture content. The quality of soaked ricebean can be judged by such quality parameters as length/breadth ratio (LB ratio), water uptake ratio (weight increased ratio), swelling ratio (volume increased ratio), and solid loss percentage. Soaking ricebean overnight can increase the LB ratio (1.6 ± 0.2), water uptake ratio (2 ± 0.1), and swelling ratio (1.1 ± 0) and reduce hardness (39 ± 10% reduction in hardness as compared to native grain hardness) (Hollington et al. 2010; Bepary et al. 2017). With increased soaking water temperature, the rate of water absorption is also increased. Soaking ricebean at 40–45°C can reduce soaking time from 12–16 to 7–7.5 h (Bepary and Wadikar 2018). High-temperature soaking induces a brown colour to the seed from leaching out of the water-soluble pigments of the seed coat and causes hard-to-cook grain. As in other pulses, hard-to-soak grains are also found in ricebean (Hollington et al. 2010). Ricebean grains are conventionally soaked overnight in tap water to prepare various traditional products such as dhal, paste, *pakauda*, and *biraula*. Soaking hydrates the starch granules and protein bodies of the cotyledon, which reduces cooking time by facilitating better starch gelatinization and protein denaturation. Soaking significantly improves overall quality of the protein, protein digestibility, starch digestibility, and mineral bioavailability by decreasing antinutritional factors. Soaking of ricebean in water for 12–16 h can reduce protein (3.62–12%), fat (1.62–3.92%), ash (2.2–4.72%), calcium (29%), and magnesium (25%), while increasing the crude fibre (+2.92–6.77%) insignificantly and improving starch digestibility by 35–69% and protein digestibility by 5.57–17.68% as compared to native grain (Kaur and Kapoor 1990b; Chau and Cheung 1997; Saharan et al. 2002; Pawar et al. 2012). Phytate:zinc, phytate:calcium, and calcium:zinc ratios are indicators for zinc availability in the diet, which is slightly improved after soaking in tap water (Kaur and Kawatra 2002b). The effects of soaking on sodium, potassium, zinc, and water-soluble vitamins are not available for ricebean. However, soaking can reduce potassium by 35%, sodium by 20%, zinc by 0%, thiamine by 4.87%, riboflavin by 17.9%, niacin by 12.74%, and folate by 28.5% while increasing vitamin C by 24.5% as compared to the raw bean (Rockland et al. 1977; Barampama and Simard 1995; Mubarak 2005; Kakati et al. 2010). Soaking of ricebean grains in water for 12–16 h can reduce the antinutritional factors such as tannin by 30.65%, polyphenolic compounds by 10–52%, trypsin inhibitor by 9–17%, amylase inhibitor by 11%, phytic acid by 6–33%, saponin by 3–9%, raffinose by 9.5–14%, and stachyose by 5–16.4% (Kaur and Kapoor 1990a; Chau and Cheung 1997; Kaur and Kawatra 2000; Saharan et al. 2002; Pawar et al. 2012). Most of the antinutritional factors are reduced by leaching out into the soaking water and enzymatic activities during soaking; the loss of saponin is not caused by leaching but rather by hydrolysis of the glycosidic linkage between the sapogenin and its sugar during soaking. The flavonoids (52%) and antioxidant activity (145%) are increased whereas oxalate (55%), hydrogen cyanide (HCN, 54.9%), and verbascose (49.5%) are decreased in soaked bean as compared to native bean (Oboh et al. 2000; Boateng et al. 2008; Okudu and Ojinnaka 2017).

Cooking

Cooking is one of the important and most commonly used processing operations for the utilization of ricebean. In most ricebean-consuming areas, cooking is carried out by boiling the overnight-soaked grains with water until reaching the appropriate softness for preparing household recipes. The introduction of modern cookery appliances allows cooking ricebean in a pressure-cooker without prior soaking. Cooking is one of the simplest types of heat processing that transforms native ricebean grain into an edible form. A cooked ricebean grain is considered edible when the grain becomes dark brown in colour with transverse splits and soft texture, with a characteristic cooked flavour and palatability (Bepary and Wadikar 2018). During cooking, the middle lamellae of native ricebean grains are broken down, resulting in the disruption and softening of the cell containing starch bodies in the protein matrix; this is followed by starch gelatinization and protein denaturation. Upon heating, starch gelatinization starts once the gelatinization temperature is reached, which is characterized by swelling of starch granules and loss of the birefringent property. The swelling power, pasting temperature, and peak melting temperature of ricebean starch are 71–75 and 62–70 °C and 7.5–14.8 g/g, respectively (Singh et al. 2012). Gelatinization temperature, peak melting temperature, and swelling power of starch are dependent on the amylose/amylopectin ratio. A higher content of amylopectin in ricebean leads to higher swelling power and greater softness of texture (Sánchez-Arteaga et al. 2015). During heating, the protein bodies present in cells start denaturing when denaturation temperature is reached, which causes coagulation of protein, thus reducing its solubility. Protein denaturation temperature is dependent on the molecular weight of the protein and mineral concentration. Proteins of low molecular weight are denatured first, and then high molecular weight and heat-resistant proteins are denatured subsequently as heating proceeds (Sánchez-Arteaga et al. 2015). High mineral content increases denaturation temperature. In easy-to-cook beans the protein denaturation temperature is always greater than the starch gelatinization temperature, meaning that the point for ending starch gelatinization is the point for protein denaturation. Although cooking increases the volume of individual cells by the action of starch gelatinization and protein denaturation, the whole cell remains intact because of the plasticizing property of the cell walls. At the end stage of cooking, the swollen intact cells initiate pulling the cells apart from each other, which leads to development of the soft texture.

The physicochemical transformations of native grains during cooking can be judge by certain qualitative parameters such as cooking time, texture, swelling ratio, solid loss, appearance, and flavour. These quality parameters are called cooking quality, which is dependent on variety, physicochemical composition of grain, and storage conditions. Cooking time is important in the cooking process, the time from adding the grains to boiled water till achievement of desired softness. Cooking time depends on grain hydration behaviour, variety, hardness, seed coat permeability, compactness of endosperm internal structure, etc. (Kaur et al. 2013). Short cooking times are always convenient to reduce energy requirements during cooking and to reduce nutritional losses. Average cooking time for unsoaked ricebean varieties is 47.72 ± 9.85 min (Saikia et al. 1999; Hira et al. 1988; Kaur et al. 2013). Cooking time for ricebean can be reduced by soaking. Bepary et al. (2017) reported that the average cooking time of ricebean varieties soaked for 12 h was 35 ± 5 min. By modifying soaking conditions, cooking time can be further be reduced. Soaking ricebean at 42 °C for 7 h can reduce cooking time by 37% as compared to conventional soaking (Bepary and Wadikar 2018). Cooking time is increased fivefold if ricebean is stored in high moisture and at high temperature, but the cooking time of this high moisture bean can be reduced by soaking with phytic acid or EDTA. Reduction in phytic acid content during storage increases cooking time, and increase in percentage phytic acid to percentage calcium ratio reduces cooking time (Kon and Sanshuck 1981).

Ricebean stored up to 1 year has good cooking qualities, hence is in the easy-to-cook category. After 1 year, stored ricebean begins to lose cooking quality because of changes in physiological conditions that induce hardening defects in the stored grain. These grains absorb sufficient water during soaking but do not soften sufficiently even after cooking for a long time and are termed hard-to-cook (HTC) grain. In easy-to-cook grain, individual cells separate easily, leading to tenderness; however, individual cells of HTC bean grain are not separated because the middle lamella is intact. Multiple physiochemical factors and mechanisms are involved in the development of HTC. Of these, storage environmental conditions and genetics are considered as prime factors. Beans stored at high temperature and high relative humidity generally develop HTC. HTC beans require more cooking time to soften the cotyledon, which ultimately increases energy consumption, with solid loss and decreased protein quality, destroying the heat-sensitive micronutrients. The percentage of water absorption, solid loss, and hardness in the unsoaked ricebean cooking process was 107.56 ± 9.42%, 8.47 ± 2.91%, and 27.34 ± 7.48 N, respectively (Hira et al. 1988; Saikia et al. 1999; Kaur et al. 2013). The percentage of water absorption, swelling ratio, cooked hardness, and degree of gelatinization can be improved by soaking. Bepary et al. (2017) reported the mean value cooking parameters in 12-h-soaked ricebean varieties cooked for 29–40 min as follows: hardness, 25 ± 1.96 N; percentage of water absorption, 121 ± 8; solid loss, 27 ± 1.58%; swelling ratio, 1.11 ± 0.13; and degree of gelatinization, 51 ± 2%.

Open Pan Cooking

Open pan cooking of ricebean for 20 min with 12 h prior soaking can decrease protein (12%), ash (5.45%), and fat (0.57%) whereas crude fibre (15.27%) and carbohydrate (4.78%) are increased (Kaur 2015). However, open pan cooking of ricebean for 50 min without prior soaking can reduce protein (24 ± 0.82%), ash (10.75 ± 1.26%), fat (53.75 ± 3.52%), crude fibre (55.55 ± 0.58%), and starch (16.5 ± 2%) (Saikia et al. 1999). The conventional cooking of ricebean can reduce significant amount of minerals and water-soluble vitamins. Open pan cooking of ricebean can reduce calcium (30.25 ± 4.6%), iron (55 ± 1%), phosphorus (38 ± 3%), potassium (13 ± 2%), sodium (7.75 ± 4.6%) magnesium (28.1 ± 5.6%), and zinc (17.5 ± 6.0%) (Saikia et al. 1999; El Maki et al. 2007). The conventional cooking of ricebean can reduce thiamine (20.34–20.98%), riboflavin (23.21–31.68%), niacin (30.58–34.76%), vitamin B_6 (27.48–33.31%), folic acid (31.73–40.54), and pentothenic acid (45%) as compared to native bean (Augustin et al. 1981; Hoppner and Lampi 1993; El Maki et al. 2007). The conventional cooking of ricebean also reduces the antinutritional factors and improves the antioxidant activity, in vitro protein digestibility (IVPD), in vitro starch digestibility (IVSD), in vitro iron bioavailability (IVIB), and in vitro calcium bioavailability (IVCB). The cooking of soaked ricebean reduces antinutritional factors by a significant amount as compared to cooking of unsoaked beans, increasing antioxidant activity, IVPD, IVSD, IVIB, and IVCB (Kaur and Kapoor 1990a, b; Chau and Cheung 1997). Cooking of ricebean can decrease polyphenol by 12.4–23%, flavonoids by 47.7%, phytic acid by 21.1–41.64%, saponin by 14.8–19.6%, tannin by 63.5%, trypsin inhibition activity (TIA) by 31.65%, amylase inhibition activity (AIA) by 23.07%, raffinose by 35.13%, and stachyose by 31.31%, and increases antioxidant activity by 72% (Kaur and Kapoor 1990a, b; Chau and Cheung 1997; Kaur and Kawatra 2000; Rani and Khabiruddin 2017). Cooking of unsoaked ricebean for 30 min can increasein vitro protein digestibility (IVPD) by 17.68% and in vitro starch digestibility (IVSD) by 100% (Chau and Cheung 1997).

Microwave Cooking

Microwave heating has gained popularity in food processing for its ability to achieve high heating rates, significant reduction in cooking time, more uniform heating, safe handling, and ease of operation. Application of microwave energy for cooking ricebean is a new approach and very little work is being carried out on this bean. Bepary et al. (2018b) first tried the microwave cooking of ricebean and then the cooking process has been optimized. For microwave cooking of ricebean, the cleaned grains need to be soaked in 250 mL distilled water at 42 °C for 7 h (Bepary and Wadikar 2018), and then the soaked grains are allowed to cook in a cylindrical polypropylene bowl (20 cm diameter and 10 cm height) with 400 mL salt solution (0.7%) in a domestic microwave oven at 2450 MHz with 900 W for 15 min. During cooking, the position of the bowl needs to be marked on the turntable of the microwave oven to uniform and repeatable power distribution, as the temperature is very sensitive to the position in the oven. Also, the bowl should be placed toward the periphery of the turntable to facilitate more uniform power distribution as the turntable rotates. During pulsed microwave input, the magnetron power should be kept constant for a period of 30 s followed by a pause of 5 s. The process parameters of the microwave cooking process such as microwave power, concentration of salt solution, and cooking time are being optimized based on the cooking quality of the bean. The cooking quality of ricebean is determined in terms of water uptake (%), solid loss (%), swelling ratio (%), hardness (g), protein denaturation (%), degree of gelatinization (%), and overall acceptability (OAA). Cooking of soaked ricebean at 900 W by using 0.7% salt solution for 15–20 min can reduce the cooking time by 43.43% and solid loss by 31% as compared to native ricebean. Bepary et al. (2018b) reported that the optimal microwave cooking process can increase the protein, fat, ash, polyphenols, and in vitro antioxidant activity and also slightly improve in vitro iron and calcium bioavailability, whereas crude fibre, calcium, phytic acid, and iron are decreased as compared to a conventional cooking process. Microwave cooking can reduce the content of minerals such as calcium (7.14%), iron (17.52%), magnesium (14.04%), phosphorus (6.65%), potassium (22.65%), sodium (32.5%), and zinc (8.65%) and can reduce the content of vitamin C (11.3%), thiamine (20.2%), riboflavin (40.8%), niacin (86.06%), and vitamin B_6 (18.58%) (Chung et al. 1981; Alajaji and El-Adawy 2006). Microwave cooking of spinach causes no significant loss of ascorbic acid but significant loss of folic acid as compare to conventional cooking (Klein et al. 1981). This cooking process causes reduction in functional, nonnutritional components and improves IVPD and IVSD, with less impact on IVIB, IVCB, and antioxidant activity. It is established that microwave cooking can decrease tannin (62.12%), saponin (47.25%), phytic acid (26.03%), TIA (100%), AIA (83.3%), oxalate (85.9%), HCN (83.2%), raffinose (60.62%), stachyose (60.71%), and verbascose (59.55%) while increasing IVPD (12.78%) and IVSD (319%) (Mulimani and Supriya 1994; Quinteros et al. 2003; Feng et al. 2003; Khatoon and Prakash 2004; Mubarak 2005; Alajaji and El-Adawy 2006; Khattab and Arntfield 2009).

Dehulling

Dehulling is an important unit operation in processing and value addition for legumes including ricebean. It is defined as removal of the seed coat from cotyledons before use. The seed coat of ricebean is hard and hydrophobic, which acts as a hurdle during soaking and cooking and also imparts a bitter taste and dark colour to the cooked bean, ultimately reducing the acceptability and palatability of ricebean. However, dehulling of ricebean is not a common practice because the seed is difficult to remove from the cotyledons (Andersen et al. 2009). Hence, ricebean can be categorized as a hard-to-dehull group. In hard-to-dehull beans, mucilage and gum with high uronic acid content form a strong bond between the hulls and the cotyledons (Ramakrishnaiah and Kurien 1985). Mucilage and gum are chemically known as the cellulosic microfibril network that is attached to the matrix of protein and nonstarch polysaccharides (NSP) located between hull and cotyledon. In some ricebean growing locations, the bean is dehulled by peeling the overnight soaked grain followed by sun drying. These dehulled grains are used to prepare several traditional products such as *pakora (halwa)*. Parvathi and Kumar (2006) studied the dehusking characteristics of ricebean using a dhal stone mortar and power-operated mini dhal mill; the dhal recovery percentage by stone mortar and power-operated mini dhal mill was reported as 70% and 45%, respectively. Kaur and Kawatra (2002a,b) prepared dehulled spilt ricebean. Whole ricebeans were split into two halves with a grain pearler, the split grain halves were soaked for 12 h, and then the hull was removed from the spilt halves by hand rubbing between the palms and then sun dried for 24 h. Dehulling of bean can reduce fibre content, antinutritional factors (tannin, polyphenol), and improve nutritional qualities such as protein digestibility, mineral bioavailability, and protein quality. The cooking quality, appearance, and texture are also improved in dehulled beans (Joyner and Yadav 2015; Deshpande et al. 1982). Dehulling also facilitates the production of higher quality flours, without browning/speckling, and also increases leavening ability. The dehulled legume has a higher value of true protein digestibility and net protein utilization as compared to whole legumes (Singh 1993). Dehulling of ricebean can decrease proximate components and minerals. The manual dehulling of split ricebean soaked for 12 h can decrease crude protein (8.76–9.32%), fat (13%), ash (11.82%), crude fibre (75–86%), total soluble sugar (66.29%), and total sugar (50%), and reduce sugar (82%) and increase carbohydrates (10.72%) (Kaur and Kawatra 2002a, b; Parvathi and Kumar 2006; Kaur 2015). Dehulling can cause loss of calcium (10.88%), magnesium (2.33%), iron (34.65%), phosphorus (0.44%), zinc (57%), copper (50%), manganese (14.7%), potassium (19.88%), and sodium (15%) (Saharan et al. 2001; Mubarak 2005; Parvathi and Kumar 2006). Dehulling causes little loss in thiamine, riboflavin, or niacin but causes more than 30% loss in vitamin C, vitamin B_6, folate, and pantothenic acid (Kik 1956; Nnanna and Phillips 1989; Ibeanu et al. 2012). The dehulling of ricebean can reduce antinutritional factors and improve antioxidant activity, IVPD, IVSD, IVIB, and IVCB. The dehulling process can decrease polyphenols (46.67%), tannin (11.76–85%), phytic acid (14.55%), saponin (12.94), raffinose (8.78%), stachyose (22.49%), verbascose (76.4%), oxalate (100%), HCl extractability of calcium (15%), and iron (25.26%), but increases flavonoids (8.93%), antioxidant activity (40%), TIA (15%), AIA (83%), IVSD (29–42%), and IVPD (3.5%) in ricebean (Deshpande et al. 1982; Akinyele and Akinlosotu 1991; Bishnoi and Khetarpaul 1993; Duhan et al. 2002; Kaur and Kawatra 2002a; Parvathi and Kumar 2006; Jayalaxmi et al. 2016; Rani and Khabiruddin 2017).

Germination

Germination or sprouting is one of the important household processing practices commonly followed in the ricebean growing belt of India and Nepal to improve taste and flavour. *Kwanti*, a popular dish in Nepal, is prepared from sprouted ricebean (Andersen et al. 2009). For germination of ricebean, grains are soaked overnight (6–12 h), and then the grains are allowed to develop rootlets under humid conditions at room temperature for 24–48 h (Sritongtae et al. 2017; Kaur and Kawatra 2000). Germination of 12-h soaked ricebean for 48 h at 37 ± 1 °C followed by pressure-cooking for 5 min can reduce the carbohydrate by 1.98%, fat by 3.4%, and ash by 0.18% whereas protein is increased by 2.99% and crude fibre by 14% (Kaur 2015). Germination of ricebean for 24 h at 30 ± 1 °C (73 ± 5% relative humidity) and followed by steam cooking for 10 min increases protein by 11% and reduces 45% carbohydrate, 40% of fat, and 0.37% of ash as compared to soaked bean (Sritongtae et al. 2017). Germination of ricebean soaked for 12 h at 30 °C for 24 h can reduce calcium by 4.03%, iron by 3.03%, and phosphorus by 0.65%, whereas germination for 48 h at 37 °C followed by pressure-cooking for 4 min reduces zinc by 2.67%. Magnesium is increased by 1.9% and potassium by 9.11%, and sodium is decreased by 3.3%, in germinated mung bean (72 h) (Mubarak 2005).

Germination of ricebean can increase the content of water-soluble vitamins such as vitamin C, thiamine, riboflavin, niacin, pyridoxine, folate, and pantothenic acid (Banerjee et al. 1954; Nnanna and Phillips 1989; Sattar et al. 1989; Ochanda et al. 2010; Hefni and Witthöft 2014). Germination of ricebean for 24 h at 30 ± 1 °C (73 ± 5% relative humidity) and followed by steam-cooking for 10 min increased thiamine by 210%, riboflavin by 87.5%, and niacin by 200% (Sritongtae et al. 2017).

Germination of ricebean can reduce nonnutritional components and increase digestibility (starch and protein), bioavailability of minerals (calcium and iron), and antioxidant activity. Germination of ricebean for 40–48 h can decrease polyphenol by 35%, phytate by 26.98–55%, tannin by 63%, saponin by 18.68%, trypsin inhibition activity by 42%, amylase inhibition by 57%, raffinose by 15%, stachyose by 75%, in vitro starch digestibility by 212%, in vitro protein digestibility by 12%, HCl extractability of calcium by 8.2%, and HCl extractability of iron by13%, as compared to native grain (Chau and Cheung 1997; Saharan et al. 2001; Kaur and Kawatra 2000; Kaur 2015). Germination can diminish flavonoids by 5.34% and verbascose by 51.21% (Pal et al. 2015; Oboh et al. 2000). The citric acid (1%) pretreatment followed by germination for 24 h followed by steam-cooking for 10 min can decrease phytate by 19% and increase total phenol by 105%, and DPPH (assay) by 111% as compared to 6-h soaked grain (Sritongtae et al. 2017), with increased total polyphenol and B-vitamins.

Roasting

Roasting of ricebean is usually not a common practice in its growing belt because expansion is limited during roasting. Roasting causes starch gelatinization, protein denaturation, and inactivation of antinutritional factors and improves the nutritional value of the bean. Roasting of ricebean develops some unique texture, flavour, and sensory attributes. Sometimes roasting is also practiced to reduce cooking time. It is traditionally carried out in hot sand or salt or without sand/salt. In the roasting process, grains are tempered with water and then roasted in four volumes of preheated sand or salt followed by cooling. Roasting of ricebean in sand heated to 250 °C for 2 min has negligible effect on proximate composition but it can reduce total soluble solid (10.29%), raffinose (25.67%), and stachyose (28.26%) (Kaur 2015; Kaur and Kawatra 2000). Roasting of ricebean at 103 °C can reduce protein (6.3%), TSS (7.3%), total free amino acids (22.8%), and tannin (25%) (Mankotia 2011). Roasting of ricebean can slightly reduce calcium, magnesium, phosphorus, potassium, and sodium and increase iron and zinc (Kaur and Kawatra 2002a, b; Jayalaxmi et al. 2016). Roasting can reduce the heat-, photo-, and oxygen-sensitive vitamins such as vitamin C (40%), thiamine (30%), vitamin B_6 (12.51%), beta-carotene (24.5%), and vitamin E (21.72 %) (Lawal 1986; Jayalaxmi et al. 2016; Chukwuma et al. 2016). Roasting causes little loss of polyphenol (16–48%), tannin (16.54%), saponin (22.22%), phytic acid (26.04%), raffinose (24.71%), stachyose (24.27%), verbascose (24.29%), and oxalate (11.81%), and little increase of flavonoids (15%), whereas it causes more loss of TIA (82.04%), AIA (78.9%), and HCN (66.93%), hence improving IVPD (16.96%) and IVSD (16.47%) (Siddhuraju et al. 1996; Siddhuraju and Becker 2007; Khattab and Arntfield 2009; Sharma and Punia 2017).

Fermentation

Fermentation of ricebean is limited; only in a part of Northeast India is this practice followed during pickle preparation. Fermentation of ricebean eliminates the beany flavour and improves the taste and palatability of foods in which complex food components (carbohydrates, proteins, lipids) are broken down into simple and absorbable fractions such as sugar, amino acids, and fatty acids by the action of microorganism (yeasts, fungi, or bacteria). Kaur and Mehta (1993) fermented soaked ricebean paste for 4 h to prepare *voda*. Kaur and Kawatra (2000) studied the ricebean fermentation process wherein the dhal of ricebean soaked overnight was made into a coarse paste and allowed to ferment for 12 h at 37 ± 1 °C in an incubator by using the natural microorganisms present in the bean. Gan et al. (2016) fermented ricebean by dissolving flour in sterile water (1:5 w/v) and incubating at 37 °C for 48 h (continuous agitation at 250 rpm) either with microorganisms existing in the ricebean or inoculated with *Lactobacillus paracasei* ASCC 279 and *Lactobacillus plantarum* WCSF1. Fermentation of ricebean for 12 h can reduce TSS (3.56%), protein (5.49%), ash (12.9%), fat (14%), fibre (62%), raffinose (30.4%), and stachyose (38%) while increasing carbohydrates (8%) (Kaur 2015; Kaur and Kawatra 2000). Fermentation of ricebean can increase total phenolic content (81–85%), ferric-reducing antioxidant power (FRAP) (26.25–33.2% and 2,2′-azino-*bis*(3-ethylbenzothiazoline-6-sulphonic acid) diammonium salt (ABTS) (17.9–20.7%) (Gan et al. 2016). It is reported that the fermentation process can increase potassium (11.62%), zinc (1%), vitamin C (243%), thiamine (26%), riboflavin (248%), and niacin (68%) and decrease calcium (23.9%), sodium (11.4%), and iron and magnesium negligibly (Barampama and Simard 1995; Nwanekezi et al. 2017). There is a substantial decrease in antinutritional factors and increase in IVPD, IVSD, and antioxidant activity after fermentation of bean. Application of the fermentation process in ricebean can diminish polyphenol (48%), tannin (28%), saponin (61%), phytic acid (67%), TIA (65.5%), oxalate (64%), HCN (86%), raffinose (71%), stachyose (71.7%), and verbascose (70.6%), which facilitates improvement of IVPD (45.7%), IVSD (86.6%), and antioxidant activity (49%) (Yadav and Khetarpaul 1994; Khattab and Arntfield 2009; Gan et al. 2016; Nwanekezi et al. 2017).

Extrusion

Extrusion is a high-temperature thermo-mechanical process that can improve the nutritional status of existing cereal-based snacks and breakfast foods by inclusion of pulses or beans, including ricebean. Very limited work has been carried out concerning extrusion cooking of ricebean. Prabhavat et al. (1996) prepared different types of extruded products from either ricebean only or a combination of ricebean flour blended with mung bean, black gram, rice, wheat, cassava, corn, or soy flour by using a twin-screw extruder. Lamichhane et al. (2013) extruded 17% moistened flour from ricebean (15%) in combination with maize flour (75%) and sorghum flour (10%) at 135 °C barrel temperature and 153 rpm screw speed to develop extruded snacks. Bepary et al. (2019b) studied the sole ricebean extrusion process. For extrusion cooking, total moisture of the flour needed is adjusted to 15–18% and the mixture is equilibrated for 16 h; then, extrusion cooking is carried out in a co-rotating twin-screw extruder (EB-10 model; M/s. Basic Technologies, Kolkata, India) at 110–120 °C of barrel temperature and 350–355 rpm of screw speed. Extrudates are collected when a steady state (constant temperature and torque) is achieved. Extrudates are dried at 60 °C for 1 h to reduce moisture content. Bepary et al. (2019b) also optimized the independent parameters involved in extrusion process-based quality characteristics of extrudates. The optimum process condition that gave extrudates a high expansion ratio but minimum extrudate density and breaking strength was 15% moistened flour extruded at 110 °C barrel temperature and 350 rpm screw speed. The water absorption index (WAI, cold and hot), water solubility index (WSI, cold and hot), swelling power (SP, cold and hot), oil absorption index (OAI), bulk density (BD), true density (TD), and colour (L, a, b) values for optimized extruded flour are significantly different ($p < 0.05$) than the native flour whereas the differences in values of carbohydrates, protein, fat, crude fibre, and ash are insignificant ($p > 0.05$). The value of carbohydrate, protein, crude fibre, TD, porosity, WAI (30 °C), WSI (30 °C), OAI (30 °C), and 'b' (redness) increased in extruded flour compared to native ricebean flour. However, the value of fat, ash, WAI (90 °C), WSI (90 °C), SP (30 and 90 °C), BD, L (lightness), and 'a' (greenness) decreased compared to native ricebean flour (Bepary et al. 2019b). Extrusion cooking can decrease antinutritional factors such as enzyme inhibitors, tannin, phytic acid, saponin, and oligosaccharides, which overall improve the nutritional qualities of extrudates by increasing nutrient digestibility and bioavailability. Extrusion cooking can reduce the percentage content of protein (2.2%), fat (47%), ash (4.87%), crude fibre (7.89%), and sodium (14.14%) whereas increasing the content of carbohydrates (3.3%), calcium (1.6%), iron (32.89%), magnesium (2.8%), phosphorus (4.15%), potassium (0.4%), and zinc (6.67%) (Alonso et al. 2001; Anuonye et al. 2012). Extrusion cooking also affects the vitamin content of bean, and the level of loss depends on extrusion conditions and the chemical composition of feed materials. Extrusion cooking can cause loss of vitamin C (14–68%), thiamine (3–78%), riboflavin (10–65%), niacin (20%), vitamin B_6 (10%), folate (45–65%), and pantothenic acid (9%) (Killeit 1994). The extrusion process can lessen the functional components such as polyphenols (45.89%), flavonoids (39.37%), and antioxidant activities (5.71%) but improve IVPD (21.87%), IVSD (128%), IVIB (39.8%), and IVCB (17.27%) (Alonso et al. 2001; Korus et al. 2007; Patil et al. 2015). The extrusion process greatly decreases the content of saponin (84.5%), TIA (86.12%), AIA (100%), oxalate (94.44%), HCN (78.18%), and raffinose (65.62%), with less impact on phytic acid (20.75%), stachyose (18.8%) and verbascose (20.83%) (Alonso et al. 2000, 2001; Anuonye et al. 2012).

Flaking

Flaking is an important processing technology known for creation of a crispy, flavourful, and tasty product that improves not only the nutritional and functional characteristics but also the palatability of the products. It has been used commercially to produce ready-to-eat, ready-to-cook breakfast cereals and snacks for many years. Recently, this technology has been used for the development of protein-rich breakfast flakes as well as quick-cooking dhal from pulses or beans, including ricebean. Although this technology has been used to develop flakes from pigeon pea (Sethi et al. 2014; Nayak and Samuel 2012), lentil (Ryland et al. 2010), mung bean, cowpea, soybean, horsegram (Perera et al. 2017), and pea (Yang et al. 2008), very little information is available on ricebean flakes. Wadikar et al. (2018) developed production of ricebean flakes by using hydrothermal and extrusion processes. In the hydrothermal flaking process, soaked ricebean grains are cooked (6 min), then surface dried and flattened in a roller flaking machine. These flattened ricebean grains were toasted using fine salt (material to salt ratio, 1:4), and finally the salts were separated from the toasted flakes with a sieve. However, in the extrusion process, the 25% moistened flour is extruded at a screw speed of 345 rpm and barrel temperature of 55 °C after 16 h conditioning, and the extrudate strands (0.9–1.3 mm length) coming from the die are collected and immediately flattened in the roller flaking machine. These flattened extrudates are then toasted using fine salt (material to salt, 1:4). The ricebean flakes from the extrusion flaking process are significantly higher in crude fibre, iron, flavonoids, antioxidant activity, IVSD, IVCB, and IVIB than those from the hydrothermal flaking process (Wadikar et al. 2018). The thick hydrothermal flaking process can reduce fat (68%), fibre (30%), and ash (8.05%) while increasing carbohydrate (1.8%), moisture (18.31%), and protein (0.8%) (Sahu 2017). Hydrothermal roller flaking can increase iron (12–50.47%), zinc (3.52–19%), calcium (5.8–70%), and phosphorus (4.5%) and decrease magnesium (3.5%) and copper (10%) (Gruner et al. 1996; Wu et al. 2018). The degree of flaking (i.e., from thick to thin flakes) decreases starch, protein, lipid, and fibre components (Mujoo 1998). Hydrothermal flaking can cause loss of polyphenols (27.85–75.47%), phytate (40–88%), and tannin (70–94%), and improve IVSD (by severalfold), IVPD (some), IVIB (122–923%), and IVCB (70%) (Itagi et al. 2012; Wu et al. 2018; Mujoo and Ali 1998; Sailaya 1992). The loss of total polyphenols results from the loss of the bran layer from grains and thermal dissociation of conjugated phenolic into moderate reduction of hydroxycinnamic acid derivatives (Randhir et al. 2008). Flaking can decrease free radical scavenging activity, and flaking followed by toasting can increase free radical scavenging activity (Itagi et al. 2012). Protein digestibility is also increased but as compared to starch less so as starch is complexed with protein, thereby partly decreasing its susceptibility to hydrolysis (Mujoo et al.1998; Sailaya 1992).

Product Development

The purpose of ricebean cultivation and processing is the development, utilization, and consumption of ricebean-based products. Ricebean-based products have evolved in the confined growing belts based on traditional knowledge, consumer preferences, and availability over periods of time. Most of the traditional ricebean-based products are prepared by using simple conventional processing technologies such as soaking, cooking, sprouting, fermentation, and frying that are applied in other grains also. The consumption and utilization patterns of ricebean greatly vary among growing areas and depends on the food habits of each tribe. The consumption of rice bean and its products is an ancient practice in these areas. In Nagaland, it is believed that consumption of soaked ricebean by wrestlers can enhance their energy and can heal injuries acquired during wrestling competitions. The inhabitants of Khonoma, a village near Kohima, survived and remained defiant for a month by eating raw ricebean when British troops laid siege to the village in 1879. In Nepal, ricebean is considered as a hot food that is preferred during the winter season and is not served to individuals who are sensitive to cold. People have believed ricebean to be a sacred *dal*; hence, it has a distinct value in the religious aspects and cultural festivals of Nepalese society. Some popular products of ricebean served in those festivals are *khichadi* (ricebean and rice cooked together), *kwati* (soup from nine whole grain legumes), and *batuk* (Andersen et al. 2009).

Ricebean Curry

Curry is a traditional recipe of Southeast Asia that is eaten with rice and roti. For preparation of curry, grains soaked overnight are cooked and seasoned with spices, salt, and condiments in gravy form. In some places the unsoaked grains are pressure-cooked to prepare curry.

Sundal

Parvathi and Kumar (2006) developed this recipe from ricebean. It is prepared by boiling the whole grain that has been soaked for 12 h with water and salt until a soft texture is reached. Cooked grains are seasoned with onion, chilly, curry leaves, and coconut scraps; the resultant products are used as snacks. Sensory attributes are reported as appearance, 3.7, colour, 4.0, taste, 3.7, flavour, and OAA, 3.7.

Pulikulambu

Parvathi and Kumar (2006) developed this product from ricebean at Tamil Nadu Agricultural University, Coimbatore. First, whole grain is soaked for 12 h, then boiled in water with salt until texture is soft and set aside. Second, onion and garlic are fried in oil, followed by cooking for 5 min after adding tamarind juice, then cooked for 5 min after adding coconut paste, tomato paste, turmeric powder, coriander powder, chilli powder, and salt, and finally cooked for 2 min after adding the cooked ricebean. Sensory attributes were reported as appearance, 3.8, colour, 3.6, taste, 3.6, flavour, 3.4, and OAA, 3.9.

Ricebean Ball Curry

Parvathi and Kumar (2006) developed this curry product from ricebean. For preparation of this recipe, first whole grain soaked for 12 h is coarsely ground into paste without adding more water. The paste is mixed with desired amounts of chilli curry leaves, chopped onion, and salt and then steam-cooked as 30-cm-diameter paste balls. These steamed balls are used for curry by the same process and recipe as *Pulikulambu*. Sensory attributes were reported to be appearance, 3.8, colour, 3.6, taste, 3.5, flavour, 3.7, and OAA, 3.9.

Biramla

This traditional snack of Nepal is prepared by cooking overnight-soaked beans, followed by frying with desired spices, salt, and condiments (Andersen et al. 2009).

Ricebean Pork Curry

This curry, which is popular in Nagaland, is prepared by boiling the soaked beans with pork until the desired softness is developed. It is served with rice.

Ricebean Carp Decoction

This decoction is one kind of soup traditionally prepared in the southern part of China from ricebean and crucian crap (or carp). Soaked ricebean and fried crucian carp are boiled in water to reach full softness followed by further cooking after adding *kudzu* (root of *Pueraria thomsonii)* and orange (pericarp of *Citrus reticulata*). The finished soup is used as a decoction believed to have the functions of invigorating the spleen and eliminating diuresis, detumescence, and dampness (Wei et al. 2015).

Ricebean Decoction

This decoction is also a traditional product from China that is drunk as a tea and can reduce weight and enhance cosmetology. It is prepared by boiling the overnight-soaked ricebean in water until the cooking water has a soupy appearance (Wei et al. 2015).

Ricebean Sweetened Paste

Ricebean sweetened paste is a product of China and Japan where it is either consumed directly or used as a filling for desserts. For preparation of the paste, ricebean grains, after soaking for 2 h, are boiled in water until full softness develops, and the water is then allowed to evaporate. The cooked grains are crushed and mixed with crystal sugar and salad oil. After proper mixing, the paste is ready for use.

Ricebean Coix Gruel

This product is also from China where it is used medicinally to remove swelling and dampness, cure constipation, calm the mind, energize the heart, and refresh the spleen. It is the best food for patients with obesity or edema and for postpartum women. It prepared by boiling the soaked bean and coix seed initially with a hot flame, after which slow cooking ensues until the rice beans look like blowing sand and the coix seed is exploding. The resultant clear soup is seasoned with spices and beaten for smoothness (Wei et al. 2015).

Eromba

Eromba is in the traditional cuisine of Manipur. It is made from brinjal, cabbage, potato, bean, and onion chilli and served with ricebean. To prepare *eromba*, brinjal, cabbage outer leaf, soaked ricebean, and potato are boiled to softness and then these boiled vegetables are mashed into a paste. The water extract of roasted dry red chilli is added into the paste and mixed uniformly after adding salt.

Kwati Soup

This soup is a traditional dish from Nepal specially prepared from nine beans (black gram, ricebean, field bean, chickpea, soybean, field pea, garden pea, cowpea) on the occasion of the Gun Punhi festival. It is believed that *kwati*soup can cure cold and cough and is one of the best foods for women during maternity leave. Sprouted grains are boiled, and fried lovage seed is then added for special seasoning. The final product is served with flat bread (Andersen et al. 2009).

Nuggets

Nuggets or *Bori* is a popular traditional dish of India and Nepal made from pulse, specially from blackgram. In Nepal the nuggets are also prepared from ricebean and called *masaura*. For *masaura*, ricebean soaked overnight is made into a paste and mixed with taro petioles or corms; then a small ball is formed from the paste and dried to lower the moisture. Nuggets are cooked along with other vegetables in lean periods (Andersen et al. 2009).

Ricebean Kheer

For preparation of kheer, dehulled ricebean soaked for 3–4 h is cooked until it reaches a soft texture. The required amounts of jaggey, coconut milk, cardamom powder, and salt are added after mashing the cooked dhal, cooked to a slurry-like texture, and served as dessert.

Khichadi

Khichadi is a national dish of India and is also a popular dish in India, Pakistan, Nepal, and Bangladesh. It is prepared mainly from rice and legumes. Selection of cereals and pulses depends on the availability of these grains in the respective areas. In ricebean growing areas, *khichadi* is made from ricebean and rice. Split dehulled ricebeans are cooked with rice, spices, salt, and condiments (Andersen et al. 2009).

Ricebean Dhal

For preparation of dhal, split dehulled grain are boiled with turmeric and salt, and then fried seasoning such as other spices and condiments is added. It is generally served with rice and chapattis.

Pakora

Pakora is a popular fried snack of the Indian subcontinent. Gram flour is generally used to make the batter. Kaur and Mehta (1993) used ricebean flour for *pakora* preparation and found more crude fibre and calcium than in Bengal gram *pakora*. Seed coats of ricebean grains soaked overnight are removed; the grain is allowed to dry for 3–4 days, and the dried dehulled grain is then milled into flour. Ricebean flour and spinach leaf are mixed with water and then beaten for uniformity, followed by a second mixing after adding chopped onion, garlic, ginger, coriander leaves, green chillies, and salt. The shaped paste (0.5 in. thick, 2 in. diameter) is deep fried. Kaur and Mehta (1993) reported the nutritional composition of *pakora* as moisture, 15.5%; crude protein, 13.1%; fat, 16.8%; ash, 2.3%; crude fibre, 2.1%; calcium, 138.5 mg/100 g; iron, 6.7 mg/100 g; zinc, 3.1 mg/100 g; copper, 0.6 mg/100 g; while amino acids (g/16g N) were methionine,1.0; cystine, 1.0; tryptophan, 0.9; and lysine, 4.0.

Sepu vadi

Sepu vadi is a traditional dish of Himachal Pradesh. It is commonly prepared from lentils and blackgram with leafy vegetables and other spices, but in some ricebean growing areas it is also prepared from dehulled ricebean. Sharma (2014) prepared ricebean-based *sepu vadi* and found that it had more fat, crude fibre, and zinc than blackgram *sepu vadi* but with a lower overall acceptability (6.7) compared to blackgram (7.3). Wet grinding of soaked split dhal produces the paste. The paste is mixed with the desired quantity of garam masala and salt and shaped into large-sized balls, then steam-cooking ensues until the core of the balls is cooked properly. Rectangular pieces are made from the cooked balls and deep fried.

Papad

Papad is another traditional food product of the Indian subcontinent popular because of its crispness and taste. It is generally prepared from dehulled blackgram flour, but Sharma (2014) prepared ricebean *papad* and reported it had more crude fibre and zinc but overall acceptability was lower (6.5) than for blackgram *papad* (7.8). To prepare ricebean *papad*, ricebean whole flour is sieved and blended with desired quantities of Ajwan, cumin seed, sodium bicarbonate, chilly powder, and salt. Water is added into blended flour to make a dough that can be held for 2 h after covering with wet muslin cloth. Small dough balls are formed from soft dough made by hammering with a heavy pestle. Dough balls are shaped into a circular dish shape and dried in hot air at 60 °C, then deep fried in oil.

Boondi

Boondi is a dessert or savoury type of food available in the Indian subcontinent in various forms. It generally made from chickpea flour. Sharma (2014) prepared *boondi* from ricebean flour and found more crude fibre, ash, calcium, and zinc than in Bengal gram flour. For preparation, ricebean flour, baking powder, salt, gram masala, and chilli powder are blended uniformly; the flour blend is transformed into a lump-free batter after adding the desired quantity of water. The ready batter passes through a slotted spoon into heated oil where it forms small pearl-like balls after frying. The frying is continued to a light brown colour. *Boondi* is ready for use after draining the excess oil.

Bhujia

Bhujia is a popular crispy Indian snack usually made from moth bean, besan, and spices. Sharma (2014) developed ricebean-based *bhujia* and reported more crude fibre, ash, calcium, and zinc than with Bengal gram flour. For development of ricebean *bhujia*, the desired quantity of ricebean flour is kneaded with other ingredients such as boiled potatoes, salt, turmeric powder, *garam masala*, chilly powder, and citric acid into a smooth dough that is then covered for 15–20 min. The rolled dough is allowed to pass through a vermicelli-making machine fitted with a fine net; the machine's piston pushes the raw *bhujia* into already heated oil. The raw *bhujia* is fried till it turns golden brown in colour. The *Bhujia* is ready for use after removing excess oil.

Muruku

Muruku or *chakli* is a popular snack product of the Indian subcontinent, especially southern India and Sri Lanka. This crunchy savoury product is also available in Malaysia, Singapur, and Fiji and is usually made from rice flour and urad dal. Parvathi and Kumar (2006) developed ricebean-based *muruku* in the ratio 50:50 rice and dehulled ricebean with a sensory acceptability of 3.7 of 4.

Ladoo

Ladoo is a popular sweet product of the Indian subcontinent usually served at festivals and religious ceremonies. This sphere-shaped sweet product is made from sugar, ghee/butter/oil, and flour. Sharma (2014) developed a ricebean-based *ladoo* that had more crude fibre, ash, calcium, and zinc than Bengal gram flour *ladoo*. For making of *ladoo*, ricebean flour is roasted in ghee till golden brown and the aroma is released. The cooled roasted flour is mixed with powdered sugar and shaped into small ball-shaped *ladoo*. Parvathi and Kumar (2006) also developed a dehulled ricebean-based *sweetened ball* with 3.6 sensory acceptability of 4.

Supplementary Food Beverage

Four ricebean-based supplementary food beverages were developed by Parvathi and Kumar (2006) from starchy grain [rice, wheat, sorghum, and kodomillet (3 parts)], ricebean (2 parts), ground nut (1 part), and jaggary (2 parts). Of the four supplementary food beverages, that containing ricebean scored the highest in sensory acceptability (3.6 in the 4-point Hedonic scale).

Cake

Cake is a baked product usually served as a sweetened dessert. It is commonly made from soft wheat flour, sugar, eggs, margarine/butter, milk, and baking powder. Sharma (2014) prepared a ricebean-based cake with greater quantities of protein, crude fibre, ash, calcium, iron, and zinc than a cake made from wheat flour with comparable sensory acceptability.

Cookies

Kii et al. (2013) developed cookies by blending ricebean flour from 0% to 30% with wheat flour and found a significantly increased texture and calcium content with an insignificant change in sensory quality.

Munthiri Kothu

This product from Kanyakumari, Tamil Nadu, is usually made during the festival season. Parvathi and Kumar (2006) developed ricebean-based *munthiri kothu* with highest sensory acceptability. Roasted ricebean flour, fried coconut scrapings, and gingelly (sesame) seeds are blended uniformly. The blended flour is transformed into dough with the desired quantity of jaggery syrup: 15-mm balls are formed from the dough and coated in batter made from rice flour. Coated balls are fried in oil till reaching the characteristic brown colour. Shelf life is 2–3 months.

Halwa

Halwa is a popular sweet confectionary widely consume in the Indian subcontinent, Central Asia, and Middle East that is generally made from grain flour, ghee, and sugar. Sharma (2014) developed a ricebean-based *halwa* that contained more ash, crude fibre, calcium, and zinc than Bengal gram flour *halwa*. Ricebean flour was roasted in ghee till a golden-brown colour was reached, releasing a roasted aroma. Water and sugar were then added slowly, cooking with continuous stirring. When the desirable consistency is reached, *halwa* is ready for consumption.

Extruded Snacks

Prabhavat et al. (1996) prepared 17 different types of extruded products from ricebean, ricebean flour blended with mung bean, black gram, rice, wheat, cassava, corn, and soy flour using a twin-screw extruder (ZE 25X 33D) and coated with BQ flavour. Of 17 formulae, formulas no. 9 and 14 were reported with maximum sensory score (OAA, 7.4) whereas sole ricebean extrudates had OAA of 7.27. Extruded product prepared from formula 9 used 57.5% ricebean flour, 20% rice flour, 2.5% wheat flour, 20% corn grit; extruded product prepared from formula 14 used 28.6% ricebean flour, 23.8% black gram, 21.4% rice flour, 21.4% corn grit, and 4.8 full-fat soy flour. Formula 9 was reported as moisture, 7.16%; fat, 9.10%; protein, 15.23%; ash, 3.32%; crude fibre, 1.93%; and carbohydrate, 70.42%. Formula 14 proximate composition was 6.85%; fat, 11.95%; protein, 16.25%; ash, 3.88%; crude fibre, 1.24%; and carbohydrate, 66.87%. For formula 14 reported maximum protein efficiency ratio was 2.00 ± 0.11, followed by formula 9 (1.92 ± 0.13), which was far better than extrudates prepared from ricebean flour alone (1.60 ± 0.19).

Lamichhane et al. (2013) developed extruded snacks from 75% maize flour, 10% sorghum flour, and 15% ricebean flour with particle size 1090 μm. For extrusion, these flours are adjusted to moisture content of 17% and extruded at 135 °C barrel temperature and 153 rpm screw speed. The extruded products have expansion ratio 4.0, bulk density 80 kh/m^3, water-soluble index 21.48 ±0.82, and water absorption index 9.77 ± 0.52, moisture, 0.667%; crude protein, 2.97%; fat, 1.87%; ash, 2.54%; crude fibre, 12.06%; carbohydrate, 79.86%; and beta-glucan, 6.52 ± 0.61. The sensory quality of extrudates as colour, 7.5; taste, 7.0; texture, 7.5; and OAA, 7.5.

Vada

Kaur and Mehta (1993) developed ricebean-based vada. For preparation, bean grains are soaked overnight, ground to a coarse paste, and fermented for 4 h at room temperature. The fermented paste is beaten for 7–10 min and mixed properly after adding chopped onion, garlic, ginger, coriander leaves, green chillies, and salt.

Doughnut shapes (0.5 in. thick, 2 in. diameter) of paste are fried at 190 °C for 1 min, and the fried product is called vada. Nutritional composition of vada is moisture, 17.5%; crude protein, 19%; fat, 18.7%; ash, 2.5%; crude fibre, 4.3%; calcium, 282.6 mg/100 g; iron, 7.8 mg/100 g; zinc, 3.3 mg/100 g; copper, 9 mg/100 g; methionine, 9; cystine, 1.0; tryptophan, 0.7; lysine, 4.0 g/16 g N. The content of ash, crude fibre, calcium, iron, and zinc was found to be greater in rice vada than blackgram vada prepared from the same ingredients.

Ricebean Pickle

Ricebean pickle is usually prepared in Nagaland. Bean grains are soaked overnight, ground to a coarse paste, fermented, and mixed with spices and herbs.

Complementary Food

Ijeomah (2017) developed a ricebean-based complementary food from fonio (*Digitaria exilis*), ricebean, carrot, and crayfish. For preparation of final products, fonio powder was prepared by soaking then boiling followed by drying and milling, carrot powder slicing, blanching, drying, and milling; crayfish were prepared by cleaning and drying. Ricebean grain was prepared by soaking, sprouting, dehulling, and milling. Normal fonibean (FNBN)was prepared by blending 70 g fonio, 30 g ricebean, 30 g carrot, 30 g crayfish, 5 g sugar, and 1 g salt with 5 mL vegetable oil. Fonibean plus (FNBP) was prepared by blending a similar recipe of FNBN with 20 powdered milk, fonibean minus (FNBM) was designed by mixing fonio and sprouted ricebean, and fonibean untreated (FNBU) was prepared with unsprouted ricebean only with a recipe similar to FNBN. The overall acceptability of these products was reported as FNBP 8.52, FNBU 7.0, FNBN 8.33, and FNBM 5.62. The nutritional qualities of FNBP are as follows: body weight gain (g), 89.88 ± 0.04 g; biological value, 91.67 ± 0.20%; net protein utilization, 89.43a ± 0.40%; and digestibility, 97.56 ± 0.06%. The nutritional qualities of FNBN are body weight gain (g), 70.45 ± 0.01 g; biological value, 88.76 ± 0.35%; net protein utilization, 86.81 ± 0.10%; and digestibility, 97.80 ± 0.06. Although the ricebean used in the sample of FNBU was not sprouted, the sample showed a better quality protein than the sample of FNBM that contained sprouted ricebean.

Convenient Food Multimixes

Convenient food multimixes (Baruah et al. 2018a) were developed from ricebean (3 parts), foxtail millet (4 parts), flax seed (1 part), and tomato powder (1part) with maximum energy density of 446 kcal. For preparation of food mixes, milling of sprouted ricebean, toasted flax seed, and toasted foxtail millet was followed by sieving through a 100 mesh sieve. The product was prepared by blending all ingredients and compared with a product prepared with unsprouted ricebean. The food mix prepared from sprouted ricebean was higher in protein (17.86%) and lower in fat (3.91%), phytate (2.09%), and saponin (0.23%) than the food mix prepared from unsprouted ricebean.

Probiotic Food Multimixes

Baruah et al. (2018b) developed probiotic food multimixes from ricebean (3 parts), foxtail millet (4 parts), flax seed (1 part), and tomato powder (1 part), inoculated with *Lactobacillus plantarum* and *Lactobacillus rhamnosus*, which had maximum energy density (446 kcal). For preparation of food mixes, milling of sprouted ricebean, toasted flax seed, and toasted foxtail millet was followed by sieving through a 100 mesh sieve. The product was prepared by blending all ingredients and compared with a product prepared without probiotic microbes of ricebean. The food mix prepared from probiotic inoculation was reported as higher in protein (17.86%) and lower in fat (3.91%) and crude fibre (12%), with 30 days probiotic microbial viability compared to the noninoculated products.

Ojojo

Ojojo is a crispy-crust traditional fried product of Nigeria that is usually prepared from water yam with salt and spices. Okoye et al. (2018) developed ricebean-based *ojojo* by replacing water yam flour by 10–50%. To prepare *ojojo*, ricebean grain is soaked, dehulled, dried and milled into flour. A thick batter is made from the desired quantity of water yam, ricebean flour, and water. Onions (chopped or ground), seasoning cubes, fresh pepper, salt, and garlic (ground) are added to the batter and mixed uniformly. Batter formed into ball shapes is deep fried in ground nut oil until golden brown in colour and served after draining off oil. *Ojojo* prepared by replacing 50% water yam flour with ricebean flour was reported to have maximum overall acceptability (7.2) and higher amounts of nutritional attributes such as protein, ash, crude fibre, calcium, magnesium, vitamin B_{12}, vitamin C, and phosphorus than the *ojojo* prepared from 100% water yam flour. The nutritional attributes of this ojojo were reported as moisture, 18.56 ± 0.02%; crude protein, 10.84 ± 0.92%; fat, 14.78 ± 0.04%; ash, 2.81 ± 0.14%; crude fibre, 2.92 ± 0.14%; carbohydrate, 43.25 ± 0%; phosphorus, 83.04 + 0.03 mg; calcium, 75.05 + 0.0 mg; magnesium, 91.01 + 0.02 mg; vitamin B_{12}, 35.51 + 0.01 mg; and vitamin C, 39.26 + 0.37 mg per 100 g.

Future Trends in Processing and Product Development

Although ricebean is processed by various technologies such as soaking, conventional cooking, dehulling, germination, roasting, fermentation, and extrusion, the process parameters are not being optimized. Moreover, very limited studies are available on processes such as microwave cooking, flaking, and frying, which are not studied in terms of process or impact on functional components, nonnutritional components, digestibility (starch and protein), and mineral bioavailability (calcium and iron). Studies of the influence of the soaking process in ricebean on nutritional and nonnutritional components such as potassium, sodium, zinc, vitamin C, thiamin, riboflavin, niacin, folate, patothenic acid, flavonoids, oxalate, HCN, verbascose, and antioxidant activity are not available in the literature. Even though the processing effects of conventional cooking on functional components, nonnutritional components, and digestibility (starch and protein) for ricebean are available in part, there are wide variations in cooking processes. Information on the status of magnesium, zinc, vitamin C, thiamin, riboflavin, niacin, vitamin B_6, folate, pantothenic acid, oxalate, HCN, and mineral bioavailability (calcium and iron) in conventional cooking is sparse. The impact of dehulling on magnesium, potassium, sodium, vitamin C, thiamin, riboflavin, niacin, vitamin B_6, folate, patothenic acid, TIA, AIA, oxalate, HCN, raffinose, stachyose, verbascose, IVPD, IVSD, IVIB, IVCB, and antioxidant activity is also not reported. The sprouting of ricebean and functional components, nonnutritional components, and digestibility (starch and protein) is available in part but wide variations in the germination process have been observed. The available literature on the effect of ricebean germination on magnesium, potassium, sodium, vitamin B_6, folate, pantothenic acid, flavonoids, oxalate, HCN, and verbascose is sparse. The consequences of roasting on minerals, water-soluble vitamins, flavonoids, TIA, AIA, oxalate, HCN, raffinose, stachyose, verbascose, IVPD, IVSD, IVIB, IVCB, and antioxidant activity are not found in scientific texts. The effect of fermentation on calcium, iron, magnesium, phosphorus, potassium, sodium, zinc, vitamin C, thiamine, riboflavin, niacin, vitamin B_6, folate, pantothenic acid, tannin, flavonoids, saponin, phytic acid, TIA, AIA, oxalate, HCN, IVPD, IVSD, IVIB, and IVCB is not available in scientific reports. Hence, there is a need to study microwave cooking, extrusion cooking, flaking, and frying in terms of their influence on the functional components, nonnutritional components, digestibility (starch and protein), and mineral bioavailability (calcium and iron) in ricebean.

Most of the traditional ricebean-based products are prepared by using simple household processing methods such as soaking, cooking, sprouting, fermentation, and frying that are applied in other grains also. Other traditional products available in ricebean-growing areas are usually prepared using other food grains and ingredients, but recently such products are also trying with ricebean to increase the taste variability among consumers and to develop new products. Most of these products should be consumed immediately after preparation and are not suited for marketing because of the lack of a proper packing system. The existing developed products of ricebean also lack proper nutritional profiling and storage study. Hence, there is a need to develop new ricebean-based products in ready-to-eat (RTE) or ready-to-cook (RTC) form in proper packing modules that will remain viable for a long time. Apart from this, there is also a need to study the nutritional profile (minerals, and amino acids) and storage stability of such new products.

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