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Review Article

Nutritional Composition, Functionality, and Processing Technologies for Amaranth

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The current production levels of the major staple food crops are not sufficient to fulfill the projected global food requirements, with more than 75% of total grain production being maize (corn), wheat, and rice together. Accordingly, there is an acute need to explore alternative crops such as amaranth with the potential to play a crucial role in sustainable agriculture and their use in nutrition-dense food products. Amaranth (*Amaranthus* spp.) is one of the oldest food crops in the world with broad leaves and inflorescence. It has a tolerance to drought and heat and is considered a smart crop. Amaranth is gluten-free and high in quality proteins, fiber, minerals, and bioactive compounds. The grains are processed by popping, flaking, and grinding for flour production which works well in blends with flours from other cereals. Besides nutritional value, amaranth grains keep religious importance in some countries. Even being a potential crop with substantial nutrient content amaranth grains remain underutilized as food. This article presents a critical overview of the nutritional composition, functionality, and processing technologies of amaranth grains and their utilization in different sustainable products. It also presents the effect of production on the composition and properties. Understanding the effect of processing technologies on the amaranth product functionality and nutritional value will assist in its utilization as a solution to alleviate food sustainability and food insecurity.

1. Introduction

Ending hunger, food insecurity, and all forms of malnutrition keeps growing and remains the greatest challenge of our time [1]. The World Food Program [2] estimated that 828 million people do not have enough food, and 49 million people are facing emergency levels of hunger. Trends in child malnutrition—including stunting and wasting, deficiencies in essential micronutrients, and overweight and obesity in children, continue to be of great concern. In addition, maternal anemia and obesity among adults continue to be alarming. Food insecurity was further aggravated due to combined impacts of conflicts, climate change, disasters, and structural poverty and inequality. The disruption of the food supply chain and the rising consumer food prices were further exacerbated during the COVID-19 pandemic which had a significant effect, especially in low-income countries [2]. This has further highlighted the fragilities in the global agrifood systems and the inequalities in societies. The Food and Agriculture Organization (FAO) estimates that cereals supply about half of the calories and 47% of the protein in the average diet. While the total annual cereal production globally is about 2,500 million tons, maize (corn), wheat, and rice together account for more than 75% of total grain production. The current production levels of the major staple food crops are not sufficient to fulfill the projected global food requirements. Accordingly, there is a dire need to explore alternative crops with the potential to play a crucial role in sustainable agriculture and their use in nutrition-dense food products to meet the future food demands of the growing world population. Amaranth, which is an ancient grain, remains one of the underutilized species with such potential [3]. Amaranth (*Amaranthus* spp.) is a dicotyledonous plant, unlike typical cereals which are monocotyledonous in morphology and hence are known as pseudocereal. The seed structure differs from the traditional cereals, as amaranth encompasses three distinct layers: perisperm, embryo, and seed coat [4, 5]. It has a unique physiology as it falls under the category of C4 plant, which indicates that the first product of photosynthesis in this plant is a four-carbon compound. This unique attribute in a dicot plant, along with other anatomical features in an amaranth plant, results in improved efficiency to use CO_2 under a wide range of temperatures as well as in a moisture-stress environment, which is the basis for its contribution to the plant's vast geographic adaptability to diverse environmental conditions. It is thereby a sustainable and climate-smart crop and can contribute to food security [3, 6]. There are more than 60 species in the genus *Amaranthus L.* [7]. The major species cultivated for grains and human nutrition are *A. caudatus* of Peru and other Andean countries, *A. cruentus* of Guatemala, and *A. hypochondriacus* of Mexico [8]. In India, amaranth is grown majorly in the Himalayan area and a few states. The plant is also popular as an ornamental owing to its colorful and eye-catching inflorescence. Amaranth, an economical source of proteins, minerals, and vitamins A and C, seems to be a future crop because of its high yield, good phenotypic plasticity, adaptability to adverse growing conditions, resistivity to drought and heat, and good nutritional characteristics [3, 9, 10]. Amaranth's nutritional composition has the potential to attract health-conscious consumers with high protein quality, a well-balanced amino acid profile, and gluten-free composition [11]. Owing to various nutritional benefits, it was recently concluded that amaranth is a pseudocereal with a dual character, as it not only has features of food but also has health-promoting capabilities [12]. The leaves are used as vegetables and feed, while its grains are consumed as other cereals. Amaranth grains are processed in various ways depending on the traditions and convenience of consumers in different parts of the world. Amaranth comprises certain biologically active chemical compounds which reduce the availability of nutrients to the body and often interfere with metabolic processes. However, precooked foods from amaranth have good physical, chemical, and functional properties and the desired acceptability that makes them a potential ingredient in value-added foods [13]. Amaranth grains can also be parched or cooked into gruel or milled to produce sweet, light-colored flour suitable for biscuits, bread, cake, and other bakery foods. These have little or no gluten, so blending it with wheat flour is required for the preparation of yeast-leavened bakery products [14]. Popped amaranth is light and crispy in texture and is eaten as a snack, sweet, cold cereal with milk and honey, or "breading" on meats or vegetables [14]. Two breakfast drinks, "*Kiwigen*" and "*Kiwi-Instant*," are prepared using toasted amaranth, quinoa flour, cocoa, and sugar by mixing these with water or milk. A gelatin-type dessert, *Kiwimor*is, made with amaranth and potato [15].

Data available in the literature will help broaden its applications. This review article focuses on the current state of knowledge on the composition, properties, and processing treatments employed for the efficient and sustainable utilization of amaranth grains. It focuses on the most advanced and sustainable applications of different forms of amaranth in a variety of sustainable food products.

2. Composition

The physicochemical properties of amaranth grains and flour obtained from previous studies are summarized in Table 1. Grains and flour were mainly composed of carbohydrates, followed by protein, water, and fat. The noticeable differences in the composition of its grains were based on different varieties, cultivars, or growing conditions. Less difference was found for protein and fat contents among its cultivars [16]. Nutritionally, protein content is 9.41% in wheat and 14.19% in amaranth; fat levels of 1.33% in wheat and 7.49% in amaranth are higher than in wheat [17]. Being a good source of minerals, vitamins, and proteins, amaranth has a higher nutritional value than those cereals and some legumes [18]. *A. powelli* was found to be the highest in protein and fat levels among its different cultivars [19]. Therefore, the appreciable exploitation of amaranth grains could help us to overcome the present scarcity of conventional cereals.

2.1. Carbohydrates. Amaranth grains contain 65 to 75% starch, 4 to 5% dietary fibers, a 2 to 3 times higher content of sucrose in comparison to wheat grain, and nonstarch polysaccharide components (Table 1). Sucrose is the major sugar, followed by raffinose, whereas inositol, stachyose, and maltose are in small amounts in the amaranth grains [20]. The percentage of low-molecular-weight carbohydrates, namely, sucrose, glucose, fructose, maltose, raffinose, stachyose, and inositol in *A. cruentus* and *A. caudatus* were reported. Starch is the major component of *A. cruentus* grains that contributes to about 50% of raw grains, popped grains, and flakes, respectively [21–24]. The size of its starch granules is very small, 1-2 μm with an average diameter of 1.38 μm and even smaller than buckwheat, maize, and rice starches [25–28] (Table 1). Starch, tightly packed in grain structure, is mainly composed of amylopectin (97.9%) [27]. The proportion of short-chain amylopectin to long-chain amylopectin was found to be 2.2-2.6 which is slightly lower than maize starch. The digestion time of amaranth starch (3 h) by amylase is also less than that of maize starch [29]. The amylose contents in amaranth flour and starch were found to be 5.9% and 6.9%, respectively [30–32]. Its low amylose content is also a crucial factor affecting its textural, pasting, and thermal properties ([33–37]). The alkali extraction method yielded starch with about 80% starch recovery and 0.2% protein content [27]. Resistant starch RS3, dietary fiber, and prebiotics that arise during freezing, cooking, and baking were found to be 12.4 g/kg (on a dry weight basis) which is very low in comparison with rye, buckwheat, wheat,

Table 1: Physicochemical properties of amaranth grains and flour (on dry weight basis).

Parameter (on dry weight basis)	Amaranth Grains	Amaranth Flour	Reference
Weight of 1000 grains (gram)	0.5-0.7		Grains: Emire and Arega [17]; Akingbala et al. [132]; Resio et al. [103]; Stone et al. [104]; Tomoskozi et al. [16]; Grace et al. [170]; Ogrodowska et al. [21]; Sangeeta and Grewal [78]; Amare et al. [171]; Paucar et al. [152]; Capriles et al. [91]; Alvarez et al. [163]; Amador et al. [172]; Babor et al. [97]; Liberal et al. [173]; Bressani and Garcia [49]; Srivastava et al. [174]; Akin et al. [56]; Mota et al. [137]; Bhat et al. [58]; Tang et al. [52]; and Kariuki et al. [175]. Flour: Dodok et al. [79]; Emire and Arega [17]; Sanz et al. [176]; Rosell et al. [86]; Sindhuja et al. [177]; Choi et al. [92]; Chauhan et al. [178]; Mlakar et al. [167]; Alonso et al. [25]; Kahlon and Chiu [77]; Mokrejs et al. [179]; Escudero et al. [116]; Romero et al. [180]; and Uriyapongson and Rayas [89]
Bulk weight (g/dm$^{3)}$	660-850		
Perimeter (mm)	2.90		
Circulatory	0.97		
Aspect ratio	1.06		
Area (mm^2)	1.98		
In vitro protein digestibility (%)	71.9-79.8		
Moisture (%)	6.5-11.1	6.2-11.6	
Ash (%)	2.2-3.5	1.7-5.1	
Fat (%)	1.7-10.3	4.9-9.8	
Protein (%)	12.7-19.8	12.34-17.7	
*Carbohydrate (%)	40.5-87.1	54.5-72.7	
Energy (kcal/100 g)	250.8-441.2		
Starch (%)	49.5-73	52.8-65.8	
Crude fiber (%)	2.4-5.8	3.0	
Soluble dietary fiber (%)	2.20-5.61	4.29	
Insoluble dietary fiber (%)	7.4-12.64	5.54	
Total dietary fiber (%)	1.8-37.6	8.8-11.3	
Thiamin (mg/kg)	0.3-0.9	0.23	
Riboflavin (mg/kg)	0.1-0.7	1.22	
Niacin (mg/kg)	1.042		
Phytate (mg/100 g)	237.7-1440		
Tannin (mg/100 g)	1.2-1.6		
Calcium (mg/kg)	1463-2000	2040-2410	
Magnesium (mg/kg)	2466.2-3280	2690-2720	
Iron (mg/kg)	65.4-660	82.1-139	
Potassium (mg/kg)	4005-5520	3957.3-5470	
Phosphorous (mg/kg)	4731.25-6630	4780-5650	
Sulphur (mg/kg)	2072.50		
Manganese (mg/kg)	8.8-57.1	36.5-45.3	
Zinc (mg/kg)	28.9-113	34.5-42.3	
Copper (mg/kg)	2.8-10.7	6.9-11.7	
Unsaturated fatty acid (% of total fatty acids)	48.8-77.1		

*Analyzed using standard method.

chickpea, pea, faba bean, and lentil that have RS3 up to 82 g/kg. The proportion of resistant starch to the total starch was as low as 1.98%.

2.2. Proteins. Amaranth grains contain 15.4-16% protein with a balanced composition of amino acids as compared to wheat (13.5-14.5%), maize (10.6-13.8%), barley (10-14.9%), and oats (12.4-12.9%) and total essential amino acids of about 47.6 g/100g protein (Table 1). It was also observed that the prolamin part of its protein is not a storage protein [21, 38]. The protein content of amaranth (about 16%) is higher than major cereals like wheat, rice, and maize (as per FAO, 8-11% protein), as well as other pseudocereals including buckwheat and quinoa [39]. It is known for its higher sulfur-containing amino acids which are limited in pulses, due to which it has been recommended by FAO/WHO owing to its balanced amino acid profile [40]. The endosperm is the dominat region for the existence of proteins in grains of major cereals, while in amaranth grains, proteins are present mainly in embryonic and perisperm parts. Cysteine and methionine in amaranth protein are also higher than in cereals and legumes [41]. The amount of indispensable amino acids excluding tryptophan is 43-49%, while its reference pattern is 31% [41]. Lysine content (55 mg/g to 65 mg/g) was found to be higher than cereals yet like legumes [16]. Amaranth grains contain lysine about two folds of that in wheat and three folds of that in maize [14]. Its high lysine level [42] makes it a nutritious complement to cereals like wheat, corn, and rice. Amaranth protein contains a low leucine content, but it is not a considerable limitation due to its presence in other common cereal grains. Amaranth protein has good nutritional value with a 1.5-2.0 protein efficiency ratio and about 90% total digestibility in cooked grains. At a biological value of 75, it became similar to other cereal proteins with the desired essential amino acid balance and scored 100 on the scale of nutrition based on its amino acid composition while, corn, wheat, and soybean scored only 53-72 [43, 44]. In grain flour, the content of albumin, globulin, prolamin, and glutelin was found to be 3-3.6, 2-3.5, 0.5-0.6, and 5.7-6.6%, respectively, with 14.9% total protein. Albumin showed polymorphism upon electrophoresis, while glutelin was found to be the major protein in grain [45, 46]. The amaranth protein comprises albumins and globulins that have high essential amino acids such as lysine, methionine, cysteine, and histidine but less glutamic acid and proline than prolamins [47, 48]. Bressani and Garcia [49] reported high values of lysine in prolamines and low in glutelin and glutelin-like fractions. *Klubicova* et al. [50] identified 249 out of 461 quantified grain proteins using protein extraction coupled with gel-LC-MS/MS proteomics in which 14 spots were identified as 11S globulin and 4 spots of ama1 protein, representing protein fractions with good nutrition. Ama1 protein was found to be nonallergenic with well-balanced amino acids and high levels of essential amino acids. Only one protein spot with a very low amount was identified as glutenin, a major storage protein associated with intolerances. Delta12 oleic acid desaturase was also observed which helps in the biosynthesis of PUFA. Fractionation of amaranth components promotes the preparation of functional foodstuffs and some quality supplements.

2.3. Lipids and Oil Composition. Amaranth grains contain 6.98-7.22% lipids, with 71.58-72.44% of it being unsaturated fatty acids [3]. Amaranth has about twice the saturated fatty acids (C16:0 and C18:0) than quinoa. Amaranth grains are found to be rich in palmitic but deficient in oleic and linolenic acids in comparison with major grains and oilseeds [51]. Linoleic and oleic acids are mainly responsible for their unsaturated-to-saturated ratio of 27 : 10 [48, 52]. Amaranth oil comprises around 70% oleic and linoleic acids, 20% stearic acid, and around 1% linolenic acid [21, 53, 54]. This oil also has a unique level of squalene [44]. The oil yield of amaranth grain was about 7% which was slightly higher than that of quinoa (6.5%) [52]. The PUFA content in amaranth oil was 73% which was 10% lower than in quinoa oil. Squalene is the highest in *A. cruentus* oil and varied from 53% to 94% depending on its species [19]. Squalene (470mg/100g grains and 5662 mg/100 g of grain fat) and phytosterols are the bioactive compounds of amaranth oil.

The oil is also a good source of tocopherol. It has been reported that 100 g of oil extracted by pressing method had 78 g of triglycerides, 6 g of squalene, 8 g of phospholipids, 2 g of phytosterols, 300 mg of tocopherols, 0.5 mg of carotenoids, and 87 kJ of energy. Accordingly, amaranth oil has numerous beneficial effects on health. A dose of 18 ml/day would be beneficial in curing coronary heart disease and hypertension because this oil has increased PUFA levels, especially long-chain omega-3 fatty acids, and decreased total cholesterol, triglycerides, LDL, and VLDL. In addition, the high antioxidant value of this oil may protect cellular membranes from oxidation [55].

2.4. Minerals, Vitamins, and Other Bioactive Compounds. Amaranth grains contain a high amount of macro- and microelements. Macromineral components are usually less those or comparable to that of wheat grains except for magnesium, as amaranth has twice as much Mg as that of wheat [16]. Amaranth grains have higher antioxidant activity and phytochemical content than oat, barley, wheat, corn, millet, and rice, revealing it to be a good substitute for traditional cereals and a potential source of health-promoting bioactive compounds [56]. Amaranth-based products were found to be good sources of minerals in comparison with other traditional food products like buckwheat, millet, or brown rice [57]. Amaranth grains are reported to have a considerable amount of essential minerals like Mg (848 μg/g), Ca (519.3 μg/g), P (330 μg/g), and Fe (65 μg/g) [58]. Small amounts of tannin (1.49 mg/100 g) may be present in amaranth flour [17]. Zn and Fe in amaranth stabilize the immune and alleviate anemic conditions, respectively, while Mg and Mn are important for infant growth. While considering vitamins, thiamine, riboflavin, and niacin are important for improvement in blood circulation, the nervous system, maintenance of healthy skin, dilation of the blood capillary system, functions of the gastrointestinal tract, and good metabolism of carbohydrates and proteins. Amaranth grains are reported to have 0.12, 0.20, 0.92, and 4.20 mg/100 g of vitamins B1, B2, B3, and C, respectively [59]. A hundred grams of amaranth flour contained 53% of the Recommended Dietary Allowance (RDA) for vitamin B6. It is a good source of folate, especially 5-MTHF (methyltetrahydrofolate). Total folate, in terms of the sum of folic acid, 5-MTHF, and 10-formyl tetrahydrofolate expressed as folic acid equivalent, was about 228 μg/100 g (DWB). Boiling and steaming treatments reduced total folate by 58% and 22%, respectively, malting increased it by 21%. According to European Food Safety Authority (EFSA) recommendations, 35 g of amaranth, either boiled/steamed/malted may provide 25% of the dietary reference value of folates. Storage of foods caused loss of folate, despite losses, folate content of noodles, cookies, and bread was reported to be 17-98 mg/100 g, 18-62 mg/100 g, and 26-41 mg/100 g [60–62]. Beta-tocopherol contributes 38% to total tocopherol, whereas 32%, 18%, and 12% are δ-tocopherol, α-tocopherol, and γ-tocopherol, respectively [21]. In another study, δ- and α-tocopherols were observed as dominant tocopherols [52]. *A. hypochondriacus* is a moderate source of nutraceuticals like phenolics (0.8459 mg GAE/100 mg extract), flavonoids (0.629mg CE/100 mg extract), alkaloids (5.57%), and saponins (0.06%) [58]. Amaranth is a good source of rutin (quercetin-3-O-rutinoside) having a content of 0.08 g/kg. This rutin might be crucial for dietetic patients. It has been suggested that the intake of 100 g of amaranth grains may significantly enhance the daily intake of flavonoids (rutin) by 5-10 mg/day. Therefore, amaranth has good potential for being utilized as a functional food [63]. Methanolic extracts of amaranth grains showed antidiabetic, antihyperlipidemic, and antihelmintic characteristics, and its water extracts had antifungal, antidiarrheic, and antimalarial characteristics. Some polyphenols like rutin, nicotiflorin, and isoquercetin were also found in amaranth grains [64]. A high concentration of Pb, 19-35 mg/kg which is more than the WHO limit (10 mg/kg), suggests its reduction or removal to avoid the intake of toxic components [65]. Nonnutritional components, namely, saponin, trypsin inhibitor, and tannin, are similar to those in legumes and some other grains like sorghum [44]. Major antioxidants in amaranth are not in the lipid part because, after fat extraction, the antioxidant value remained the same [66]. Some other researchers also reported that amaranth may act as a nutraceutical therapy in type 2 diabetes as it stimulates insulin secretion, as well as in obesity health improvements [67–70]. Unprocessed and extruded amaranth flours were found to be good sources of peptides with potential biological activity, such as ACE-inhibitor and dipeptidyl peptidase IV inhibitor, thereby preventing chronic diseases [71, 72]. *A. hypochondriacus* grains had a high antioxidant level in terms of ferric reducing ability of plasma activity (FRAP) [58]. Antioxidants in terms of DPPH, FRAP, and ORAC activities of amaranth were also evaluated and found to have values as 3.50 μmol of TE/g, 4.59 μmol of AAE/g, and 4.43 μmol of TE/g, respectively. Amaranth is also a good source of carotenoids, especially lutein and zeaxanthin, while being deficient in β-carotene [52, 73]. Radical scavenging activity was found to be 22.6 mg gallic acid equivalent/g, indicating that pseudocereals have a higher radical scavenging ability than cereals having 2.5-17.7 mg gallic acid equivalent/g. Angiotensin-converting enzyme (ACE) inhibition activity is higher than that of rice and wheat but lower than that of quinoa. Thus, amaranth can be a good substitute for cereals [74]. Studies indicate that amaranth is a richer source of many essential vitamins, minerals, and antioxidants as compared to common cereals. Major studies on carotenoids have been conducted on their leaves rather than grains. Amaranth grains also positively affect total cholesterol levels and low-density lipoprotein cholesterol [75], stimulate the immune system, and show antitumor and antiallergic activities [76]. Therefore, more exploitation of their identification, retention in processing, and impact on health is needed.

3. Grain Physical Properties

Amaranth grains are cream, golden brown, or beige yellow in color with lenticular or spherical in shape. The size of amaranth grains is smaller than major cereal grains, and about 1500 grains of amaranth weigh in the range of 0.4-1 g [15, 77, 78]. Amaranth grains are sweet to spicy in taste and odor which is similar to that of sugar beet pulp [79]. The average values of measurements for the *A. cruentus* grains were for the length (1.4 mm), width (1.3 mm), thickness (0.87 mm), diameter (1.1-1.2 mm), sphericity (0.82), pycnometer volume (0.65 mm^3), and surface area (4 mm^2) of about 1.4 mm, 1.3 mm, 0.87 mm, 1.1-1.2 mm, 0.82, and 0.65, respectively. Thousand-grain weight, specific volume, and porosity vary directly with moisture value, but true density, bulk density, and angle of repose inversely vary with moisture content [80, 81]. The hydration index, bulk density, and swelling index of amaranth grains were reported as 0.80, 0.66 g/ml, and 0.63, respectively [78].

4. Storage of Grain and Flour

Amaranth grains can be safely stored at 15°C and 35°C because there exists a weak dependence of water activity on temperature [82]. The optimal moisture level in grain should be as low as possible with 9.82% considered optimal for *A. cruentus* BRS Alegria with no further drying for up to 10 months of ambient storage and 3 months in the cold chamber [83]. In flour, a moisture of less than 13% is suggested, and the relative humidity in the surrounding is less than 60%; otherwise, proper packaging is to be considered [82]. Optimal moisture can be achieved by cutting plants before harvest, stopping irrigation before a few weeks of harvest, or drying grains before storage [15]. Fresh amaranth grains with about 67% moisture can be dried within 4.5-7 h using solar-energy tent dryers covered with polyvinyl chloride (PVC) material under natural convection and in 7.5 h using open sun drying to attain 7% moisture content [84]. Moisture content is determined using convection oven drying at 105 ± 3°C for 24 h following the rules of seed analysis. Storage time should be controlled depending on the fat percentage in flour to limit oxidation reaction. During 6 weeks of storage of flour, titratable acidity as lactic acid was reported to increased from 61.2 mmol/kg to 66.2 mmol/kg [79]. The underlying mechanism of its packaging and storage is not clear yet, and further research should be conducted to elucidate it.

5. Functionality

Some important functional properties of amaranth flour and its major components including starch and protein are reviewed in this part, and related data from the literature has been presented in Tables 2–4.

5.1. Functionality of Amaranth Flour. The functional properties of amaranth flour are different for different milling fractions milled at different grain moisture levels. Moisture level during grain milling and the proportion of carbohydrates, protein, and fat within grains are factors affecting the pasting profile. Kumar et al. found that the gelatinization temperature of grain coat was higher than that of fine flour and middling fractions, though starch in fine grain coat was comparable to that of flour and middling. Flours obtained at 14% and 16% moisture levels showed lower values of viscosity parameters as compared to those at other levels. For fine flour, viscosity parameters were higher at grain moisture of 11% and 12%, and then a decreasing pattern in these parameters was seen when grain moisture was 14-16%. The highest swelling ability upon cooking was seen in flour obtained at 11% grain moisture, but it decreased at 11-16% moisture while showing an increasing pattern again after 16% moisture content [85]. As far as a middling fraction is concerned, an increase in moisture level from 11% to 16% showed a decrease in gelatinization temperature, while viscosity parameters were lowest at 16% moisture

Table 2: Pasting properties of amaranth flours and starches.

Amaranth product	Amaranth cultivar	V_p (RVU)	V_f (RVU)	B (RVU)	S (RVU)	Reference
Flour	*A. caudatus*	418.0*		73.0*	17.0*	Burgos and Armada [13]
	A. cruentus	101.87	96.62	21.50	17.25	Muyonga et al. [142]
	A. hypochondriacus	163.62	135.42	70.58	42.37	Muyonga et al. [142]
	Not specified	273.0	225.50	321.60	47.50	Alvarez et al. [127, 128]
Starch	*A. caudatus*	33.22	39.11			Lara et al. [183]
	A. cruentus	68.30	59.20	16.50	7.50	Choi et al. [92]
		630.0*	-	-	450.0*	Radosavljevic, [27]
		-	181.0*	2.0*	129.0*	Xia et al. [28]
		383.33*			377.66*	Uriyapongson et al. [89]
	A. hypochondriacus	101.0	86.0	30.92	15.50	Sindhu and Khatkar [30–32]
	15 cultivars	103-275	-	31-86	23-82	Kong et al., [181]
	A. hybridus×*A. hypochondriacus*	367.0*	-	-	350.66*	Uriyapongson et al. [89]

V_p, V_t, V_f, B, and S are peak, trough, final, breakdown, and setback viscosities, respectively. RVU represent rapid visco unit. Values with * are represented as BU (Brabender unit).

Table 3: Functional properties of amaranth starch.

Amaranth cultivar	Amylose content (%)	Water binding capacity (%)	Oil absorption capacity (%)	Solubility (%)	Swelling power (g/g)	Paste clarity (%)	Reference
A. cruentus	—	134		33.32	9.82		Resio et al. [103]
	—	154		91.30	26.90		Babor et al. [97]
	3.20	130.70		–	–		Choi et al. [92]
	4.87	252.30		20.14	9.35		Stone et al. [104]
A. hypochondriacus	0.20	242.0	—	1.03	10.84		Stone et al. [104]
	—	—	—	0.20	10.80		Singhal and Kulkarni [182]
	7.24	119.66	146.0	76.33	13.60		Sindhu and Khatkar [30–32]
A. chaulai	1.87	179.60	170.33	36.47	8.40	91.70	Chandla et al. [26]
A. hypochondriacus	3.13	199.23	236.02	38.50	9.76	84.87	
	3.43	199.47	185.67	35.60	10.29	88.60	
A. paniculata	2.81	198.41	193.40	54.60	8.10	92.23	
Amaranth(15 cultivars)	7.02			79.0	12.29		Kong et al. [181]
A. hybridus× *A. hypochondriacus*	0.30	246		0.83	10.70		Stone et al. [104]
A. caudatus		216			2.50		Lara et al. [183].

content of grain. The fraction of coarse grain coat had a higher gelatinization temperature than all other fractions. Viscosity parameters had a negative correlation with soluble amylose content. Fractions of flour and middling obtained from grains milled at 14-16 % moisture levels had lower values for viscosity parameters, while their starch had no relation with viscosity parameters. A negative correlation (-0.492 to -0.76) was found between starch and viscosity parameters for the fine grain coat fraction, and a positive correlation (0.856 and 0.879) was seen for the coarse grain coat fraction, suggesting that grain coat can be fractionated at 14-16 % grain moisture [85]. The mechanical characteristics of dough prepared using an amaranth-wheat blend were found to be comparable to that of wheat flour. Divergence in the mixolab plot was seen when starch gelatinization began. Its flour resulted in the dough with desired torque which was higher than in other Andean crops [86]. The addition of amaranth flour to wheat flour up to 10% increased water absorption from about 51% to 57% [17]. Supplementation of whole-hulled amaranth flour in leaven products enhances the activity of lactic acid bacteria which is desired in sourdough fermentation [87]. The water absorption rate of amaranth grains was increased after soaking in solutions having lactic acid and SO_2 [88]. Higher amounts of globulins and

Table 4: Thermal properties of amaranth starches using differential scanning calorimetric.

Amaranth cultivars	T_O (°C)	T_P (°C)	T_C (°C)	ΔH (J/g)	Reference
A. caudatus	57.09	63.42	70.10	5.51	Lara et al. [183]; Villarreal and Iturriaga [98]
	63.87	73.81	84.46	14.22	
A. hypochondriacus	63.20	72.40	80.10	10.0	Inouchiet al. [29]; Sindhu and Khatkar [30–32]; Chandla et al. [26]; Sindhu and Khatkar [109, 110]
	64.10	75.90	89.10	15.10	
	68.89	72.30	78.90	13.29	
	66.70	72.41	79.23	11.68	
	67.06	71.42	80.67	3.59	
	66.77	72.12	82.51	3.57	
A. cruentus	69.30	74.90	82.20	10.60	Choi et al. [92]; Radosavljevic[27]; Xia et al. [28]; Chandla et al. [26]; Resio et al. [103]; Resio et al. [105]; Villarreal et al. [98]; Uriyapongson and Rayas [89]
	65.50	69.20	77.70	14.40	
	66.50	72.20	78.40	22.93	
	68.80	74.31	84.56	10.76	
	64.80	69.30	81.10	10.70	
	64.80	69.0	85.40	8.50	
	69.97	74.50	82.20	16.15	
	69.10	72.0	79.30	11.70	
A. cruentus (8 cultivars)	65.3-71.6	71.2-76.9	77.9-83.9	9.5-13.5	Inouchi et al. [29]
A. paniculata	68.70	73.54	80.64	17.96	Chandla et al. [26]
Amaranth (15 cultivars)	63.4-72.5	68.8-77.8	78.8-83.7	15-18.4	Kong et al. [181]
A. hybridus×*A. hypochondriacus*	63.30	67.80	75.90	20.20	Uriyapongson and Rayas[89]

T_o, T_p, and T_c are onset, peak, and conclusion temperatures, respectively, and ΔH is enthalpy.

albumins in pseudocereals increase their applications because of their good solubility in water and salt solutions that are desired for food products, especially plant-based beverages. The pasting properties of amaranth starch in terms of final viscosity are even less than that of buckwheat and quinoa [25]. Pasting properties are an important indicator of the predictive behavior of starch upon gelatinization in the presence of heat and water.

5.2. Starch Functionality. Amaranth starch is likely to have wider applications not only in the food industries but also in packaging, cosmetics, and other manufacturing sectors. Steeping amaranth grains in NaOH at 5°C for 24h, followed by centrifugation at 1500 rpm for 20 min, scraping, neutralizing, and air drying, is the process generally followed to isolate starch for food applications. Dry-wet milling of amaranth grains may give about 5% higher starch efficiency while requiring less time in isolation than wet milling. Starch obtained by this process may have low viscosity and enthalpy, but more damaged starch will be attained with a clearer paste [89]. After starch and protein separation, solubilized water-soluble polysaccharides can be isolated from the insoluble cell wall material using wet sieving in the presence of mild alkali. These separated components are fibrous compounds of amaranth. Highly branched arabinoxylan and arabinogalactan are also attainable [90]. The extremely small size of its granules, their ability to lose their crystalline and granular structure when heated, and the presence of less than 1% resistant starch of total amaranth starch make amaranth a high glycemic food [91]. The shape of amaranth starch granules is angular, polygonal, or slightly round [92] with a dodecahedral structure and high water-absorption capacity. Its high luminosity is also a desirable property for the food sector [30–32]. Its good clarity is due to its less amylose content, promoted its use in making clear edible films of 0.28-0.32 mm thickness with low water vapor permeability, good tensile strength, and 97-98% transparency. All these values were within the desired range of starch-based edible films [93–95]. Being an amylopectin-type starch, it contains around 1700 molecules of amylopectin which are proven to be stable and not retrograding solution. It does not contain long external/inner chains that can absorb iodine. On the other hand, inner chains are long enough to allow good α-amylolysis, and regular branching with a homogeneous distribution of inner and external chains [96, 97]. The efficiency of amaranth starch to bind water is higher than that of wheat and maize starches, making it a highly water-soluble starch. The high degree of crystallinity (41%) of amaranth starch is related to its slow apparent amylose content (1.06-7.39 g/100 g). *A. cruentus* starch was found to be viscoelastic and somewhat similar to waxy corn starch, but *A. caudatus* starch was found to be similar to normal corn starch [98]. Its structure differs from other cereals in terms of color, purity, functional characteristics, and water or oil binding [26]. It has some unique characteristics like high freeze-thaw stability, retrogradation stability, viscosity, temperature of gelatinization, swelling capacity, water-absorption index, and enzyme susceptibility. However, some of these factors may reduce the baking quality of the product and hence be considered unfavorable for amaranth utilization. Though its stability can broaden its applications in frozen foods if it is modified, some modification methods enhance starch stability after freezing and thawing [99–102]. The water absorption capacity and swelling power of amaranth starch were found to be higher than that of corn starch, while its solubility was lower [103]. Sindhu and Khatkar [30–32] reported that the swelling capacity and swelling index of amaranth (0.72-0.76) were higher than that of buckwheat (0.13-0.18). It has been reported that swelling power remained constant and only slowly increased at temperatures above 75°C. The broad range of gelatinization temperature, good swelling, solubility, and water absorption capacity of amaranth starch allow its use in products processed at high temperatures. In a study, the least gelation concentration and bulk density of *A. hypochondriacus* starch were found to be 24% and 0.69 g/ml, respectively [30–32]. When amaranth starch was cooled to 35°C, it did not show an increase in viscosity, pointing out the weak intermolecular forces within starch granules [104]. Enzymatic digestibility, pasting temperature (70.7°C), and thermal stability of amaranth starch were found to be higher when compared to cassava, corn, and sweet potato starches, but its iodine binding capacity was lower than that of other starches, making it useful for functional products. Xia et al. [28] studied X-ray diffraction of amaranth starch and observed an A-type pattern with intense peaks of 15.2°C, 17.5°C, and 23.2°C with a peak viscosity of 181 Brabender units (BU) and a breakdown value of 2 BU. Resio and Suarez [105] observed that the degree of gelatinization was found to be decreased with decreasing starch moisture level. At the water-to-starch ratios of 0.81 : 1 and 2 : 1, a linear relationship was observed between moisture value and gelatinization enthalpy. When excess water with 75% moisture content was used, the enthalpy of transition had a maximum value of 10.0-10.2 J/g because, in excess water, raising the rate of heating increased the enthalpy of transition. An increase in heating rate of 1-15°C/min caused an increase of about 10°C in peak temperature. The commencement of the endotherm did not depend on the heating rate, but the conclusion temperature increased by 9°C on increasing the heating rate from 1 to 15 °C/min. In excess water and heating rates above 10°C/min, gelatinization followed first-order kinetics. In total, the water diffusion rate of starch granules was negligible, while the gelatinization rate was hindered by the rate of chemical reaction between starch constituents and water [105]. For water-to-starch ratio above 2 : 1, peak temperature remained constant at 68.3°C, and the enthalpy of gelatinization had a maximum value of 11.5-11.7/g. Rapid gelatinization of starch began at two activation energies with a distinct break point at 69.2°C [103].

In one another study, Singh et al. [106] stated that modified starch from amaranth grains had high binding capacity, disintegrating ability, and dissolution characteristics. It was also reported that the amount of modified amaranth starch used as a binding and disintegrating agent was 3/4th of the quantity as that of maize and potato starches required [106]. Upon heat-moisture treatment, amaranth starch showed an increase in thermal stability. During modification, an increase in moisture and time raised onset and peak temperatures. An increase in pasting temperature was found to be associated with a decrease in viscosities, setback, and breakdown viscosities that were proportional to moisture and time. But the morphology of modified samples was not altered while it caused agglomeration. Overall, modified amaranth starch may act as an ingredient in frozen and canned products [107]. Chandla et al. [108] successfully prepared noodles with firm texture, less cooking time and good expansion using native (AS), heat moisture-treated (HMT-AS), amaranth starch, and corn starch (CS). A lesser cooking loss of 20.15 g/100 g was observed for noodles prepared using HMT-AS compared to AS noodles (22.20 g/100 g). Also, a firmer texture, along with distinct flavor and augmented taste, was found for HMT-AS starch noodles compared with AS and CS noodles. The amaranth starch modified using sodium hypochlorite and heat-moisture treatment at 85°C for 6 h produced starch films with increased tensile strength. Oxidation decreased the water vapor permeability of films, while heat-moisture treatment increased the same. These two modification treatments also decreased the water solubility of films prepared from treated amaranth starches. But heat-moisture treatment enhanced the yellowness of starch films [109, 110]. Noticeably decreased swelling power and solubility were recorded for heat-moisture-treated, oxidized, and acetylated amaranth starch samples except for increased swelling power in the case of acetylated starches. These modifications improved the paste transparency. The hardness, adhesiveness, gumminess, and chewiness of gels were decreased for all treated starch samples except oxidized, supporting its application in soft gels. The surface of the granules was smooth, showing no physical damage during heat-moisture treatments and acetylation. However, oxidation caused dents on some granules of starch. Physical and chemical modification treatments produced starches with diverse properties, expanding the potential of amaranth starch applications [23]. Gonzalez et al. [111] observed that heating at high temperatures caused a limited loss in the crystalline structure of amaranth starch, but its granular integrity was preserved. The loss of crystalline structure and degree of gelatinization of starch increased with an increase in moisture and temperature. Modified amaranth flour can be of desired properties at low temperatures, with high consistency after cooking and low water solubility, broadening their industrial applications. It can also be modified using an economical and efficient acetylation process. In an investigation, about 10-11 ml of acetic anhydride and 149-152 g of starch with a reaction time of about 3 min gave an acetyl content of 1.6-1.74% [112]. Amaranth starch is also a good substrate for the production of cyclodextrin due to its good dispersibility, desired susceptibility to amylases, and its unique amylopectin value. These factors promoted CGTase (cyclodextrin glycosyltransferase) production through submerged fermentation and the synthesis of cyclodextrins when partially purified CGTase was used in the enzymatic reaction. So, this starch may be a better source for obtaining CGTase and α-, β-, and γ-cyclodextrins even higher than that obtained by corn starch [96, 113]. Dough structure in gluten-free foods can be improved using microbial transglutaminase (mTG) that improves the protein network. Sourdough and mTG promote the formation of volatile compounds and are favorable to the leavening, aroma, and preservation of bakery foods [114]. Overall, starch is a major component of amaranth grain with some unique qualities like good water binding, solubility, swelling, and a high gelatinization temperature. The quantity and nature of starch within various species are diversified. Being an amylopectin-type starch, it has potential applications in the food packaging sector. More studies are required on its fractionation, modification, and dough and baking qualities.

5.3. Proteins and Amino Acids as a Potential Functional Ingredient. Protein in amaranth is mainly constituted by globulins and albumins, whereas prolamins are present in very less quantities and are the chief storage proteins in major cereals. Amaranth proteins contain lysine but are deficient in some other amino acids such as leucine, isoleucine, and valine, and this composition of protein makes amaranth grains compatible with cereals for blending purposes. Amaranth albumins have maximum solubility at pH above 6, and this solubility value is comparable to the solubility of egg albumins. These also have good foaming capacity and foaming stability at pH 5, therefore, can act as whipping agents similar to egg albumin. Albumins are suitable for the preparation of acidic foods because water and oil absorption values reached the maximum at an acidic pH. Supplementation of amaranth albumins in wheat flour up to 1% improved dough properties and produced bread with better crumb characteristics due to higher mixing stability. High levels of essential amino acids and their desired functional roles make amaranth albumin isolate a good-quality protein component [115]. In a study, it was observed that sulfur amino acids were not affected, but cooking greatly affected essential amino acids [47]. Protein concentrate from *A. cruentus* flour was produced and compared with amaranth flour. Protein, soluble dietary fiber, unsaturated fatty acid, and squalene (affects the biosynthesis of cholesterol) were 16.6, 4.29, 75.44, and 6.23% in flour, while 52.56, 12.90, 56.95, and 9.53% in protein concentrate, respectively. The presence of saponins, phytic acid, and trypsin inhibitors in protein concentrate makes it suitable for reducing the risk of heart disease, as these components favor the metabolism of lipids. Overall, processing amaranth flour can lead to a product with good nutritional quality and characteristics that directly or indirectly influence lipid metabolism [116]. Processing also increases protein digestibility because the protein in whole meals is bound with other components which hamper enzyme action, and heating breaks such complexes and inactivates trypsin inhibitors [117]. As per the compositional studies of amaranth presented in Table 1, there is a lot of diversity in the amount of protein present in various species of amaranth, and appropriate combinations of these species will make it unique.

6. Processing Technologies for Amaranth

The increase/decrease in its *in vitro* protein digestibility, antinutrients, minerals, and antioxidant activity of grains or flours of any cereals or pseudocereals depends on the conditions during processing. Amaranth grains are processed in a number of ways to produce different types of products depending on their utilization or consumption habits by consumers. Figure 1 shows some of the general processing treatments given to amaranth grains for their application as a food ingredient or as a food product.

6.1. Milling. Milling these small grains requires special approaches through convenient technical equipment. Whole-grain meal or white flour with a short shelf life is the main product of its grinding or milling. An abrasive mill that is generally used for milling sorghum or rice is found suitable for amaranth milling. Though roller mills used to mill wheat may also be suitable to handle amaranth, planetary ball milling can be used to produce starch-enriched flours from pearled amaranth grains obtained after abrasive milling [118]. Ball milling is also reported to be a simple process with minimal environmental problems, convenient operation, and suitable efficiency in liquid food production because it achieves particle size reduction, rupturing of starch granules, loss of gelatinization enthalpy/crystalline structure, increasing solubility, which consequently decreases pseudoplastic behavior, and high stability of soups during storage [44]. Modified amaranth starch was found to be more stable than native starch in the preparation of liquid foods as it prolongs or avoids phase separation in foods. Hence, the development of liquid foods can be better achieved using modified amaranth flour through ball milling [119]. Differential milling allows adequate separation of germ, endosperm, and bran from amaranth grains producing product/flour rich in protein, starch, and fiber. It is a dry process without any effluent production as it does not involve any dissolving or filtering step. Moreover, pneumatic classification of milled products provided three granulometric fractions simultaneously: 16.4-16.7% high protein flour including oil fraction (may pass through 50 mesh), 46.2-47.6% high starch flour (may pass through 20 mesh), and 6.5-7.1% high fiber fraction (may pass through 30 mesh). Fiber yield may be enhanced by pneumatic classification until a product with 64% insoluble fiber and 7% soluble fiber is obtained. So, fiber-rich products can be attained by exclusive physical means of low or no environmental effect, comprising differential milling, followed by sieving and pneumatic classification. After oil extraction using solvent extraction from a protein-rich fraction, protein content increased up to 0.5 in the ultimate product of this process. Also, the flour obtained was yellow in color without any bean flavor. This study suggested that amaranth grains are an important part of the food fiber market [120]. The friction generated during milling reduces the moisture level of amaranth flour and it is a favorable effect as high moisture causes the plucking of burr mill

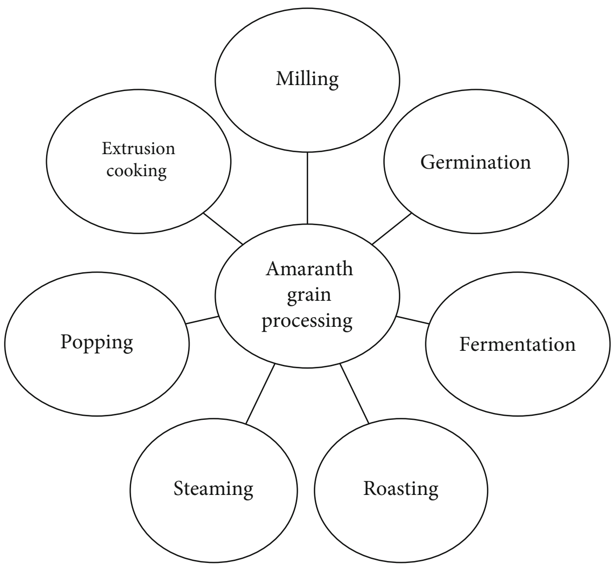

Figure 1: Various types of processing of amaranth grains.

plates at the fine setting. This moisture loss must be considered when computing the mass balance of the milling system and the yield of flour. The average particle size of flour from the burr, roller, and nutrimill was found to increase with an increase in moisture for all mill settings (fine/coarse/medium) as reported by Ozoh [121]. During milling, various components including fat, protein, vitamins, and minerals get concentrated in bran/germ fractions [14]. Milling characteristics like a fraction of the grain coat are dependent on the moisture of the grain [85]. Olawoye and Gbadamosi [122] studied the effects of different methods used to obtain special type of amaranth flours like whole, defatted, fermented, germinated, blanched, and cooked, and its effect on the nutritional properties. It was found that fermentation and blanching had a significant effect on the in vitro digestibility of the processed amaranth flour, and germination had the most profound effect on protein digestibility. However, optimization of the amaranth milling process needs more focus. There are few researches on the effects of milling on different components and the utilization of milling waste. Abundant uses of whole grain of amaranth may be the potential reason for these loopholes because its popped, germinated, or boiled form is more common among people.

6.2. Soaking/Germination/Steaming. Germination and sprouting treatments are inexpensive and efficient ways to enhance the nutraceutical properties of pseudocereals, legumes, and other grains [123]. Though amaranth sprouts are not as common as sprouts of other cereals, their popularity is increasing among health-conscious consumers [124]. Germination was found to be a useful method to obtain functional food from amaranth [122]. It was recommended as a significant pretreatment for the preparation of traditional food like *dosa* [125]. Steeping for 8 h at 30°C followed by germination for 24 h at 23°C and kilning for 4 h at 42°C significantly increased seven amino acids, namely, lysine, leucine, aspartic acid, valine, alanine, threonine, serine, and decreased cysteine revealing improved protein quality [47]. Hejazi and Orsat [126] observed that 48 h germination of amaranth grains at 26°C increased protein availability by 8%, total energy by 11%, linoleic acid by 10%, and decreased resistant starch by 70%. This treatment indicated enhanced starch digestibility and protein availability. Other researchers stated that soaking and sprouting increase antioxidants and total phenols [127–129].

A reduction in phytate content was also observed after soaking *A. caudatus* grains in warm water (50°C) and then germinating in water (at 32°C) having lemon juice for 72 h [130]. Cornejo et al. [131] compared 24 h germination of *A. quitensis* and *A. caudatus* and found that decrement in pasting and viscoelastic properties, as well as, total and resistant starch levels was higher in the former. They recommended germinating *A. caudatus* for bakery products and germinated *A. quintensis* for beverages. The rate of water absorption capacity of *A. cruentus* was the maximum between 18 h and 36 h of steeping, and at the 26th hour, amaranth was saturated [132]. Mburu et al. [133] suggested 20 min of steaming for a ready-to-eat pregelatinized *A. cruentus*-based food for infants. Though the nutritional composition of grains was not significantly affected by steeping and steaming pregelatinization except for a noticeable decrease in water-soluble vitamins, soaking golden-colored amaranth for 24 h followed by germination for 48 h and steaming for 19 min resulted in a product with good acceptability, high protein and starch digestibility, and a significant reduction in antinutrient factors [134]. Treatment of *A. hypochondriacus* by electric current (500 mA for 5 min) prior to germination for 6 days at 25°C caused quantitative changes in the enzymatic antioxidant system and in the total value of phenolics and flavonoids suggested to be an economical method of sprouting [135]. The sprouts of *A. hypochondriacus* are rich sources of nutrition with potential health characteristics because of their high fiber content and protein that have potential antihypertensive and antioxidant activities. These proteins can inhibit angiotensin-converting enzyme activity and have $ABTS^+$ radical scavenging activity that was increased after *in vitro* gastrointestinal digestion [136]. Motta et al. [60] reported that boiling and steaming decreased total folate by 58% and 22%, respectively, while malting significantly increased it by 21%. They suggested that 35 g of steamed/boiled/malted amaranth may provide 25% of the dietary requirement for folate. Copper retention after boiling grains was 98%, whereas magnesium retention after steaming was 80%. Steamed amaranth is reported to be mineral-rich products, especially magnesium, manganese, and phosphorus contributing 65%, 70%, and 44% to the required nutrient levels, respectively [137]. Overall, steeping, germination, and steaming of amaranth under different time-temperature combinations affect its nutritional properties. The effects of these treatments on functional properties are loopholes in this area, and further research is required to attain the best combination of all parameters.

6.3. Fermentation. Fermentation as a processing method for cereals has been used since ancient times. The quality of protein affected by the fermentation process of amaranth grains was studied by Amare et al. [41]. The retention of all free amino acids except tyrosine, proline, and glutamic acid which remained unchanged was higher in fermentation as compared to popping in red, white, and brown-colored amaranth cultivated in Ethiopia. Fermentation also improved protein digestibility by 5-7.5%, while lysine, cysteine, and methionine were found to be reduced by 20%, 16%, and 20%, respectively [41]. Sterr et al. [138] extracted *L. plantarum* RTa12 and *P. pentosaceus* RTa11 from spontaneous amaranth sourdough fermentation and studied their characteristics. Both strains reduced pH sharply and caused overgrowth of autochthonous microbiota, allowing stable fermentation at 25°C, 30°C, and 35°C as a single culture or in combination. It was also observed that amaranth sourdough had similar viscoelastic behavior to wheat because of lactic acid bacteria and high flour enzymatic activity under acidic conditions during sourdough fermentation [139]. Sourdough fermentation using LAB in wheat bread significantly changed its organoleptic properties [140]. It was concluded that *L. plantarum*, *L. paralimentarius*, and *L. helveticus* can be an efficient strains for the sourdough fermentation of amaranth. *L. plantarum* and *L. paralimentarius* followed a similar pattern of pH and titratable acidity. *L. helveticus* required more time to adapt to substrates provided higher acidification. At 35°C, 25% increase in lactic acid was observed. Bread prepared using *L. helveticus*/18 h/30°C had better overall flavor as compared to bread made using *L. plantarum*/18 and 24 h/30°C. *L. helveticus* produced the highest amount of lactic acid 202 mmol/L and 236 mmol/L sourdough levels in 18 h and 24 h (at 35°C), respectively. Thus, excess lactic acid production results in a product of unacceptable flavor.

6.4. Roasting. Roasting is a food processing technique that works on the principle of heating to cook the product uniformly and improve the digestibility, palatability, and sensory characteristics of products with desirable structural alterations in the product matrix [141]. The roasting of amaranth grains was done in a Gallenkamp oven. About 1 kg of dry amaranth (*A. hypochondriacus* and *A. cruentus*) grains were spread uniformly in a baking tray of 0.3×0.6 m size and roasted at 200°C for 8 min, followed by cooling and milling. The viscosity of roasted grain amaranth gruels was significantly higher than those obtained from raw. This may be due to the disintegration of starch which increased their susceptibility to hydration. So, roasting should be preferable over popping for preparing flour to be used as a thickening agent. Antioxidant activity was also increased because of the increase in flavonoid content, while roasting did not significantly affect the total phenolics. Reduction in protein digestibility was seen in roasted samples but was lower than in popping because of the higher temperature during the popping process [142]. Some other researchers roasted *A. cruentus* by placing grains on a hot plate preheated at 120°C for 1 min. They observed that roasted amaranth has fast and complete starch digestion as compared to raw, cooked, or extruded forms because it significantly increases total rapid digestible starch content, glycemic index, and hydrolysis index. Resistant starch was increased from 0.5% to 1.4%, possibly due to retrogradation of amylose chains after cooling. Starch digestibility was 106, 105.8, and 91-101 for flaked, roasted, and cooked/popped/extruded forms, respectively, indicating a greater capacity of increasing glycemic response during roasting. High amylopectin content, the small size of starch granules, less resistant starch and soluble fibers, and low gelatinization temperature (which causes loss of crystalline and granular structure and increases susceptibility to enzymatic digestion) are key reasons for higher starch digestibility [91]. Puffing did not affect squalene, while roasting at 150°C for 20 min reduced it by 13%. The antioxidant activity of pure squalene was reported to be very low, but its lipophilic extract had improved antioxidant activity as compared to pure squalene, suggesting that tocotrienols and other minor ingredients also played a role as antioxidants. The antioxidant activity of roasted grains was slightly higher in comparison with raw due to increased extractability of other minor ingredients like tocotrienols and the generation of maillard reaction products with antioxidant activity [143]. Nevertheless, studies on the technological properties of roasted amaranth are limited.

6.5. Popping. Popping involves exposing grains to high temperatures for a short period of time and simultaneously gelatinizing and expanding starch. The popped form of amaranth is most popular among people consuming it. So, it can be an important process for value addition in this area. Mexican mix popped amaranth with honey to prepare a candy, *alegria*. North Indians mix it with melted jaggery to prepare *laddoo* known as *rajgeera* [77, 144]. Lara and Ruales [145] optimized the popping process for *A. caudatus* grains and inferred that 200°C, 14 g load, 0.015 m^3/s airflow, and 16% grain moisture provided the lowest popping efficiency, while 240°C, 22 g load, 0.013 m^3/s airflow, and 12% grain moisture provided the highest popping efficiency of 80% with good crunchiness and expansion. No starch retrogradation was seen in these conditions. These popped grains were recommended as the most important ingredient in breakfast cereals or crunchy bars because of their good nutrition, desired digestible protein, and lysine content. Including sensory parameters, the maximum force of compression and peroxide value were also associated with shelf life and stability. Capriles et al. [91] popped *A. cruentus* grains by heating grains on a hot plate at 90°C for about 10-15 s. On the contrary, Gamel and Linssen [146] stated that the popping of *A. caudatus* grains are not possible at 150°C. They suggested that the optimum temperature for 90% popping on a hot plate was 180°C. Above 190°C, faster popping was seen within a few seconds because of the small size of amaranth grains and the extreme heat. Unpopped grains, expansion volume, and flake size were 2-10%, 9-11 cm^3/g, and 0.010-0.012 cm/g, respectively, and the size obtained was smaller than popcorn. Major volatile compounds in raw grains that contributed 70% to total volatiles were 2, 4-dimethyl-1-heptene, 4-methyl heptane, branched $C_{11}H_{24}$ alkane, and dodecene $C_{12}H_{24}$ isomer. In popped grains, aldehydes from strecker degradation, 2-methylpropanal, 2-methylbutanal, 3-methylbutanal, and phenylacetaldehyde were found. Alkylpyrazines such as methylpyrazine, vinylpyrazine, 2,5-

dimethylptrazine, and 3-ethyl-2,5-dimethylpyrazine were also present. All these compounds provide corn-like, nutty, hazelnut, and roasty odors that were not found in raw grains [146]. Muyonga et al. [142] made popped amaranth (*A. hypochondriacus* and *A. cruentus*) by heating grains on an aluminium pan using an Ariston K3G2/G gas cooker set to maximum heat. About 100 g of grains were placed and heated for 1-2 min while stirring. Popping started after 30 s and heating continued until all grains turned whitish. Total popping time was 90 s, and unpopped grains were separated using a 1 mm mesh. Popped amaranth grains had less digestibility (observed using the pepsin-pancreatin enzyme system) as compared to raw grains. This change in digestibility might be due to the formation of complexes among proteins and other components of grains and the level of matrix disintegration, which affects proteolytic enzymes in their way to access protein bodies. Viscosity was also lower in popped samples as compared to raw which may be due to the pregelatinization and the extreme dehydration of starch during heating, though it did not significantly affect total phenolics and antioxidants. So, popping is suggested to make dense nutritious food [142]. Some other researchers obtained the expansion of 8.7 folds in *A. hypochondriacus* grains having 16% moisture at 260°C/15 s using a fluidized bed system. Above 290°C, the expansion ratio decreased, and product browning was experienced. The decrease in popping volume below and above 260°C was due to insufficient inner pressure within the grains and the collapsing of the pericarp as a barrier, respectively. The moisture of the heating medium also affects popping.

For popping, hot air should be preferred because superheated steam decreases volume by 12-20%. Steam condensation on the grain surface was observed, because of which the grain pericarp acting as a barrier to popping became softer/weaker and the inner pressure became low, which could be the reason for the volume reduction in superheated steam heating. Heat causes the vaporization of water present in starch and produces steam fills within starch. This will cause an increase in temperature and pressure within the starch pores. Starch gets gelatinized, and rupturing of the pericarp and grain coat takes place, which act like a pressure vessel. This transforms the perisperm into a bubbly matrix providing a spongy texture. Proteins in embryos also act as a barrier because starchy perisperm is surrounded by the embryo. Grains denatured by steam can allow high pressure to develop within the grain. Further research is needed to explore and improve these effects [147–149]. Solanki et al. [150] reported that the fluidized bed system was more efficient than the batch process for *A. paniculatus*. Using the former method at 120-150°C for 5-30 s, 20% better popping characteristics like a popping volume of 0.42-0.48 cm^3/100 grains and a popping rate of 44-65% were achieved in comparison with the later method, which gave 0.41-0.54 cm^3/100 grains popping volume and a 28-80% popping rate. The former method also saved 30% in labour and processing time [150]. Popped amaranth was found to be more beneficial than raw grains because of their high antioxidant activity, dietary fiber, flavonoids, fat, ash, and easy milling (due to more grain volume). But popping decreased proteins and their digestibility, vitamins, iron (loss of iron-rich pericarp), calcium, tocopherol (by 50%), and phytates. The increase in fat from 7.6% to 8.5% may be due to the partial removal of low-fat pericarp [21, 142, 151]. Amino acids, hydroxycinnamic, and hydroxybenzoic acids were found to be the most susceptible compounds during popping [152]. A slight reduction in lysine and sulfur-containing amino acids was observed which might be due to the maillard reaction [16]. Amare et al. [41] inferred that popping at 150°C improves the sensorial parameters of amaranth-enhanced porridge. But it highly affected all free amino acids, including phenylalanine, and tyrosine. They observed a decrease of 90% in tryptophan, 36% in lysine, 37% in cysteine, and 8-17% in *in vitro* protein digestibility. Popping of *A. caudatus* increased absorption index, solubility, swelling power, setback viscosity, and pasting temperature but reduced breakdown viscosity showing high stability to heating and cooling, fast cooking, and swelling in cold. Therefore, it is convincing to prepare precooked amaranth foods of improved quality, chemical composition, and acceptability [13]. Flour from popped *A. cruentus* grains was recommended for diabetic people because disruption of lipids, changes in insoluble fiber, formation of indigestible complex fiber components with protein and amino acids, and low retrogradation of starch after popping resulted in *chapatti*s with low glycemic index as compared to made from raw, boiled or roasted flour [153]. Optimization of popping to achieve a more efficient process with highest retention of nutrients is needed.

6.6. Extrusion Cooking. Extrusion cooking is a potential method to make nutritious and acceptable instant composite flours, but it is increasing barrel temperature and feed moisture can cause the reduction in polyphenol, phytic acid, and iron extractability. Though zinc extractability was increased and higher feed moisture improved vitamin A retention. Therefore, the optimum extrusion process to obtain amaranth-enhanced porridge was the use of 14% feed moisture at a 169°C barrel temperature [154]. Montoya et al. [72] extruded amaranth in a single-screw extruder at 125°C and 130 rpm screw speed. They suggested that the extrusion process can be a good alternative to any other pretreatment in characterizing peptides using pepsin/pancreatin enzyme because extrusion broke food proteins and enhanced their availability to enzymes. These peptides can be used to make a healthy diet to prevent the risk of developing chronic diseases [72]. Capriles et al. [91] extruded defatted amaranth flour having 15% moisture in a single-screw extruder with a 20 L/D ratio, 4 heating zones, 404 rpm screw speed, 1 : 1 screw compression ratio, constant temperature of 25°C in feed and compression metering zones, and 90°C at the die. These conditions increased the soluble fiber level of amaranth grains but did not significantly affect the resistant starch level and rate of starch digestibility (similar to white bread) as compared to raw amaranth grains [91, 155]. Ferreira and Areas [156] extruded defatted amaranth flour at 150°C and four different moisture levels (11%, 13%, 15%, and 24%) through a screw of 3.55 : 1 compression ratio, 20 : 1 L/D ratio at 200 rpm. Extruded amaranth at 24%

moisture had the highest corrected protein efficiency ratio. The true digestibility of raw and extruded samples was similar. So, extruded amaranth may be considered a food having high protein bioavailability because of its higher biological indexes of protein quality as compared to raw [156]. Mendoza and Bressani [157] worked on the extrusion of amaranth and reported similar results for protein. Extrusion was done using a Brady extruder model 2160 with a constant feed rate of 7 kg/min and cone opening of less than 1.5 mm. The extruder was heated to 166 °C using soybean, and then amaranth was extruded. Extruded amaranth flour had good quality protein, higher water absorption and retention, damaged starch, and a lower viscosity as compared to raw. Most suitable combination of all extrusion parameters for obtaining flour used in making amaranth-based beverages with higher antioxidants and acceptability was 130°C temperature and 124 rpm screw speed [157]. Extruded flour had an antioxidant activity of 3903 μmol Trolox equivalents/100g sample. Prepared beverages with an intake of 200 ml contributed 15.5-25.5% to the recommended daily intake of antioxidants and may be used to promote health and prevent diseases [158]. Dokic et al. [159] extruded an amaranth-corn grit blend having 16% moisture at 120°C, 130°C, and 140°C as temperatures of the 1st, 2nd, and 3rd zones, respectively, a compression ratio of 4 : 1, die diameter of 3 mm, and a screw speed of 120 rpm. Amaranth grits reduced the extrusion index and increased the density and hardness of extrudates because of their low expanding ability, giving denser extrudates with small air cells. The low extruding quality of amaranth may be due to its high fat.

6.7. Oil Extraction Techniques. Westerman et al. [160] extracted amaranth oil using supercritical CO_2 as a solvent. The extraction rate depended on the flow rate of the solvent; however, oil yield depended on pre-treatment, flow rate, temperature, and pressure during extraction. Yield and extraction rate decreased with increasing solvent rate due to less solvent-grain contact time. Flouring of grains was found to be the most effective pre-treatment method for extracting oil efficiently. The solubility of oil increased with the increase in temperature at high pressures (>200 bar) because of the enhanced solubility effect and decreased with increasing temperature at lower pressures of 100 bar. Rosales-Garcia et al. [161] optimized supecritical fluid extraction using CO_2 at 313 K/20 MPa to obtain squalene-rich 460 g/kg oil extract from whole puffed amaranth grains which was higher than that from hexane extraction. The extraction method do not affected the nutritional content and morphology of the extracted oil. Different fatty acids such as palmitic, oleic, and linoleic acids were found in sufficient quantity, suggesting its utilization in different functional food development. Sun et al. [162] fractionated degummed, alkali-refined, and simulated amaranth oils to obtain squalene-rich fractions. After fractionation of degummed oil at 180°C and 3 mTorr vacuum, squalene concentration was increased by sevenfold with 76% squalene recovery. Codistillation of free fatty acid (FFA) with reduced squalene in distillate resulted in a semisolid distillate. The FFA value in distillate at 180°C and 100 mTorr was about 7%. A reduction in FFA and di- and triglyceride levels enhanced the purity of squalene from 78% to 84%. So, alkali refining of the sample was done before fractionation to reduce FFA. Simulated (7% squalene/93% soybean oil) and alkali-refined oils were fractionated at different temperatures and vacuum settings and found that 180°C and 100 mTorr gave the highest squalene recoveries of 73% and 68% from simulated oil and alkali-refined, respectively. The data from this study can be used to select the best combination for fractionating amaranth grain [162].

7. Amaranth-Derived Products

Being nutritionally rich and gluten-free, amaranth-derived food products are popular among people. Many researchers reported very favorable nutritional, rheological, physical, and sensory characteristics for products prepared using amaranth. Various traditionally and commercially prepared amaranth-based food products are presented in Table 5. Alvarez et al. [163] observed that pseudocereal-based, gluten-free breads were rich in protein, fat, fiber, and minerals which may be considered as a good energy source. The nutritional value of amaranth-based bread is also comparable to nutritional recommendations for celiac diets and products [164]. Amaranth grains have good amino acid balances and easily digestible albumins and globulins (50%) and glutelins (31%) [38]. As most of the cereals are deficient in methionine and lysine, supplementation of these cereals with amaranth can be helpful in balancing the amino acid composition of the ultimate product. Rybicka and Gliszczynska [165, 166] observed that the amount of minerals like Ca, Cu, Fe, Mg, Mn, K, Na, and Zn was higher in gluten-free foods made from buckwheat, amaranth, chickpea, oats, millets, and quinoa in comparison with gluten-free products prepared using rice, corn, potato, and gluten-free wheat starch. Therefore, pseudocereal-based products in the diet make it more helpful than a gluten-free diet based on major cereals like rice, corn, or gluten-free wheat starch. However, low values of some physical parameters of amaranth flour, like falling number and gluten amount (revealing nil dough-raising capacity), obstruct its way of obtaining high-quality baked products such as bread and biscuit. However, the supplementation of wheat flours with amaranth flour has a great potential to enrich the final product [17]. Mlakar et al. [167] observed that the increase in amaranth replacement ratio increased the gelatinization temperature, water absorption capacity, dough development time, and stability. The strengthening of dough could be due to a decrease in extensibility and an increase in dough resistance to extension with spelt flours caused by amaranth. It was concluded that increasing amaranth quantity in the mixture delayed maximum viscosity, and consequently, flour gelatinization occurred at higher temperatures. Kuhn et al. [168] reported that the addition of 20% amaranth flour to the base for the development of baked goods did not affect the technological properties of the product [168]. Tosi et al. [169] suggested that hyperproteic amaranth flours are appropriate ingredients for supplementation of wheat flour for increasing protein and lysine levels, but only up to 4% and 8% substitution levels were found suitable for hyperproteic defatted amaranth flour (HDAF) and hyperproteic whole amaranth flour (HWAF), respectively. It was reported that HWAF performed

Table 5: Amaranth-based food products and their properties.

Product	Amaranth (%)	Other components	Properties	Reference
Composite flour	5-30	Wheat flour	Suggested 5-10% level of amaranth flour, dough raising capacity, gluten, and falling number were negatively correlated with the level of amaranth flour incorporated, but it increased Fe, Zn, Ca, water absorption, dough consistency, softening, and development time	Emire and Arega [17]
	0-100	Wheat flour	Water absorption increased from 2.55% to 3.65%	Ayo [184]
Multigrain health mix	20-100	Buckwheat, flaxgrain, ragi	Blend 30 g of amaranth, 10 g of buckwheat, flaxgrain, and quinoa each, 20 g of ragi and 20 g of soybean was found nutritious with an 8.2 sensory score, high amount of proteins, B complex vitamins, iron, and zinc; product was found safe and acceptable during storage for 60 days	Singh [185]
Protein-rich flour	100	—	Less final viscosity than quinoa, buckwheat, rice, and maize protein-rich flours; circular flour granules of 2.5-3 μm size	Alonso and Mahony [25]
Protein concentrate	100	—	Highly nutritious, 52.56% protein, 9.53% squalene; may influence lipid metabolism and cardiovascular disease	Escudero [116]
Extrusion-cooked flour	100	—	Extrusion improved protein quality and changed starch properties, attained higher water absorption retention and damaged starch but had low viscosity	Mendoza and Bressani [157]
Porridge blend	0-70	Maize, chickpea	Product having 70% amaranth had higher Fe, Zn, Ca, fat, and protein levels, while phytates and viscosity were lesser; overall, moderate acceptability of the porridge blend was observed	Zebdewos et al. [130]
Extruded flour-based beverage	11	—	Intake of 200 ml provided 15.5-25.5% of daily antioxidant intake, average acceptability, and health-promoting, and disease-preventing nutraceutical beverage	Milan et al. [158]
Extruded-porridge flour	0-40	Bean, maize, groundnut	Use of 20% amaranth flour had a 6.94 sensory score, undesirable aftertaste, 2500-3000 cP drinking viscosity, 90.75 kcal of energy, 100 μg of RAE vit A. It was found to be more desirable than maize-based flour	Akande et al. [154]
Porridge	90	Sorghum flour	5 kcal/g energy, less antinutrients, high nutrient availability, and digestibility	Okoth et al. [186]
Dough	10-30		High-water absorption, dough development time of 3-5 min, stability time of 7-8 min, degree of softening of 70-85 VU, and elasticity of 50-66 VU	Tomoskozi et al. [187]
	10-30	Refined wheat and spelt flours	Amaranth delayed maximum viscosity; gelatinization occurred at higher temperatures; water absorption and development time increased; higher dough stability; strengthening dough by decreasing its extensibility; 10-20% was recommended	Mlakar et al. [167]
	10-35	Wheat flour	Increased dough development time and mixing tolerance indicate weakening of the dough, while decreased stability, peak viscosity, cold paste viscosity, breakdown viscosity, and setback values	Sindhuja et al. [177]
Bread	10, 20, and 30	—	Above 20%, attained very low bread volume, high softening, two-fold increase in resistance to compression, and addition above 30% caused deterioration	Tomoskozi et al. [187]
	5-20	Wheat flour	10% level increased protein and mineral; crumb texture scored highest at 5%; crust texture and flavor scored highest at 10%; quality deterioration was above 15%	Emire and Arega [17]
	5-50	Wheat flour	Recommended 15%, high lysine content, negatively correlated loaf volume	Ayo [184]
	20	Native/ modified wheat	Modified wheat flour amaranth based-bread had more thiol groups that gave a sensorially acceptable bread with only 60 mg/kg^1 immunoreactive gluten	Heredia et al. [188]

Table 5: Continued.

Product	Amaranth (%)	Other components	Properties	Reference
	100	–	Volatiles, high 2-methylbutanol and 3-methylbutanol (fruity aromas), low hexanal (grassy) and 2,4-decadienal (fatty off-flavor), and saponins gave a bitter taste	Pico et al. [189]
	10, native, popped	Spelt wheat flour	Its different forms did not affect quality loss in stored bread; popped form better over native except for protein digestibility and vitamins; popped form had good antioxidant and dietary fiber levels and better millability	Filipcev et al. [151]
	20	Wheat flour	High ash content of 2.29%, acceptable center thickness of 18.57 mm and very low extensibility value of 8.87	Pourafshar et al. [190]
	50	Wheat flour	Enhanced nutrient profile with high protein, fat, fiber, and mineral, bread followed the recommendation of celiacs	Pagano [164]
	63 (starch)	Wet gluten	Longer proof time, sticky and stringy dough, lower specific volume, poor gas holding and baking, inferior grain and texture, poor quality bread, crust of gray color with nonuniform browning, and crumb of grayish color	Stone et al. [104]
	50	Rice flour	Healthy and high-quality ingredient; soft, weak, and cohesive crumb; no adverse effect on sensory attributes; more polar lipids may act as gas stabilizing agent	Alvarez et al. [127, 128]
	0-40	Wheat flour	Increased nutritive value, slight reduction in bread performance at 10-20% level, increased crumb hardness and elasticity, increased phytates at 30-40% level, and maximum 20% substitution were suggested	Sanz et al. [176]
	0-100	Wheat flour	Nonaerated crumb at 100% improved nutritional value with acceptable technological performance; hardness increased but springiness and cohesiveness decreased; 25% substitution was acceptable; 12.5% was suggested	Rosell et al. [86]
	1% of A. albumin	Wheat flour	Improved dough properties due to higher mixing stability; bread with better characteristics; albumins have excellent foaming capacity and foam stability	Silva et al. [115]
	—	Corn starch	Use of 10% amaranth flour increased protein and fiber contents by 32% and 152%, respectively; sensory score was not affected	Amador et al. [172]
Biscuit	0-30	Buckwheat & corn flours	Good consumer scores, shelf life of at least 3 months, increased protein and dietary fiber contents, higher macro- and microelements, good amino acid composition as compared to lingrain supplementation	Gambus et al. [191]
Cookie	0-100	Whole wheat flour	Reduced viscosity parameters, baking loss, and hardness while increasing diameter and spread ratio up to 60% were acceptable with 8 sensory at 60% and no noticeable change in sensory except for taste up to 100%	Chauhan et al. [178]
	—	Navy bean flour	High volume due to high thickness, lower width and spread factors, high yield than wheat flour cookies, acceptable composite cookies with greater water holding capacity, pasting viscosities, and elastic properties	Liu et al. [192]
	7	Wheat flour, oats	Positive consumer acceptance except for color; very good nutritional properties with 434.72 kcal energy, 8.8% protein, 15.8% fat, and 64.4% carbohydrate	Bhat et al. [58]
	10-35	Wheat flour	Good quality at the 25-30% level of amaranth flour: hardness was reduced, but color and surface cracking were improved due to amaranth, a potential bakery ingredient. 25% was to be found optimum	Sindhuja et al. [177]

Table 5: Continued.

Product	Amaranth (%)	Other components	Properties	Reference
Cake	Waxy starch	Wet gluten	Dense and gummy dough, good initial volume but collapsed at baking end due to excess water, low volume and poorer grain, poor quality cake due to no amylose	Stone et al. [104]
	20.8, sprout	Finger millet	Nutritious, palatable, and dense cake with high iron, low cake volume of 454.4 cm^3, and volume index of 88.4 mm	Agrahar et al. [193]
	50	Corn flour	Good sensory in cake without corn; protein increased by 40%; 3 fold increase in dietary fiber; good amino acid composition; and macro- and microelements	Gambus et al. [191]
Pasta	15, 30, 40, and 50	Bread wheat flour	Pasta with 30% amaranth flour was of acceptable quality; protein and fiber contents were improved by 23% and 50%, respectively; GI and protein digestibility were also improved	Martinez et al. [194]
	20-100	Buckwheat, quinoa	Amaranth reduced texture firmness and cooking time; 40:60:40 amaranth, buckwheat, and quinoa were optimum with good texture firmness and low cooking loss	Schoenlechner et al. [61, 62]
	25.45–49.57	Dried amaranth leaves	Improved functional benefits, decreased cooking time and luminosity while increasing cooking loss, high protein, fiber, ash, and antioxidant, and pasta with 35% amaranth flour was highly accepted	Cardenas et al. [195]
	95	Guargum, 5%	Strong aftertaste, amaranth pasta had the lowest sensory scores than teff, quinoa, and buckwheat except for color	Kahlon et al. [77]
Noodle	20	Quinoa, buckwheatt	Less suitable ingredient as it lowered firmness, cooking time, and cooking tolerance, the blend was found to be optimum	Schoenlechner et al. [196]
Extrudates	0-100	Corn flour	Sectional expansion index highest was at 20% and lowest in pure corn; hexanal formation was higher in milled than in whole extrudates, while fat stability was higher in whole	Ramos et al. [197]
	20 and 50	Corn grits	Increased density and hardness but decreased expansion index and gel viscosity that resulted in denser extrudates	Dokic et al. [159]
Gluten-free fish patties	0, 5, and 15	Fish slices	Increased Na, K, oleic, linoleic and linolenic, but decreased Ca, Fe, EPA, DHA, and DPA, acceptable color, while sensory score was not better than corn flour	Romero et al. [180]
Popped grain, flake	100		Not significantly different from rawgrains except for tocopherol (reduced by 35%) and sterol	Ogrodowska et al. [21]
	100		Good nutrition, a source of breakfast cereal and crunchy bars, relevant digestible protein and lysine, increased swelling, water absorption, and peak viscosity	Lara et al. [183]
Puffed and laminated grains	100		Precooked foods had excellent expansion, good quality, composition, and acceptability as precooking increased absorption, solubility, and swelling while decreasing fibers. Puffed form had the highest acceptability	Burgos and Armada [13]
Puffed grains	100		Popping increased protein and lipid contents while decreasing carbohydrate, essential amino acids and flavonoids; there was no change in fatty acids	Paucar et al. [152]
Sprouts	100		Health-promoting food with high fiber and protein levels and good antihypertensive and antioxidant activities	Aphalo et al. [136]
Ogi	100		Lower yield (70%) than corn, high protein content and peak viscosity, low setback, suitable ogi-making source	Akingbala et al. [132]
Drink	46	Milk, sugar	Highly acceptable for taste and color, though the drink had a viscous nature	Mendoza and Bressani [157]
Frozen product	A. starch		Amaranth starch has higher freeze-thaw stability than corn starch, promoting its use in frozen foods	Bello et al. [198]

Table 5: Continued.

Product	Amaranth (%)	Other components	Properties	Reference
Infant food	100 (ungelatinized and gelatinized A. starch)		Ready-to-eat food with 20 min of steaming, good reconstitution at 15% flour, less antinutrients and viscosity, high energy density and water absorption, Mg, Mn, and tocopherol were far above the required intake	Mburu et al. [133]
Filler in LDPE	(3-20) A. starch	Corn and chenopodium starches	Better mechanical properties than corn starch-based due to its fine grain size and extensive branched amylopectin	Ahamed et al. [199]
Starch film	100		Optimal conditions of casting: pH 10.5 to 11.5, Cg 22 to 35, and Tg 76 to 85°C; films of a slight yellow color with moderate opacity; better flexibility and barrier property; relatively low mechanical resistance	Tapia et al. [200]
	Amaranth starch		Transparent, continuous, easily peelable and with good tensile strength	Sindhu and Khatkar [109, 110]

better if compared with HDAF at the same substitution level due to the higher oil content in HWAF [169].

8. Conclusion and Future Recommendations

Overall, this review article exploits the favorable nutritional, rheological, physical, and sensory characteristics of amaranth for the preparation of nutrition-dense and health-promoting food products. Amaranth starch has less amylose content, and its granules are smaller size than that of wheat starch that broadens its applications. Its protein comprises globulins and albumins with lower amounts of glutamic acid and proline than that of prolamin and high levels of lysine, methionine, cystine, and histidine. The low content of gluten in amaranth allows its use in gluten-free foods recommended for celiac patients. It can be used to prepare palatable, nutritionally enriched, and functional baked foods. Whole grains of amaranth can be processed using various processing treatments like popping, roasting, germination, and fermentation to obtain nutritionally preferable food products. Amaranth flour can also be processed to prepare cake, bread, cookies, extruded foods, instant foods, baby foods, etc. Though these products are not readily available on the market, the low gluten is also a limitation for its use in composite flour for leavened foods. The distinct aroma and taste of amaranth with spicy, slightly pungent, and bitter aftertaste is also a limiting factor in its usage. Further, food acceptability depends not only on sensory but also on heath-benefiting properties, and these are provided by amaranth. The literature published to date provides a sufficient understanding of the compositional and other functional properties and applications of amaranth grains and flour. Further studies are required to develop more efficient processes for amaranth and to understand the relationship between various processing and qualitative parameters.

Data Availability

The data supporting this systematic review are from previously reported studies, which have been cited.

Additional Points

Novelty Impact Statement. Since numerous aspects like historical, taxonomical, genetical, and marketing of amaranth have already been extensively reviewed, our objective is to focus primarily on the unique nutritional composition, major components, processing technologies, and food applications of amaranth grains. Understanding the effect of processing technologies on the amaranth product functionality and nutritional value will assist in its utilization as a solution to alleviate food sustainability and food insecurity. *Highlights*. (i) Amaranth (*Amaranthus* spp.) has a tolerance to drought and heat and is considered a smart crop. (ii) The nutritional and bioactive composition of amaranth grains is summarized. Amaranth is gluten-free and high in quality proteins, fiber, minerals, and bioactive compounds. (iii) The effect of processing on the functionality and digestibility of its components is discussed. (iv) Available products on the market are presented.

Conflicts of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Authors' Contributions

M.M. designed the study, collected the data, conducted data analyses, and prepared the manuscript. R.S. did the conceptualization, drafting the article, and proofreading. S.B.D. did the conceptualization, supervision, and critical revision. C.B.M. made critical corrections and revised the manuscript. Y.S. did the reviewing and editing. S. P. did the proofreading and editing. B.S.K. provided technical guidance and supervision. All authors read and approved the final manuscript.

References

[1] FAO, IFAD, UNICEF, WFP, and WHO, *The State of Food Security and Nutrition in the World 2022. Repurposing Food and Agricultural Policies to make Healthy Diets more Affordable*, FAO, Rome, Italy, 2022, https://www.fao.org/documents/card/en/c/cc0639en.

[2] WFP (World Food Program), "Ending hunger," 2022, https://www.wfp.org/ending-hunger.

[3] F. R. Alemayehu, M. A. Bendevis, and S. E. Jacobsen, "The potential for utilizing the grain crop amaranth (*Amarathus spp.*) in East Africa as an alternative crop to support food security and climate change mitigation," *Journal of Agronomy and Crop Science*, vol. 201, pp. 321–329, 2015.

[4] G. Balakrishnan and R. G. Schneider, "The role of amaranth, quinoa, and millets for the development of healthy, sustainable food products—a concise review," *Foods*, vol. 11, no. 16, p. 2442, 2022.

[5] R. Schoenlechner, S. Siebenhandl, and E. Berghofer, "Pseudocereals," in *Gluten-Free Cereal Products and Beverages*, p. 149, Academic Press, 2008.

[6] A. Cheng, "Review: shaping a sustainable food future by rediscovering long-forgotten ancient grains," *Plant Science*, vol. 269, pp. 136–142, 2018.

[7] G. F. Stallknecht and J. R. Schulz-Schaeffer, "Amaranth rediscovered," in *New Crops*, pp. 211–218, Wiley, New York, NY, USA, 1993.

[8] R. Bressani, "Amaranth," in *Encyclopedia of Food Sciences and Nutrition*, B. Caballero, Ed., pp. 166–173, Academic Press, Oxford, UK, 2003.

[9] D. C. Joshi, S. Sood, R. Hosahatti et al., "From zero to hero: the past, present and future of grain amaranth breeding," *Theoritical and Applied Genetics*, vol. 131, pp. 1807–1823, 2018.

[10] A. Rastogi and S. Shukla, "Amaranth: a new millenium crop of nutraceutical values," *Critical Reviews in Food Science and Nutrition*, vol. 53, pp. 109–125, 2013.

[11] M. Soriano-García and I. S. Aguirre-Díaz, "Nutritional functional value and therapeutic utilization of amaranth," in *Nutritional Value of Amaranth*, pp. 101–118, IntechOpen, 2019.

[12] J. Baraniak and M. Kania-Dobrowolska, "The dual nature of amaranth—functional food and potential medicine," *Foods*, vol. 11, no. 4, p. 618, 2022.

[13] V. Burgos and M. Armada, "Characterization and nutritional value of precooked products of kiwicha grains (*Amaranthus caudatus*)," *Food Science and Technology*, vol. 35, pp. 531–538, 2015.

[14] National Research Council, *Amaranth: Modern Prospects for an Ancient Crop*, The National Academy Press, Washington, DC, USA, 1984.

[15] L. S. Kalinowski, J. P. Navarro, A. I. R. Concha et al., "Grain amaranth research in Peru," *Food Reviews International*, vol. 8, pp. 87–124, 1992.

[16] S. Tomoskozi, I. Baracskai, R. Schonlechner, E. Berghofer, and R. Lasztity, "Comparative study of composition and technological quality of amaranth," *Acta Alimentaria*, vol. 38, pp. 341–347, 2009.

[17] S. A. Emire and M. Arega, "Value added product development and quality characterization of amaranth *(Amaranthus caudatus L.*) grown in East Africa," *African Journal of Food Science and Technology*, vol. 3, pp. 129–141, 2012.

[18] S. Gorinstein, O. J. M. Vargas, N. O. Jaramillo et al., "The total polyphenols and the antioxidant potentials of some selected cereals and pseudocereals," *European Food Research and Technology*, vol. 225, pp. 321–328, 2007.

[19] E. Bojorquez-Velazquez, A. J. Velarde-Salcedo, A. Leon-Rodriguez et al., "Morphological, proximal composition, and bioactive compunds characterization of wild and cultivated amaranth (*Amaranthus spp.*) species," *Journal of Cereal Science*, vol. 83, pp. 222–228, 2018.

[20] P. R. Venskutonis and P. Kraujalis, "Nutritional components of amaranth grains and vegetables: a review on composition, properties and uses," *Comprehensive Reviews in Food Science and Food Safety*, vol. 12, pp. 381–412, 2013.

[21] D. Ogrodowska, R. Zadernowski, S. Czaplicki, D. Derewiaka, and B. Wronowska, "Amaranth grains and products-the source of bioactive compounds," *Polish Journal of Food and Nutrition Sciences*, vol. 64, pp. 165–170, 2014.

[22] S. B. Dhull, S. P. Bangar, R. Deswal et al., "Development and characterization of active native and cross-linked pearl millet starch-based film loaded with fenugreek oil," *Foods*, vol. 10, no. 12, p. 3097, 2021.

[23] R. Sindhu, D. Amita, and B. S. Khatkar, "Morphology, structure and functionality of acetylated, oxidized and heat moisture treated amaranth starches," *Food Hydrocolloids*, vol. 118, 2021.

[24] F. Zhu, "Structures, physicochemical properties, and applications of amaranth starch," *Critical Reviews in Food Science and Nutrition*, vol. 57, no. 2, pp. 313–325, 2017.

[25] L. Alonso-Miravalles and J. A. Mahony, "Composition, protein profile and rheological properties of pseudocereal-based protein-rich ingredients," *MDPI*, vol. 7, no. 5, pp. 1–17, 2018.

[26] N. K. Chandla, D. C. Saxena, and S. Singh, "Amaranth (*Amaranthus spp.)* starch isolation, characterization, and utilization in development of clear edible films," *Journal of Food Processing and Preservation*, vol. 41, no. 6, pp. 1–11, 2017.

[27] M. Radosavljevic, "Comparison of *Amaranthus cruentus* and *Zea-mays* L. starch characteristics," *Genetika*, vol. 38, pp. 31–36, 2006.

[28] X. Xia, G. Li, F. Liao, F. Zhang, J. Zheng, and J. Kan, "Granular structure and physicochemical properties of starches from amaranth grain," *International Journal of Food Properties*, vol. 18, pp. 1029–1037, 2015.

[29] N. Inouchi, K. Nishi, S. Tanaka et al., "Characterization of amaranth and quinoa starches," *Journal of Applied Glycoscience*, vol. 46, pp. 233–240, 1999.

[30] R. Sindhu and B. S. Khatkar, "Characterization of amaranth (*Amaranthus hypocondriacus*) starch," *International Journal of Engineering Research and Technology*, vol. 5, pp. 463–469, 2016.

[31] R. Sindhu and B. S. Khatkar, "Physical properties of grains of some pseudocereals," *Annals of Agri-Bio Research*, vol. 21, pp. 174–178, 2016.

[32] R. Sindhu and B. S. Khatkar, "Thermal, microstructural and pasting properties of starch and flour of grain amaranthus," *Annals of Biology*, vol. 32, pp. 269–273, 2016.

[33] L. Kaur, S. B. Dhull, P. Kumar, and A. Singh, "Banana starch: Properties, description, and modified variations - A review," *International Journal of Biological Macromolecules*, vol. 165, Part B, pp. 2096–2102, 2020.

[34] S. Punia, S. B. Dhull, P. Kunner, and S. Rohilla, "Effect of γ-radiation on physico-chemical, morphological and thermal characteristics of lotus seed (*Nelumbo nucifera*) starch," *International Journal of Biological Macromolecules*, vol. 157, pp. 584–590, 2020.

[35] S. Punia, S. B. Dhull, K. S. Sandhu, M. Kaur, and S. S. Purewal, "Kidney bean (*Phaseolus vulgaris*) starch: a review," *Legume Science*, vol. 2, no. 3, article e52, 2020.

[36] S. Punia, K. S. Sandhu, S. B. Dhull et al., "Oat starch: Physico-chemical, morphological, rheological characteristics and its applications - A review," *International Journal of Biological Macromolecules*, vol. 154, pp. 493–498, 2020.

[37] D. Singla, A. Singh, S. B. Dhull, P. Kumar, T. Malik, and P. Kumar, "Taro starch: Isolation, morphology, modification and novel applications concern - A review," *International Journal of Biological Macromolecules*, vol. 163, pp. 1283–1290, 2020.

[38] S. Gorinstein, E. Pawelzik, E. Delgado-Licon, R. Haruenkit, M. Weisz, and S. Trakhtenberg, "Characterisation of pseudo-cereal and cereal proteins by protein and amino acid analysis," *Journal of the Science of Food and Agriculture*, vol. 82, pp. 886–889, 2002.

[39] P. De Bock, L. Daelemans, L. Selis et al., "Comparison of the chemical and technological characteristics of wholemeal flours obtained from amaranth (*Amaranthus* sp.), quinoa (*Chenopodium quinoa*) and buckwheat (*Fagopyrum* sp.) Seeds," *Foods*, vol. 10, no. 3, p. 651, 2021.

[40] O. R. Aderibigbe, O. O. Ezekiel, S. O. Owolade, J. K. Korese, B. Sturm, and O. Hensel, "Exploring the potentials of underutilized grain amaranth (*Amaranthus spp.*) along the value chain for food and nutrition security: a review," *Critical Reviews in Food Science and Nutrition*, vol. 62, no. 3, pp. 656–669, 2022.

[41] E. Amare, C. Mouquet-Rivier, A. Servent, G. Morel, A. Adish, and G. D. Haki, "Protein quality of amaranth grains cultivated in Ethiopia as affected by popping and fermentation," *Food and Nutrition Sciences*, vol. 6, pp. 38–48, 2015.

[42] S. Narwade and S. Pinto, "Amaranth- a functional food," *Concepts of Dairy and Veterinary Scinces*, vol. 1, pp. 1–6, 2018.

[43] M. S. Kaldy, "Protein yield of various crops as related to protein value," *Economic Botany*, vol. 26, pp. 142–144, 1972.

[44] R. M. Saunders and R. Becker, "Amaranthus: a potential food and feed resource," in *Advances in Cereal Science and Technology(vol. 6)*, pp. 357–396, American Association of Cereal Chemists, 1984.

[45] R. Srivastava and B. K. Roy, "Proteomic analysis of different extracts from amaranth (*Amaranthus tricolor*) grains," *Asian Journal of Pharmaceutical and Clinical Research*, vol. 6, pp. 37–39, 2013.

[46] R. Srivastava and P. Srivastava, "Characterization of grain storage protein pattern of *Amaranthus viridis*: SDS-PAGE study," *Biomedical Journal of Scientific and Technical Research*, vol. 6, 2018.

[47] C. Motta, I. Castanheira, G. B. Gonzales et al., "Impact of cooking methods and malting on amino acids content in amaranth, buckwheat and quinoa," *Journal of Food Composition and Analysis*, vol. 76, pp. 58–65, 2019.

[48] B. Valcárcel-Yamani and S. C. S. Lannes, "Applications of quinoa (*Chenopodium Quinoa Willd.*) and amaranth (*Amaranthus Spp.)* and their influence in the nutritional value of cereal based foods," *Food and Public Health*, vol. 2, pp. 265–275, 2012.

[49] R. Bressani and L. A. Garcia-Vela, "Protein fractions in amaranth grain and their chemical characterization," *Journal of Agricultural and Food Chemistry*, vol. 38, pp. 1205–1209, 1990.

[50] K. Klubicova, M. Szabova, L. Skultety, G. Libiakova, and A. Hricova, "Revealing the grain proteome of the health benefitting grain amaranth (*Amaranthus cruentus L.*)," *Chemical Papers-Slovak Academy of Sciences*, vol. 70, pp. 1–14, 2016.

[51] F. Jahaniaval, Y. Kakuda, and M. F. Marcone, "Fatty acid and triacylglycerol compositions of seed oils of fiveAmaranthusaccessions and their comparison to other oils," *JAOCS*, vol. 77, no. 8, pp. 847–852, 2000.

[52] Y. Tang, X. Li, P. X. Chen et al., "Assessing the fatty acid, carotenoid, and tocopherol compositions of amaranth and quinoa grains grown in ontario and their overall contribution to nutritional quality," *Journal of Agricultural and Food Chemistr*, vol. 64, pp. 1103–1110, 2016.

[53] R. Bruni, A. Medici, A. Guerrini et al., "Wild *Amaranthus caudatus* grain oil, a nutraceutical resource from Ecuadorian flora," *Journal of Agricultural and Food Chemistry*, vol. 49, pp. 5455–5460, 2001.

[54] A. N. Gendy, S. Tavarini, G. Conte et al., "Yield and qualitative characterization of grains of *Amaranthus Hypochondriacus* L. and *Amaranthus Cruentus* L. grown in central Italy," *Italian Journal of Agronomy*, vol. 11, pp. 63–73, 2018.

[55] D. M. Martirosyan, L. A. Miroshnichenko, S. N. Kulakova, A. V. Pogojeva, and V. I. Zoloedov, "Amaranth oil application for coronary heart disease and hypertension," *Lipids in Health and Disease*, vol. 6, pp. 1–12, 2007.

[56] P. E. Akin-Idowu, O. T. Ademoyegun, Y. O. Olagunju, A. O. Aduloju, and U. G. Adebo, "Phytochemical content and antioxidant activity of five grain amaranth species," *American Journal of Food Science and Technology*, vol. 5, pp. 249–255, 2017.

[57] A. Gliszczyńska-Swiglo, I. Klimczak, and I. Rybicka, "Chemometric analysis of minerals in gluten-free products," *Journal of Science of Food and Agriculture*, vol. 98, pp. 3041–3048, 2018.

[58] A. Bhat, G. Satpathy, and R. K. Gupta, "Evaluation of nutraceutical properties of *Amaranthus hypochondriacus* L. grains and formulation of value added cookies," *Journal of Pharmacognosy and Phytochemistry*, vol. 3, pp. 51–54, 2015.

[59] D. Schmidt, M. R. Verruma-Bernardi, V. A. Forti, and M. T. M. R. Borges, "Quinoa and amaranth as functional foods: a review," *Food Reviews International*, vol. 39, 2023.

[60] C. Motta, I. Delgado, A. S. Matos et al., "Folates in quinoa (*Chenopodium quinoa*), amaranth (*Amaranthus sp.)* and buckwheat (*Fagopyrum esculentum*): influence of cooking and malting," *Journal of Food Composition and Analysis*, vol. 64, pp. 181–187, 2017.

[61] R. Schoenlechner, J. Drausinger, V. Ottenschlaeger, K. Jurackova, and E. Berghofer, "Functional properties of gluten-free pasta produced from amaranth, quinoa and buckwheat," *Plant Foods and Human Nutrition*, vol. 65, pp. 339–349, 2010.

[62] R. Schoenlechner, M. Wendner, S. Siebenhandl-Ehn, and E. Berghofer, "Pseudocereals as alternative sources for high

folate content in staple foods," *Journal of Cereal Science*, vol. 52, pp. 475–479, 2010.

[63] J. Kalinova and E. Dadakova, "Rutin and total quercetin content in amaranth (*Amaranthus spp.*)," *Plant Foods and Human Nutrition*, vol. 64, pp. 68–74, 2009.

[64] J. A. Huerta-Ocampo and A. P. B. Rosa, "Amaranth: a psedo-cereal with nutraceutical properties," *Current Nutrition and Food Science*, vol. 7, pp. 1–9, 2011.

[65] E. G. Aguilar, M. A. Cantarelli, E. J. Marchevsky, N. L. Escudero, and J. M. Camiña, "Study and determination of As, Cr, and Pb in amaranth seeds," *Journal of Chemistry*, vol. 2013, Article ID 138391, 4 pages, 2013.

[66] C. Pazinatto, L. G. Malta, G. M. Pastore, and F. M. Netto, "Antioxidant capacity of amaranth products: effects of thermal and enzymatic treatments," *Food Science and Technology*, vol. 33, pp. 485–493, 2013.

[67] A. Escobedo-Moratilla, A. J. Velarde-Salcedo, C. V. Magana-Hernandez et al., "Amaranth protein improves lipid profile and insulin resistance in a diet-induced obese mice model," *Journal of Food and Nutrition Research*, vol. 5, pp. 914–924, 2017.

[68] A. P. B. Rosa, E. E. Gomez-Cardona, E. E. Hernandez-Dominguez, J. Huerta-Ocampo, and H. Jimanez-Islas, "Effect of amaranth consumption on diabetes-related biomarkers in patients with diabetes," *Diabetes, Obesity and Metabolic Disorders*, vol. 3, pp. 5–10, 2017.

[69] J. Soriano-Santos, R. Reyes-Bautista, I. Guerrero-Legarreta et al., "Dipeptidyl peptidase IV inhibitory activity of protein hydrolyzates from *Amaranthus hypochondriacus L.* Grain and their influence on postprandial glycemia in streptozotocin-induced diabetic mice," *African Journal of Traditional, Complementary and Alternative Mmedicine*, vol. 12, pp. 90–98, 2015.

[70] S. Zambrana, L. C. E. L. Lundqvist, V. Veliz, S. B. Catrina, E. Gonzales, and C. G. Ostenson, "*Amaranthus caudatus* stimulates insulin secretion in Goto-Kakizaki Rats, a model of diabetes mellitus type 2," *Nutrients*, vol. 10, pp. 1–17, 2018.

[71] A. Montoya-Rodriguez, M. A. Gomez-Favela, C. Reyes-Moreno, J. Milan-Ccarrillo, and E. G. Mejia, "Identification of bioactive peptide sequences from amaranth (*Amaranthus hypochondriacus*) grain proteins and their potential role in the prevention of chronic diseases," *Comprehensive Reviews in Food Science and Food Safety*, vol. 14, pp. 139–158, 2015.

[72] A. Montoya-Rodriguez, J. Milan-Carrillo, C. Reyes-Moreno, and E. Gonzalez de Mejia, "Characterization of peptides found in unprocessed and extruded amaranth *(Amaranthus hypochondriacus)* pepsin/pancreatin hydrolysates," *International Journal of Molecular Sciences*, vol. 16, pp. 8536–8554, 2015.

[73] P. G. Peiretti, G. Meineri, F. Gai, E. Longato, and R. Amarowicz, "Antioxidative activities and phenolic compounds of pumpkin (*Cucurbita pepo)* grains and amaranth (*Amaranthus caudatus*) grain extracts," *Natural Product Research*, vol. 31, pp. 2178–2182, 2017.

[74] M. Asao and K. Watanabe, "Functional and bioactive properties of quinoa and amaranth," *Food Science and Technology Research*, vol. 16, pp. 163–168, 2010.

[75] Z. Chmelik, H. Kotolova, V. Zavalova, L. Bartosova, P. Suchy, and P. Kollar, "The effect of amarnth flour on plasma cholesterol profile in mice with diet-induced dyslipidaemia," *Current Topics in Nutraceutical Research*, vol. 11, pp. 67–74, 2013.

[76] V. Caselato-Sousa and J. Amaya-Farfan, "State of knowledge on amaranth grain: a comprehensive review," *Journal of Food Science*, vol. 77, pp. 93–104, 2012.

[77] T. S. Kahlon and M. C. M. Chiu, "Teff, buckwheat, quinoa and amaranth: ancient whole grain gluten-free egg-free pasta," *Food and Nutrition Sciences*, vol. 6, pp. 1460–1467, 2015.

[78] G. R. B. Sangeeta, "Physico-chemical properties of pseudo-cereals (amaranth and buckwheat)," *The Pharma Innovation Journal*, vol. 7, pp. 7–10, 2018.

[79] L. Dodok, A. A. Modhir, G. Halasova, I. Polacek, and B. Hozova, "Importance and utilization of amaranth in food industry Part I. Characteristic of grain and average chemical constitution of whole amaranth flour," *Food/Nahrung*, vol. 38, no. 4, pp. 378–381, 1994.

[80] R. Abalone, A. Cassinera, A. Gaston, and M. A. Lara, "Some physical properties of amaranth Seeds," *Biosystems Engineering*, vol. 89, no. 1, pp. 109–117, 2004.

[81] S. A. Kudos and C. Solanki, "Evaluation of physical properties of amaranth grain (*Amaranthus paniculatus*)," *International Journal of Chemical Studies*, vol. 6, pp. 2197–2201, 2018.

[82] J. G. P. Balderrama and S. C. C. Cadima, "Water adsorption isotherms of amaranth (*Amaranthus caudatus*) Flour," *Food and Nutrition Sciences*, vol. 5, pp. 153–157, 2014.

[83] P. M. C. da Costa, A. Bianchini, C. Caneppele et al., "Moisture content and packaging condition on the fermination of amaranth BRS Alegria seeds," *Journal of Experimental Agriculture International*, vol. 38, no. 4, pp. 1–8, 2019.

[84] E. K. Ronoh, C. L. Kanali, J. T. Mailutha, and D. Shitanda, "Evaluation of solar-energy dryer systems on drying behaviour and quality attributes of amaranth grains," *International Journal of Energy Science*, vol. 2, pp. 189–194, 2012.

[85] K. V. P. Kumar, U. Dharmaraj, S. D. Sakhare, and A. A. Inamdar, "Effect of grain moisture content during milling on pasting profile and functional properties of amaranth fractions," *Journal of Food Science and Technology*, vol. 53, pp. 2434–2442, 2016.

[86] C. M. Rosell, G. Cortez, and R. Repo-Carrasco, "Breadmaking use of Andean crops quinoa, kaniwa, kiwicha, and tarwi," *Cereal Chemistry Journal*, vol. 86, pp. 386–392, 2009.

[87] N. M. Derkanosova, S. A. Shelamova, I. N. Ponomareva, G. V. Shurshikova, and O. A. Vasilenko, "Parameters modelling of amaranth grain processing technology," *IOP Conference Series: Mmaterials Science and Engineering*, vol. 327, 2018.

[88] A. C. Resio, R. J. Aguerre, and C. Suarez, "Hydration kinetics of amaranth grain," *Journal of Food Engineering*, vol. 72, pp. 247–253, 2006.

[89] J. Uriyapongson and P. Rayas-Duarte, "Comparison of yield and properties of amaranth starches using wet and dry-wet milling processes," *Cereal Chemistry*, vol. 71, pp. 571–577, 1994.

[90] A. Burisova, B. Tomaskova, V. Sasinkova, and A. Ebringerova, "Isolation and characterization of the non-starch polysaccharides of amaranth grains," *Chemical Papers*, vol. 55, pp. 254–260, 2001.

[91] V. D. Capriles, K. D. Coelho, A. C. Guerra-Matias, and J. A. G. Areas, "Effects of processing methods on amaranth starch digestibility and predicted glycemic index," *Journal of Food Science*, vol. 73, pp. 160–164, 2008.

[92] H. Choi, W. Kim, and M. Shin, "Properties of Korean amaranth starch compared to waxy millet and waxy sorghum starches," *Starch/Stärke*, vol. 56, pp. 469–477, 2004.

[93] A. Chandak, S. B. Dhull, P. Chawla, M. Fogarasi, and S. Fogarasi, "Effect of single and Dual modifications on properties of lotus rhizome starch modified by microwave and γ-irradiation: a comparative study," *Foods*, vol. 11, no. 19, p. 2969, 2022.

[94] A. Chandak, S. B. Dhull, S. Punia Bangar, and A. V. Rusu, "Effects of cross-linking on physicochemical and film properties of lotus (*Nelumbo nucifera* G.) Seed Starch," *Foods*, vol. 11, no. 19, p. 3069, 2022.

[95] S. B. Dhull, A. Chandak, M. N. Collins, S. P. Bangar, P. Chawla, and A. Singh, "Lotus seed starch: a novel functional ingredient with promising properties and applications in food—a review," *Starch-Stärke*, vol. 74, no. 9-10, article 2200064, 2022.

[96] M. B. Arce-Vazquez, E. Ponce-Alquicira, E. Delgado-Fornue, R. Pedroza-Islas, G. Diaz-Godinez, and J. Soriano-Santos, "Integral use of amaranth starch to obtain cyclodextrin glycosyltransferase, by *Bacillus megaterium*, to produce beta-cyclodextrin," *Frontiers in Microbiology*, vol. 7, pp. 1–11, 2016.

[97] K. Babor, G. Halasova, L. Dodok, R. Geciova, and J. Lokaj, "Characterization of starch from *Amaranthus cruentus* L," *Chemical Papers*, vol. 48, pp. 58–63, 1994.

[98] M. E. Villarreal and L. B. Iturriaga, "Viscoelastic properties of amaranth starch gels and pastes. Creep compliance modeling with Maxwell model," *Starch*, vol. 68, pp. 11-12, 2016.

[99] S. P. Bangar, A. O. Ashogbon, S. B. Dhull et al., "Proso-millet starch: properties, functionality, and applications," *International Journal of Biological Macromolecules*, vol. 190, pp. 960–968, 2021.

[100] S. B. Dhull, T. Malik, R. Kaur, P. Kumar, N. Kaushal, and A. Singh, "Banana starch: properties illustration and food applications—a review," *Starch-Stärke*, vol. 73, no. 1-2, article 2000085, 2021.

[101] S. B. Dhull, S. Punia, M. Kumar, S. Singh, and P. Singh, "Effect of different modifications (physical and chemical) on morphological, pasting, and rheological properties of black rice (*Oryza sativa* L. Indica) starch: a comparative study," *Starch-Stärke*, vol. 73, no. 1-2, article 2000098, 2021.

[102] S. Punia, M. Kumar, A. K. Siroha, J. F. Kennedy, S. B. Dhull, and W. S. Whiteside, "Pearl millet grain as an emerging source of starch: a review on its structure, physicochemical properties, functionalization, and industrial applications," *Carbohydrate Polymers*, vol. 260, article 117776, 2021.

[103] A. N. C. Resio, M. P. Tolaba, and C. Suarez, "Some physical and thermal characteristics of amaranth starch," *Food Science and Technology International*, vol. 6, pp. 371–378, 2000.

[104] L. A. Stone, K. Lorenz, and F. Collins, "The starch of Amaranthus-physico-chemical properties and functional characteristics," *Starch-Starke*, vol. 36, pp. 232–237, 1984.

[105] A. C. Resio and C. Suarez, "Gelatinization kinetis of amaranth starch," *International Journal of Food Science and Technology*, vol. 36, pp. 441–448, 2001.

[106] L. Singh, P. Kumar, N. Kaushik, S. Sharma, and P. Kumar, "Preparation and characterization of modified starch isolated from *Amaranthus paniculatus* Linn," *Biotechnology: An Indian Journal*, vol. 2, pp. 123–126, 2008.

[107] C. Delinski Bet, C. Soltovski de Oliveira, T. A. D. Colman et al., "Organic amaranth starch: a study of its technological properties after heat-moisture treatment," *Food Chemistry*, vol. 264, 2018.

[108] N. K. Chandla, D. C. Saxena, and S. Singh, "Processing and evaluation of heat moisture treated (HMT) amaranth starch noodles; an inclusive comparison with corn starch noodles," *Journal of Cereal Science*, vol. 75, pp. 306–313, 2017.

[109] R. Sindhu and B. S. Khatkar, "Amaranth starch isolation, oxidation, heat-moisture treatmentand application in edible film formation," *International Journal of Advanced Engineering Research and Science*, vol. 5, pp. 136–141, 2018.

[110] R. Sindhu and B. S. Khatkar, "Thermal, structural and textural properties of amaranth and buckwheat starches," *Journal of Food Science and Technology*, vol. 55, pp. 5153–5160, 2018.

[111] R. Gonzalez, E. Tosi, R. Edmundo, M. C. Anon, A. M. R. Pilosof, and K. Martinez, "Amaranth starch-rich fraction properties modified by high-temperature heating," *Food Chemistry*, vol. 103, pp. 927–934, 2007.

[112] T. O. Fasuan, C. T. Akanbi, and E. Betiku, "Acetylation of Amaranthus viridis starch: modeling and process parameters optimization," *Food Science and Nutrition*, vol. 6, pp. 1–11, 2018.

[113] M. Urban, M. Beran, L. Adamek, J. Drahorad, P. Molik, and K. Matusova, "Cyclodextrin production from amaranth starch by cyclodextrin glycosyltransferase produced by *Paenibacillus macerans* CCM 2012," *Czech Journal of Food Science*, vol. 30, no. 1, pp. 15–20, 2012.

[114] L. Scarnato, D. I. Serrazanetti, I. Aloisi, C. Montanari, S. Duca, and R. Lanciotti, "Combination of transglutaminase and sourdough on gluten-free flours to improve dough structure," *Amino Acids*, vol. 48, 2016.

[115] C. Silva-Sanchez, J. Gonzalez-Castaneda, A. De Leon-Rodriguez, and A. P. Barba De La Rosa, "Functional and rheological properties of amaranth albumins extracted from two Mexican varieties," *Plant Foods for Human Nutrition*, vol. 59, pp. 169–174, 2004.

[116] N. L. Escudero, M. L. Arellano, J. M. Luco, M. S. Gimenez, and S. I. Mucciarelli, "Comparison of the chemical composition and nutritional value of Amaranthus cruentus flour and its protein concentrate," *Plant Foods for Human Nutrition*, vol. 59, pp. 15–21, 2004.

[117] F. P. Bejosano and H. Corke, "Protein quality evaluation of *Amaranthus* wholemeal flours and protein concentrates," *Journal of the Science of Food and Agriculture*, vol. 76, pp. 100–106, 1998.

[118] D. F. Roa, P. R. Santagapita, M. P. Buera, and M. P. Tolaba, "Amaranth milling strategies and fraction characterization by FT-IR," *Food and Bioprocess Technology*, vol. 7, no. 3, pp. 711–718, 2014.

[119] D. F. Roa, R. I. Baeza, and M. P. Tolaba, "Effect of ball milling energy on rheological and thermal properties of amaranth flour," *Journal of Food Science and Technology*, vol. 52, pp. 8389–8394, 2015.

[120] E. A. Tosi, E. Re, H. Lucero, and R. Masciarelli, "Dietary fiber obtained from amaranth (*A. cruentus*) grain by differential milling," *Food Chemistry*, vol. 73, pp. 441–443, 2001.

[121] C. F. Ozoh, *Evaluation of Physiochemical Properties and Applications of Grain Flour, [Ph.D. thesis]*, Iowa State University, Ames, IA, USA, 2016.

[122] B. T. Olawoye and S. O. Gbadamosi, "Effect of different treatments on in vitro protein digestibility, antinutrients, antioxidant properties and mineral composition of

Amaranthus viridis grain," *Cogent Food and Agriculture*, vol. 3, pp. 1–14, 2017.

[123] F. Hubner and E. K. Arendt, "Germination of cereal grains as a way to improve the nutritional value: a review," *Critical Reviews in Food Science and Nutrition*, vol. 53, pp. 853–861, 2013.

[124] P. Pasko, H. J. Barton, P. Zagrodzki, S. Gorinstein, M. Folta, and W. Zachwieja, "Anthocyanins, total polyphenols and antioxidant activity in amaranth and quinoa grains and sprouts during their growth," *Food Chemistry*, vol. 115, pp. 994–998, 2009.

[125] A. Sneha and A. Haripriya, "Development of amaranth grain (*Amaranthus cruentus*) based instant dosa mix and its quality characteristics," *International Journal of Food Science and Nutrition*, vol. 3, pp. 6–11, 2018.

[126] S. N. Hejazi and V. Orsat, "Optimization of the malting process for nutritional improvement of finger millet and amaranth flours in the infant weaning food industry," *International Journal of Food Sciences and Nutrition*, vol. 68, pp. 429–441, 2017.

[127] L. Alvarez-Jubete, M. Auty, E. K. Arendt, and E. Gallagher, "Baking properties and microstructure of pseudocereal flours in gluten-free bread formulations," *European Food Research and Technology*, vol. 230, no. 3, pp. 437–445, 2010.

[128] L. Alvarez-Jubete, H. Wijngaard, E. K. Arendt, and E. Gallagher, "Polyphenol composition and in-vitro antioxidant activity of amaranth, quinoa, buckwheat and wheat as affected by sprouting and baking," *Food Chemistry*, vol. 119, pp. 770–778, 2010.

[129] P. Pasko, H. J. Barton, M. Folta, and J. Gwizdz, "Evaluation of antioxidant activity of amaranth (*Amaranthus cruentus*) grain and by-products (flour, popping, cereal)," *Roczniki Panstwowego Zakladu Higieny*, vol. 58, no. 1, pp. 35–40, 2007.

[130] A. Zebdewos, P. Singh, G. Birhanu, S. J. Whiting, C. J. Henry, and A. Kebebu, "Formulation of complementary food using amaranth, chickpea and maize improves iron, calcium and zinc content," *African Journal of Food, Agriculture, Nutrition and Development*, vol. 15, no. 71, pp. 10290–10304, 2015.

[131] F. Cornejo, G. Novillo, E. Villacres, and C. M. Rosell, "Evaluation of the physicochemical and nutritional changes in two amaranth species (*Amaranthus quintensis* and *Amaranthus caudatus*) after germination," *Food Research International*, vol. 121, pp. 933–939, 2019.

[132] J. O. Akingbala, I. A. Adeyemi, S. O. Sangodoyin, and O. L. Oke, "Evaluation of amaranth grains for ogi manufacture," *Plant Foods for Human Nutrition*, vol. 46, no. 1, pp. 19–26, 1994.

[133] M. W. Mburu, N. K. Gikonyo, G. M. Kenji, and A. M. Mwasaru, "Properties of a complementary food based on amaranth grain (*Amaranthus cruentus*) grown in Kenya," *Journal of Agriculture and Food Technology*, vol. 1, pp. 153–178, 2011.

[134] C. T. Ndagire, J. H. Muyonga, R. Manju, and D. Nakimbugwe, "Optimized formulation and processing protocol for a supplementary bean- based composite flour," *Food Science and Nutrition*, vol. 3, pp. 527–538, 2015.

[135] C. Ozuna, A. Ceron-Garcia, E. M. Sosa-Morales, J. A. G. Salazar, F. M. Leon-Galvan, and R. M. Abraham-Juarez, "Electrically induced changes in amaranth grain enzymatic activity and their effect on bioactive compounds content after germination," *Journal of Food Science and Technology*, vol. 55, pp. 648–657, 2018.

[136] P. Aphalo, E. N. Martinez, and M. C. Anon, "Amaranth sprouts: a potential health promoting and nutritive natural food," *International Journal of Food Properties*, vol. 18, pp. 2688–2698, 2015.

[137] C. Motta, A. C. Nascimento, M. Santos et al., "The effect of cooking methods on the mineral content of quinoa (Chenopodium quinoa), amaranth (*Amaranthus sp.*) and buckwheat (*Fagopyrum esculentum*)," *Journal of Food Composition and Analysis*, vol. 49, pp. 57–64, 2016.

[138] Y. Sterr, A. Weiss, and H. Schmidt, "Evaluation of lactic acid bacteria for sourdough fermentations of amaranth," *International Journal of Food Microbiology*, vol. 136, pp. 75–82, 2009.

[139] A. Houben, H. Gotz, M. Mitzscherling, and T. Becker, "Modification of the rheological behaviour of amaranth (*Amaranthus hypochondriacus*) dough," *Journal of Cereal Science*, vol. 51, pp. 350–356, 2010.

[140] M. Jekle, A. Houben, M. Mitzscherling, and T. Becker, "Effects of selected lactic acid bacteria on the characteristics of amaranth sourdough," *Journal of the Science of Food and Agriculture*, vol. 90, pp. 2326–2332, 2010.

[141] N. U. Sruthi, Y. Premji, R. Pandiselvam, A. Kothakota, and S. V. Ramesh, "An overview of conventional and emerging techniques of roasting: effect on food bioactive signatures," *Food Chemistry*, vol. 348, article 129088, 2021.

[142] J. H. Muyonga, B. Andabati, and G. Ssepuuya, "Effect of heat processing on selected grain amaranth physicochemical properties," *Food Science & Nutrition*, vol. 2, pp. 9–16, 2014.

[143] R. V. Tikekar, R. D. Ludescher, and M. V. Karwe, "Processing stability of squalene in amaranth and antioxidant potential of amaranth extract," *Journal of Agricultural and Food Chemistr*, vol. 56, pp. 10675–10678, 2008.

[144] E. Katz and E. Lazos, "The rediscovery of native 'super foods' in Mexico," in *Eating Traditional Food: Politics, identity and practices*, B. Sebastia, Ed., p. 26, Taylor & Francis, 2016.

[145] N. Lara and J. Ruales, "Popping of amaranth grain (*Amaranthus caudatus*) and its effect on the functional, nutritional and sensory properties," *Journal of the Science of Food and Agriculture*, vol. 82, pp. 797–805, 2002.

[146] T. H. Gamel and J. P. H. Linssen, "Flavor compounds of popped amaranth grains," *Journal of Food Processing and Preservation*, vol. 32, pp. 656–668, 2008.

[147] E. Berghofer and R. Schoenlechner, "Grain amaranth," in *Pseudocereals and Less Common Cereals*, P. S. Belton and J. R. N. Taylor, Eds., pp. 219–260, Springer-Verlag, 2002.

[148] Y. Konishi, H. Iyota, K. Yoshida et al., "Effect of moisture content on the expansion volume of popped amaranth grains by hot air and superheated steam using a fluidized bed system," *Bioscience, Biotechnology, and Biochemistry*, vol. 68, pp. 2186–2189, 2004.

[149] L. R. Tovar, M. Valdivia, and E. Brito, "Popping amaranth grain, state of the art," in *Amaranth: Biology, Chemistry and Technology*, O. Paredes-Lopez, Ed., pp. 143–154, CRC Press, 1994.

[150] C. Solanki, N. Indore, D. Saha, and A. Kudos, "Effect of popping methods on popping characteristics of amaranth grain," *International Journal of Chemical Studies*, vol. 6, pp. 2779–2782, 2018.

[151] B. Filipcev, M. Bodroza-Solarov, M. Pestoric, and O. Simurina, "Breadmaking performance and textural changes during

storage of composite breads made from spelt wheat and different forms of amaranth grain," *Food Science and Technology International*, vol. 23, no. 3, pp. 235–244, 2017.

[152] L. M. Paucar-Menacho, M. Duenas, E. Penas, J. Frias, and C. Martinez-Villaluenga, "Effect of dry heat puffi ng on nutritional composition, fatty acid, amino acid and phenolic profiles of pseudocereals grains," *Polish Journal of Food and Nutrition Sciences*, vol. 68, pp. 1–10, 2018.

[153] R. Durgadevi and P. Nazni, "Comparative study of processed amaranth grains on glycemic indices in NIDDM subjects," *International Journal of Pharma Medicine and Biological Sciences*, vol. 1, pp. 1–12, 2012.

[154] O. A. Akande, D. Nakimbugwe, and I. M. Mukisa, "Optimization of extrusion conditions for the production of instant grain amaranth-based porridge flour," *Food Science and Nutrition*, vol. 5, no. 6, pp. 1205–1214, 2017.

[155] R. N. Chavez-Jauregui, M. E. M. P. Silva, and J. Areas, "Extrusion cooking process for amarnth (*Amaranthus caudatus* L.)," *Journal of Food Science*, vol. 65, pp. 1009–1015, 2000.

[156] T. Ferreira and J. Areas, "Protein biological value of extruded, raw and toasted amaranth grain," *Pesquisa Agropecuária Tropical*, vol. 34, pp. 53–59, 2004.

[157] C. M. Mendoza and R. Bressani, "Nutritional and functional characteristics of extrusion cooked amaranth flour," *Cereal Chemistry*, vol. 64, pp. 218–222, 1987.

[158] J. Milan-Carrillo, A. Montoya-Rodriguez, R. Gutierrez-Dorado, X. Perales-Sanchez, and C. Reyes-Moreno, "Optimization of extrusion process for producing high antioxidant instant amaranth (*Amaranthus hypochondriacus* L.) flour using response surface methodology," *Applied Mathematics*, vol. 3, pp. 1516–1525, 2012.

[159] L. Dokic, M. Bodroza-Solarov, M. Hadnadev, and I. Nikolic, "Properties of extruded snacks supplemented with amaranth grain grits," *Acta Periodica Technologica*, vol. 40, pp. 17–24, 2009.

[160] D. Westerman, R. Santos, J. A. Bosley, J. S. Rogers, and B. Duri, "Extraction of amaranth grain oil by supercritical carbon dioxide," *Journal of Supercritical Fluids*, vol. 37, pp. 38–52, 2006.

[161] T. Rosales-Garcia, C. J. Martinez, A. Cardador-Martinez et al., "Squalene extraction by supercritical fluids from traditionally puffed *Amaranthus hypochondriacus* grains," *Journal of Food Quality*, vol. 2017, Article ID 6879712, 8 pages, 2017.

[162] H. Sun, D. Wiesenborn, K. Tostenson, J. Gillespie, and P. Rayas-Duarte, "Fractionation of squalene from amaranth grain oil," *JAOCS*, vol. 74, pp. 413–418, 1997.

[163] L. Alvarez-Jubete, E. K. Arendt, and E. Gallagher, "Nutritive value and chemical composition of pseudocereals as gluten-free ingredients," *International Journal of Food Sciences and Nutrition*, vol. 60, Supplement 4, pp. 240–257, 2009.

[164] A. E. Pagano, "Whole grains and the gluten-free diet," *Practical Gastroenterology*, vol. 30, pp. 66–78, 2006.

[165] I. Rybicka and A. Gliszczynska-Swiglo, "Gluten-free flours from different raw materials as the source of vitamin B_1, B_2, B_3 and B_6," *Journal of Nutritional Science and Vitaminology*, vol. 63, pp. 125–132, 2017.

[166] I. Rybicka and A. Gliszczynska-Swiglo, "Minerals in grain gluten-free products. The content of calcium, potassium, magnesium, sodium, copper, iron, manganese, and zinc," *Journal of Food Composition and Analysis*, vol. 59, pp. 61–67, 2017.

[167] S. G. Mlakar, M. Bavec, M. Turinek, and F. Bavec, "Rheological properties of dough made from grain amaranth-cereal composite flours based on wheat and spelt," *Czech Journal of Food Sciences*, vol. 27, pp. 309–319, 2009.

[168] M. Kuhn and H. Goetz, "Teige und Kleber im System Amarant-Weizen," *Getreide, Mehl und Brot*, vol. 53, pp. 326–333, 1999.

[169] E. A. Tosi, E. D. Re, R. Masciarelli, H. D. Sanchez, C. A. Osella, and M. A. De La Torre, "Whole and defatted hyperproteic amaranth flours tested as wheat flour supplementation in mold breads," *LWT - Food Science and Technology*, vol. 35, pp. 472–475, 2002.

[170] A. Grace, F. Olooto, D. T. Ogundele, and F. Williams, "Nutritional characterization of grain amaranth grown in Nigeria for food security and healthy living," *Agrosearch*, vol. 17, pp. 1–10, 2017.

[171] E. Amare, C. Mouquet-Rivier, I. Rochette, A. Adish, and G. D. Haki, "Effect of popping and fermentation on proximate composition, main minerals and absorption inhibitors content, and estimated mineral bioavailability of *Amaranthus caudatus* grain cultivated in Ethiopia," *Journal of Food Science and Technology*, vol. 53, pp. 2987–2994, 2016.

[172] M. L. M. Amador, I. Comino, and C. Sousa, "Alternative grains as potential raw material for gluten-free food development in the diet of celiac and gluten-sensitive patients," *Austin Journal of Nutrition and Food Sciences*, vol. 2, pp. 1–9, 2014.

[173] A. Liberal, R. C. Calhelha, C. Pereira et al., "A comparison of the bioactivity and phytochemical profile of three different cultivars of globe amaranth: red, white, and pink," *Food and Nutrition*, vol. 7, pp. 679–688, 2016.

[174] R. Srivastava and B. K. Roy, "Analysis of genetic variation among accessions of wild and cutivated species of Amaranthus based on rapid and SDS-PAGE markers," *International Journal of Pharma and Bio Sciences*, vol. 3, pp. 168–178, 2012.

[175] S. Kariuki, D. Sila, and G. Kenji, "Nutritional profile of amaranth grain varieties grown in Kenya," *Food Science and Quality Management*, vol. 17, pp. 19–25, 2013.

[176] J. M. Sanz-Penella, M. Wronkowska, M. Soral-Smietana, and C. M. Haros, "Effect of whole amaranth flour on bread properties and nutritive value," *LWT-Food Science and Technology*, vol. 50, pp. 679–685, 2013.

[177] A. Sindhuja, M. I. Sudha, and A. Rahim, "Effect of incorporation of amaranth flour on the quality of cookies," *European Food Research and Technology*, vol. 221, pp. 597–601, 2005.

[178] A. Chauhan, D. C. Saxena, S. Singh, and F. Yildiz, "Physical, textural, and sensory characteristics of wheat and amaranth flour blend cookies," *Cogent Food and Agriculture*, vol. 2, pp. 1–8, 2016.

[179] P. Mokrejs, D. Janacova, K. Kolomaznik, and P. Svoboda, "Modeling isolation of amaranth protein by enzymatic breakdown of polysaccharides," *Rasayan Journal Chemical*, vol. 4, pp. 180–188, 2011.

[180] M. C. Romero, R. A. Fogar, F. Rolhaiser, V. V. Clavero, A. M. Romero, and M. A. Judis, "Development of gluten-free fish (*Pseudoplatystoma corruscans*) patties by response surface methodology," *Journal of Food Science and Technology*, vol. 55, pp. 1889–1902, 2018.

[181] X. Kong, J. Bao, and H. Corke, "Physical properties of amaranth starch," *Food Chemistry*, vol. 113, pp. 371–376, 2009.

[182] R. S. Singhal and P. R. Kulkarni, "Some properties of *Amaranthus paniculatas* (Rajgeera) starch pastes," *Starch*, vol. 42, pp. 5–7, 1990.

[183] N. Lara, A. Mejia, and A. Cangas, *Popped Amaranth Grains and its Products Breakfast Cereal and Crunchy Bars: Popping Process, Nutritive Value and Shelf Life*, Department of Nutrition and Quality, Santa Catalina Experimental Station of the Agriculture Research Institute (INIAP), Quito, Ecuador, 2004.

[184] J. A. Ayo, "The effect of amaranth grain flour on the quality of bread," *International Journal of Food Properties*, vol. 4, pp. 341–351, 2001.

[185] S. Singh, "Development and evaluation of gluten-free multigrain health mix," *International Journal of Advance Research*, vol. 4, pp. 1425–1432, 2018.

[186] J. K. Okoth, S. A. Ochola, N. K. Gikonyo, and A. Makokha, "Development of a nutrient- dense complementary food using amaranth- sorghum grains," *Food Science & Nutrition*, vol. 5, 2017.

[187] S. Tomoskozi, L. Gyenge, A. Pelceder, T. Abonyi, R. Schonlechner, and R. Lasztity, "The Effects of flour and protein preparations from amaranth and quinoa seeds on the rheological properties of wheat-flour dough and bread crumb," *Czech Journal of Food Sciences*, vol. 29, no. 2, pp. 109–116, 2011.

[188] N. G. Heredia-Sandoval, A. M. C. Barca, E. Carvajal-Millan, and A. R. Islas-Rubio, "Amaranth addition to enzymatically modified wheat flour improves dough functionality, bread immunoreactivity and quality," *Food and Function*, vol. 9, pp. 534–540, 2018.

[189] J. Pico, J. L. Bernal, and M. Gomez, "Influence of different flours and starches on gluten-free bread aroma," *Journal of Food Science and Technology*, vol. 54, pp. 1433–1441, 2017.

[190] S. Pourafshar, K. A. Rosentrater, and P. G. Krishnan, "Using alternative flours as partial replacement of barbari bread formulation (traditional Iranian bread)," *Journal of Food Science and Technology*, vol. 52, pp. 5691–5699, 2015.

[191] H. Gambus, F. Gambus, D. Litwinek et al., "Quality of gluten-free supplemented cakes and biscuits," *International Journal of Food Sciences and Nutrition*, vol. 60, pp. 31–50, 2009.

[192] S. X. Liu, D. Chen, and J. Xu, "Evaluation of gluten-free amaranth and navy bean flour blends on quality of sugar cookies," *Journal of Food Research*, vol. 6, pp. 63–73, 2017.

[193] D. Agrahar-Murugkar, A. Zaidi, and S. Dwivedi, "Development of gluten free eggless cake using gluten free composite flours made from sprouted and malted ingredients and its physical, nutritional, textural, rheological and sensory properties evaluation," *Journal of Food Science and Technology*, vol. 55, no. 7, pp. 2621–2630, 2018.

[194] C. S. Martinez, P. D. Ribotta, and A. E. Leon, "Influence of the addition of *Amaranthus mantegazzianus* flour on the nutritional and health properties of pasta," *Cogent Food and Agriculture*, vol. 2, pp. 1–12, 2016.

[195] A. Cardenas-Hernandez, T. Beta, M. G. F. Loarca-Pina, E. Castano-Tostado, J. O. Nieto-Barrera, and S. Mendoza, "Improved functional properties of pasta: enrichment with amaranth grain flour and dried amaranth leaves," *Jounal of Cereal Science*, vol. 72, pp. 84–90, 2016.

[196] R. Schoenlechner, K. Jurackova, and E. Berghofer, "Pasta production from the pseudo-cereals amaranth, quinoa and buckwheat," in *Using Cereal Science and Technology for the Benefit of Consumers*, pp. 74–81, Woodhead Publishing, Harrogate, UK, 2004.

[197] J. M. Ramos-Diaz, S. Kirjoranta, S. Tenitz et al., "Use of amaranth, quinoa and kaniwa in extruded corn-based snacks," *Journal of Cereal Science*, vol. 58, pp. 59–67, 2013.

[198] L. A. Bello-Perez, Y. P. Leon, E. Agama-Acevedo, and O. Paredes-Lopez, "Isolation and partial characterization of amaranth and banana starches," *Starch*, vol. 50, pp. 409–413, 1998.

[199] N. T. Ahamed, R. S. Singhal, P. R. Kulkarni, D. D. Kale, and M. Pal, "Studies on *Chenopodium quinoa* and *Amaranthus paniculatas* starch as biodegradable fillers in LDPE films," *Carbohydrate Polymers*, vol. 31, no. 3, pp. 157–160, 1996.

[200] D. R. Tapia-Blacido, P. Sobral, and F. C. Menegalli, "Development and characterization of biofilms based on amaranth flour (*Amaranthus caudatus*)," *Journal of Food Engineering*, vol. 67, pp. 215–223, 2005.