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Chapter

Rheological Stability, Enzyme Activity, and Incorporation of Pseudocereal Powder as an Alternative Ingredient in Health-Related Food

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Abstract

In response to the growing recognition of health issues, people are seeking products that are inexpensive, convenient, and health-related. The incorporation of pseudocereal powder in nutraceutical sector is currently increasing because of their high nutritional profile as well as health-promoting effects. The high nutritional profile includes low starch content, high in amino acid profile, high in mineral content, and low glyce-mic index. Moreover, it contains high levels of phytochemicals that contain considerable amounts of flavonoids, polyphenolic chemicals, and phytosterols, making them useful in the nutraceutical sector. These bioactive compounds offer antioxidant, anti-inflammatory, and reduced risk of obesity, prediabetes, and diabetic complications. With its tremendous potential and numerous food health-related uses, pseudocereal can serve as a low-cost alternative ingredient in health-related food products. Several pseudocereal processes via enzyme activity, as well as the high rheological stability of its starch, have made pseudocereal an attractive option for modern agriculture.

Keywords: rheological stability, enzyme activity, health benefits

1. Introduction

Pseudocereal grains are edible seeds of dicotyledonous species that possess the same physical characteristics as cereal grains, such as having less or similar starch content, contribute high caloric value [1, 2] and an edible appearance [3]. The trend of pseudocereals in human diet is becoming more popular, because they fulfill high nutritional and nutraceutical needs while being gluten-free (GF). Moreover,

gluten-free diet has become increasingly popular in recent years due to the increasing number of individuals having gluten intolerance, celiac disease, and self-awareness toward health. One of the topics that has received a lot of interest and is still being explored is the processing of pseudocereal powder and its application in gluten-free food development with desired texture. Pseudocereal powder manufacture has opened the door for these crops to be used into a wide range of food industries. Besides pseudocereal is an important resource for developing functional foods, research has also highlighted pseudocereal as the potential resource for health benefits [4, 5]. Secondary metabolic analysis of pseudocereals indicated that they contain considerable amounts of flavonoids family, polyphenolic components, and phytosterols, which contribute to the therapeutics properties [6–11]. In addition, they offer great potential for the future because of their high genetic diversity, allowing them to adapt to a wide range of climatic conditions, from tropical to temperate [4, 5, 12].

Pseudocereals have been referred to as twenty-first century grains due to their high nutritional value [13]. They contain high amounts of starch, fiber, and proteins with a balanced essential amino acid composition, among which are many sulfur-rich amino acids. When compared with cereals, the protein quality and quantity in pseudocereals are far superior and have emerged as a significant source of bioactive peptides in the recent decade [14]. Pseudocereal grains are rich in starch, which comprise between 60% and 80% of seed weight, which can be classified as rapidly digestible, slowly digestible, or resistant to digestion [15]. Resistant starch (RS) causes a beneficial effect on the body as it cannot be digested and absorbed in the small intestine, instead passing to the colon where it is fermented by microorganisms into short-chain fatty acids. Current dietary guidelines recommend that at least 14% RS on a total starch basis is required for health advantages. On the other hand, simple starch contains monosaccharides compound such as glucose, fructose, arabinose, xylose and disaccharides compound such as sucrose and maltose, which exist in less quantity in pseudocereal. A significant amount of dietary fiber, lipid, mineral, and vitamin contents existing in pseudocereal enhances the nutritional value of these crops and permits their entry in the functional food sector. In general, dietary fiber of pseudocereal can be divided into two groups: insoluble and soluble polysaccharides. Out of 78% of total dietary fiber content consists of insoluble polysaccharides while 22% consists of soluble polysaccharides where hemicellulose, branched-galacturonan, cellulose [4, 5] and xyloglucans, lignin, cellulose [16] are the examples of insoluble and soluble polysaccharides, respectively. For lipid profile, pseudocereal is reported to possess a high value of polyunsaturated fatty acid, which consists of linolenic acid and linoleic acid [17, 18] whereby unsaturated fatty acid, oleic acid, and palmitic acid are among the abundant fatty acids existing [19, 20]. The mineral compounds of pseudocereal are abundant in coat; therefore, as a whole pseudocereal are a good source of mineral.

2. The rheological modification of pseudocereal starches

The study of starch gelatinization properties through viscometer analysis is very important for understanding the viscosity changes and evaluating the disintegration of starch components and their tendency to regenerate when forming new hydrogen bonds, thereby forming viscoelastic gels [21]. The pasting properties of native pseudocereal starches are summarized in **Table 1**. From **Table 1**, the measurements of pseudocereal starch paste's viscosity are analyzed using Modular Compact Rheometer (unit recorded as cP), Rapid Visco-Analyzer (RVA), Brabender Amylograph (BA),

Native pseudocereal starch	Viscosity (^a cP/ ^b mPa s/ ^c RVU/ ^d BU)*					Pasting temperature (°C)	Pasting time (min)
	Peak	Trough	Breakdown	Final	Setback		
Amaranth— <i>Amaranthus hypochondriacus</i>	2176 ^a	1533 ^a	643 ^a	1710 ^a	177 ^a	72	3.95
– <i>A. caudatus</i>	2285.85 ^b	—	1247.15 ^b	1276.7 ^b	262.64 ^b	64.32	5.13
– <i>Amaranthus</i> sp.	73.42 ^c	—	13.5 ^c	68.54 ^c	8.63 ^c	81.88	—
Buckwheat	3133 ^a	1650 ^a	—	3912 ^a	—	—	—
	4019 ^a	—	1641 ^a	4293 ^a	1915 ^a	63.7	—
	4589 ^a	2171 ^a	2418 ^a	3986 ^a	1816 ^a	68.75	3.47
	600 ^d	—	1220 ^d	—	620 ^d	—	—
Quinoa	101.08 ^c	—	–0.86 ^c	114.39 ^c	12.44 ^c	95	—

*cP: centipoise; mPa s: millipascal-second; RVU: Rapid Viscosity Unit, BU: Brabender Unit.

Table 1.
 Pasting properties of native pseudocereal starches.

or using a dynamic rheometer in a flow temperature ramp mode. In general, data obtained as in **Table 1** show that the pasting temperature affects the ability of starch to imbibe water whereby as the pasting temperature rises, the likelihood of paste creation rises. Hence, it can be suggested that in the presence of water and heat, starch granules swell and form paste by imbibing water [21]. The pasting temperature of pseudocereal starch as in **Table 1** ranges from 63.7 to 95°C, and it can be differentiated into two groups, which is the higher pasting temperature ranging from 81.88–95°C [22, 23] while the lower pasting temperature ranges from 63.7 to 68.75°C [21, 24, 25]. The pasting temperature depends on the size of the starch granules where small granules are more resistant to rupture and loss of molecular order, so this might explain the relatively high pasting temperature [26].

The modifications of pseudocereal starches were studied by many researchers to improve the functional and rheological properties of pseudocereal starch [22–25, 27]. Pasting properties of modified pseudocereal starches in comparison with their respective native pseudocereal starches are summarized in **Table 2**. There are three types of modified pseudocereal, namely physical modification, chemical modification, and physicochemical modification as in **Table 2**. In general, chemical modification of starch resulted in significantly increased peak viscosity compared with the other two types of modified pseudocereal. This is probably due to the increased granular stiffness, which is resultant of starch chain interactions within the amorphous region and an increase in crystalline order [24]. Oxidization, acetylation, and octenylsuccinylated (OSA) as in **Table 2** increased the peak viscosity of *Amaranthus hypochondriacus* that might be accredited to the higher swelling power and comparable solubility of starch relative to native starch. Final viscosity signifies the starch ability to develop viscous paste on cooling after cooking the starch solution.

Physical modifications of pseudocereal starches by heat moisture treatment (HMT) were studied in two types of amaranth spp. such as *A. caudatus* [21] and *A. hypochondriacus* [22] as in **Table 2**. Heat moisture treatment causes intensifying decrement in setback viscosity with rising amylose content in starches as high-temperature treatment supports added interactions between amylose-amylose and

Type of starch modification	Type of pseudocereals starches	Pasting properties						
		viscosity					Pasting temp.	Pasting time
		Peak	Trough	Breakdown	Final	Setback		
Chemical modification								
1) Oxidation	Amaranth (<i>Amaranthus hypochondriacus</i>)	↑	↑	↑	↑	↑	↓	↓
2) Acetylation	Amaranth (<i>A. hypochondriacus</i>)	↑	↓	↑	↓	↑	↓	↓
	Buckwheat	↑	—	↓		↓	—	—
3) Alcoholic-Alkali Treatment	Buckwheat	↓	↓	↓	↑	↑	↓	↑
4) Octenylsuccinylated (OSA)	Amaranth (<i>Amaranthus</i> sp.)	↑	—	↑	↑	↑	↓	—
	Quinoa	↑	—	↑	↑	↑	↓	—
Physical modification								
1) Annealing	Buckwheat	↓	—	↓	↓	↓	↑	—
2) Heat-Moisture Treatment (HMT): 85 °C	Amaranth (<i>A. hypochondriacus</i>)	↑	↓	↑	↓	↑	↑	↑
: 00°C	Amaranth (<i>A. hypochondriacus</i>)	↑	↓	↑	↓	↑	↑	↓
: 20 °C	Amaranth (<i>A. hypochondriacus</i>)	↑	↑	↑	↑	↑	↑	↑
3) HMT at 120°C(15 min): 10% moisture	Amaranth (<i>A. caudatus</i>)	↓	—	↓	↑	↑	↓	↓
: 15% moisture	Amaranth (<i>A. caudatus</i>)	↓	—	↓	↑	↓	↑	↓
: 20% moisture	Amaranth (<i>A. caudatus</i>)	↓	—	↑	↓		↑	↑
(30 min): 10% moisture	Amaranth (<i>A. caudatus</i>)	↑	—	↑	↑	↑	↓	↓
: 15% moisture	Amaranth (<i>A. caudatus</i>)	↓	—	↓	↓	↓	↑	↓
: 20% moisture	Amaranth (<i>A. caudatus</i>)	↓	—	↓	↓	↓	↑	↑
(60 min): 10% moisture	Amaranth (<i>A. caudatus</i>)	↓	—	↓	↑	↑	↓	↓

Type of starch modification	Type of pseudocereal starches	Pasting properties						
		viscosity					Pasting temp.	Pasting time
		Peak	Trough	Breakdown	Final	Setback		
: 15% moisture	Amaranth (<i>A. caudatus</i>)	↓	—	↓	↓	↓	↑	↓
: 20% moisture	Amaranth (<i>A. caudatus</i>)	↓	—	↓	↓	↓	↑	↑
4) HMT at 110°C; 20% moisture	Buckwheat	↓	—	↓	↓	↑	↑	—
: 25% moisture	Buckwheat	↓	—	↓	↓	↑	↑	—
: 30% moisture	Buckwheat	↓	—	↓	↓	↑	↑	—
: 35% moisture	Buckwheat	↓	—	↓	↓	↓	↑	—
5) Ball Milling Treatment	Buckwheat	↓	↓	↓	↓	↓	↓	↑
6 Drum Drying	Buckwheat	↑	↓	↑	↓	↑	↓	↓
Physico-chemical modification								
Acid hydrolysis + HMT	Buckwheat	↓	↑	—	↑	—	—	—

Table 2.
Pasting properties of modified pseudocereal starches in comparison with the native starches (refer Table 1).

amylopectin-amylopectin chains that lessen amylase leaching and decrease setback viscosity. From **Table 2**, it can be observed that all HMT of modified-amaranth (*A. caudatus*) starches and modified-buckwheat starches decreases in peak viscosity and breakdown viscosity as compared with native starch. It indicates that the modified starches are more stable as compared with native one. Meanwhile, Sindhu and his team [22] found the contradict results, which increase in peak, breakdown, and setback viscosity that reflects the poor stability of modified starches and starch retrogradation occurred. All physical treatments aim to modify the granular structure of native starch and convert it to cold-dissolvable starch or crystallization of starch.

The hydrothermal treatment of native starch reduced its ultimate viscosity at lower temperatures (85 and 100°C), but increased it significantly at higher temperatures (120°C). The eventual viscosity of all starch samples was lower than the peak viscosity, which could be due to some glycosidic linkage breakdown. In addition to the breakdown viscosity, the stability of starch pastes is determined by their breaking point, and higher breaking point values indicate inferior stability during continuous heating and shearing procedures in comparison to native starch. Except for acetylated starch, which showed a nonsignificant rise in setback viscosity when compared with native starch, all treated starches showed a substantial increase in setback viscosity. The largest setback viscosity was found in oxidized starch, and results from a freeze-thaw stability experiment confirmed this. Oxidized starch had the highest syneresis, while acetylated starch had the lowest. The setback viscosity varies depending on the amount of amylose leaching, the size of the granules, and the type of swelling granules. In this study, modified starch samples had an enhanced setback viscosity due to the waxy and low amylose characteristics of the amaranth starch used. Increases in pasting temperatures of heat-moisture-treated starches indicated that amylopectin chain connections were strengthening and interactions between them expanding. Starch pastes were statistically significantly reduced in pasting temperature and peak time as a result of acetylation and oxidation processes. Because the insertion of functional groups modulated the amorphous region and decreased the intermolecular hydrogen bonds, the pasting temperature of the starch granules was lower. Modification improves the application of modified starch in products where the thickening ingredient must gelatinize quickly at low temperatures by lowering the pasting temperature and peak time. The increased efficiency of such items also decreases the energy costs involved in their processing. As a consequence, acetylated and oxidized starches are usable in formulations that require low-temperature cooking/processing to obtain pastes [22, 28].

The effect of octenyl succinylation on the functional characteristics of *Amaranthus paniculatus* starch was investigated by Bhosale and Singhal [29]. The swelling power, paste clarity, freeze-thaw stability, enhanced viscosity, and lowered gelatinization temperature of OSA-modified amaranth starch were all improved. These findings suggest that OSA-modified amaranth starch could have applications in the food business, particularly in emulsification. Pal et al. [30] investigated the qualities of hydroxypropyl derivatives derived from *A. paniculatus* starch and discovered a considerable improvement in freeze-thaw stability, suggesting that it could be used as a thickening agent in frozen foods. All starches (amaranth/quinoa) had increased pasting viscosities following modification of octenylsuccinylate (OSA), but RVA profiles were affected in different ways. In contrast to native starches, OSA starches were found to paste at a lower temperature between 73.7 and 81.4°C. Due to the fact that OSA starches have loosely packed surface areas, resulting in lower pasting

temperatures, the OSA group produces spatial hindrance, which is responsible for weakening internal hydrogen bonds, which increases water absorption and lowers energy expenditure for gelatinization [23]. There might be additional influences on PT change from starch compositional aspects, such as the chain length of amylopectin, granule surface, and packing arrangement within the granules. As a result of the substitution of OSA on starch granules, the pasting qualities are also compromised. Peak viscosity can be defined as the water-holding capacity of starch granules in terms of swelling and shearing ability. Starches with high peak viscosity are suited for application as food thickeners, while a low percentage of OSA starch can replace higher levels of unmodified starch. Amylose content and long-chain fraction of amylopectin have been reported as major factors influencing peak viscosity [23, 24]. Modification of quinoa starch with OSA showed that a substitution degree of 3.21% is optimal for emulsifier formation and stabilization. A higher degree of substitution (4.66%) results in the aggregation of starch granules and the decrease of starch granule stable emulsion. In addition, OSA modification is more effective than heat treatment in providing hydrophobic characteristics to quinoa. The heat treatment is only slightly better than the natural starch granules [31].

Several studies have been reported about different physical modification methods in buckwheat starches, some of these are roasting process [32], microwave and annealing treatments [33], drum-drying and ball-milling treatment [24] high-pressure and high-temperature treatment [34], heat moisture treatment and annealing [24], hydrothermal processing [35], autoclaving/cooling [36], and others. The duration and quality of the gelatinization process as well as the viscosity and behavior of the gelatinization also change in nearly identical ways, including decreased or increased pasting viscosity, increased or decreased swelling power and solubility, increased retrograded starch content, increased gelatinization temperature, and slower digestion of the gelatinization [37].

3. Application of enzyme in pseudocereals

Enzymes are necessary for the production of compounds from grains that are used in contemporary foods and beverages. Enzymes have been identified as having the ability to improve the processing behavior or qualities of cereal and pseudocereals meals such as flavor, texture, and shelf-life with minimal impact on nutritional content [38].

Grain contains endogenous and exogenous enzymes. Endogenous enzymes are found naturally in grain kernels and are primarily found in the outer layer, fiber, and bacteria. Meanwhile, exogenous enzymes are created by bacteria on the surface. These enzymes influence grain raw materials quality and processing properties, mainly when humidity and time are present. Some enzymes are found in cereals, are frequently of microbial origin, and are given as pretreatment and manufacturing agents. Enzymes can contribute significantly by increasing the usage of raw materials and improving the impact of food and beverages [39]. **Table 3** shows the benefits of exogenous and endogenous enzymes in the diet. In general, both exogenous and endogenous enzymes influence the quality of the pseudocereal grains as listed in **Table 3** below. Apparently, the existence of endogenous enzyme gives a huge impact on the physical-chemical properties of pseudocereal grain compared with exogenous enzyme.

Exogenous enzymes	Endogenous enzymes
<ul style="list-style-type: none"> • To boost the nutritional value • Modify and improve nutritional quality by allowing starch and non-starch components to interact. • Microbial origin • Reducing the availability of digestive enzymes and, as a result, the pace of starch digestion 	<ul style="list-style-type: none"> • Reducing the availability of digestive enzymes and, as a result, the pace of starch digestion • Increase nutritional value and palatability by manipulating the main biological macromolecules, such as carbohydrates, lipids, proteins, nucleic acids, and simple molecules such as vitamins, amino acids, and sugars. • Catalyzing natural reaction during germination and sprouting • Provides taste to the mix, which affects sensory characteristics • Involve the grain's raw material's quality and processing qualities • Deteriorate the processing characteristics of flour and other grain products • Capable of altering cereal structure and functional qualities

Table 3.

The advantages of exogenous and endogenous enzymes in food [38, 40, 41].

The areas of enzyme in grain processing are pervasive in terms of raw material and enzyme-catalyzed processes. The most important contemporary sectors involving enzyme treatment of grains are energy supply, bioethanol, biomaterials, digestible films, and sustainable biomass utilization. The enzymes work with polysaccharides and proteins to control and use starch structure, which is significant in the food and beverage industries [42].

3.1 The involvement of enzymes in seed germination

Seed germination is a phenomenon governed by various mechanisms required to transform a seed into a new plant. The mature seed includes the necessary components to participate in the processes that control germination, including the enzymes that will aid in the process. Germination demonstrates the nutritional value and availability of proteins and amino acids while decreasing the amount of anti-nutritive substances [43]. Enzymes help restore broken DNA during the drying and germination of the grain, resulting in proper seedling growth.

Unrefined cereal crops need a variety of pretreatment processes, including the use of enzymes in addition to standard techniques. By altering the molecular structure and the amount and quality of nutrients, phytochemicals, and harmful compounds, enzyme pretreatment improves processability, safety, stability, or technical and nutritional utility [43]. For example, enzymes can reduce mycotoxin levels by bio-transforming mycotoxin into harmless metabolites [38].

Research demonstrated that enzymatic mycotoxin destruction depends on the enzyme-producing source, its concentration, and the circumstances used [44]. Susanna and Prabhasankar [45] developed an outstanding quality hypoimmunogenic pasta using a blend of xylanase, protease, and transglutaminase, which might be a gluten-free alternative [45, 46] and showed the use of enzymes in cereal grain polishing. Depolymerization of bran carbohydrates happens due to cell wall degrading enzymes in this process, altering phenolic mobilization and dietary fiber solubilization. Carbohydrate-cleaving enzymes, such as cellulases (e.g., endoglucanase, exoglucanases, and beta-glucosidase), xylanases, glucanases, and esterases, undertake enzyme biopolishing [46]. **Table 4** shows the enzymes utilized and the progress

Substances	Enzymes	Improvement
Nutrition's level	<ul style="list-style-type: none"> • Hemicellulases 	Soluble dietary content is increased
Quality	<ul style="list-style-type: none"> • Amylases • Proteases • Glucose oxidases • Hemicellulases • Lipoxygenases 	Balancing the change of recipe, replacement of potassium bromates, sodium metabisulfite, emulsifier, vital gluten, and fat baking reduction
Taste	<ul style="list-style-type: none"> • Amylases • Proteases • Lipoxygenases • Lipases • Glucose oxidases 	Fermentation substrates production and aroma precursors
Color	<ul style="list-style-type: none"> • Amylases • Hemicellulases • Lipoxygenases 	Brownish, crust color improvement and bleaching effects
Surface structure	<ul style="list-style-type: none"> • Hemicellulases • Amylases • Proteases • Lipases 	Smoother particles,
Strength	<ul style="list-style-type: none"> • Amylases • Hemicellulases 	Freshen up, anti-evaporate, longer life span
Size/volume	<ul style="list-style-type: none"> • Amylases • Hemicellulases • Cellulases • Lipases 	Larger size/volume

Table 4.
The types of enzymes used and the improvement toward pseudocereals [38].

toward pseudocereals. In general, these enzymes have been used in improving nutrition level, quality, taste, color, surface structure, strength, and size. Apparently, amylases and hemicellulase are the two enzymes that are important for pseudocereal improvement. The taste and quality of pseudocereal as shown in **Table 4** were affected by the same group of enzymes, namely amylases, proteases, glucose oxidases, hemicellulases, and lipoxygenases.

3.2 Fermentation in pseudocereal processing

Fermentation is an ancient and cost-effective way of generating and storing foods that may be applied to grain processing. Fermentation is the process that releases energy by oxidizing carbohydrates without the need of an external electron acceptor. Most of the time, enzymes are required in the fermentation process to speed up the reaction. For example, alcohol cannot be produced without the enzyme amylase, which breaks down starch into simple sugar. Moreover, fermentation is impossible

without enzymes. Fermentation is one of the oldest and most cost-effective methods of food preservation and processing. Due to the enzymatic degradation of antinutritional compounds such as phytate, fermentation enhances the availability of particular amino acids, B vitamins, and minerals, including iron, zinc, and calcium [42]. Certain antinutrient substances in pseudocereals such as phytic acid, polyphenols, and protein inhibitors could negatively impact on malnutritions [47]. Fermentation with Lactic Acid Bacteria (LAB) can increase pseudocereals' nutritional and functional qualities [48].

Cereal and pseudocereal fermentation is critical in the creation of chemicals that have a significant impact on organoleptic features such as scent, taste, and texture as well as the enhancement of nutritional values, all of which have a good impact on human health [47]. Microorganisms may be found in practically every biological niche; cereals and pseudocereals generally provide an excellent substrate for microbial fermentations. Polysaccharides are abundant, which microorganisms may use as a carbon and energy source during fermentation. Fermented items made from common cereals and pseudocereals are ubiquitous worldwide [48]. LAB, enterobacteria, aerobic spore formers, and other microbiota fighting for resources are typical in cereal and pseudocereal grains. The pH value, water activity, salt concentration, temperature, and food matrix composition all influence the kind of bacteria present in each fermented meal [48].

4. Functional and health benefit offered by pseudocereal

Approximately 80% of the human diet is composed of cereals such as corn, wheat, and rice. These grains are biofortified in order to boost vitamin and other essential micronutrient levels. However, pseudocereals, which are naturally enriched with a lot of essential micronutrients and nutraceutical ingredients, are not well utilized for its functional and health benefits to the human.

Pseudocereals are a novelty in human diets as they are gluten-free (GF) grains with a high nutritional and nutraceutical value. Additionally, recent research suggests that pseudo cereals may have health benefits, placing these crops in the role of important resources for the development of functional foods [4]. Protein quality and quantity in pseudo cereals are considerably superior to cereal quality and quantity, so they can be considered functional foods. In addition to amino acids such as arginine, tryptophan, lysine, and histidine, pseudocereals are rich in essential amino acids for infant and child nutrition, rendering them useful as food supplements. Protein nutritional quality can be measured using several parameters including protein efficiency ratio (PER) or net protein use (NPU), digestibility and bioavailability of protein, and availability of lysine. Pseudo cereal protein levels are thus larger than cereal protein levels and comparable to casein levels. Proteins of pseudo cereals are similar to those of legumes, since they have 2S albumin, 11S globulin, and 7S globulin. Furthermore, pseudocereal proteins are acceptable for celiac disease patients due to their low prolamine level [49].

Buckwheat is gaining popularity as a potential functional food due to its health-promoting components such as phenolic compounds and sterols. It is a good source of protein, dietary fiber, fat, and minerals [50]. Foods that give specific health benefits (health claims) exceeding their nutritional worth are referred to as functional foods, although their intake is not required for humankind [51]. Several biological and health benefits can be attributed to the consumption of buckwheat and

buckwheat products, including hypocholesterolemic, hypoglycemic, anticancer, and anti-inflammatory properties. These health benefits are said to be, at least in part, attributed to buckwheat proteins and phenolic compounds [52]. Some of these health advantages may be due to the antioxidant activity of these compounds, but recently identified mechanisms of action may also be related [53, 54]. Despite pseudocereals' composition and properties, there are still relatively little *in vivo* studies and limited human trials supporting its functional benefit. Most studies have linked consumption of pseudocereals or their bioactive components to a protective effect against obesity, prediabetes, and diabetes complications. Thus, the rat plasma ghrelin levels were reduced while postprandial leptin and cholecystokinin levels increased after consuming amaranth-protein-based diets [55]. Amaranth protein also modulates the microbiota composition of mice with obesity induced by diet [56]. In addition, a streptozotocin-induced diabetes model revealed that amaranth protein improved glucose tolerance and boosted plasma insulin levels [57]. In Wistar rats and spontaneously hypertensive rats, protein hydrolyzates showed significant antithrombotic effects [58] and antihypertensive [59].

For 6 weeks, rats fed with high-fat diet showed a lowering of cholesterol and a reduction of inflammation caused by tartary buckwheat protein, as well as changes in the animals' microbiota [60]. In obese diabetic mice [61] and Wistar rats [62], quinoa intake prevented hyperglycemia, decreased total cholesterol, and decreased LDL cholesterol. Recent research has demonstrated that quinoa can also modulate inflammatory biomarkers in the liver as well as dwindle hepatic steatosis and cholesterol accumulation. Furthermore, there has been evidence that quinoa phytoecdysteroid-enriched extracts reduce adipose tissue, regulate gene expressions involved in fat storage, and attenuate inflammation and insulin resistance in a mouse model with diet-induced obesity [63]. The scientists also found an increase in glucose oxidation and fecal lipid discharge without influencing stool sizes, in addition to an increase in energy expenditure without modifying food consumption or activity [64].

Until recently, there have been relatively few human studies evaluating the benefits of pseudocereals. Ruales et al. [65] mentioned that two times a day administration of 100g of quinoa to 50–65-month-old boys living in low-income Ecuador increases plasma insulin-like growth factor (IGF-1). Therefore, quinoa-enriched baby food is able to prevent child malnutrition by providing sufficient protein and other essential nutrients. Additionally, supplementation of the diet with quinoa has shown to impact cardiovascular and metabolic parameters in both healthy [66] and overweight and obese people [53, 67, 68].

5. Conclusions

Various fields of study are currently being conducted, from its functional and rheological properties as well as enzyme immobilization and its application. Pseudocereal is suitable for use in a wide variety of food applications since it is packed with nutrients, consists of promising health benefits promoter, and is a source of energy. Furthermore, ongoing research into rheological modification of resistant starch could offer a number of possibilities and make it a possible source for use in the food sector, resulting in a substantial impact on food sustainability. Although research on the substances obtained from pseudocereal could be conducted, safety factors should be addressed in order to develop health-related food products.

Conflict of interest

The authors declare no conflict of interest.

Nomenclature

Gluten-free	GF
Rapid Visco-Analyzer	RVA
Brabender Amylograph	BA
Octenylsuccinylate	OSA
Heat moisture treatment	HMT
Lactic Acid Bacteria	LAB
Protein efficiency ratio	PER
Net protein use	NPU
Insulin-like growth factor	IGF-1

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