Grain Proteins: Challenges and Solutions in Developing Consumer-Relevant Foods

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ABSTRACT

Plant proteins are gaining popularity as an animal-free alternative for food and beverage formulations. Proteins from pea, wheat, corn, and rice are the most commonly used proteins derived from cereals and pulses. Consumers' desire to incorporate more protein from plant foods in their diets is driven by increasing awareness and perceptions around health, animal welfare, and sustainability. Use of proteins from grains as functional ingredients in food and beverage formulations by industry stakeholders continues to trend upward. While grains represent an efficient source of plant protein ingredients, their incorporation into innovative and reformulated foods is often required at levels that will resonate with consumers or align with initiatives that meaningfully enhance the health and sustainability profile of a food product. Higher incorporation rates of cereal-based proteins in some platforms can be challenging because of unfamiliarity with and lack of information on their functional and hedonic properties in some food matrices. However, several innovative strategies have been developed to mitigate off-flavors and enhance functionality, particularly when grain proteins are used to substitute for animal proteins in animal-free products. This review discusses novel technologies and methods that have been used to enhance the quality of foods that incorporate proteins from grains and expedite innovation across food platforms. Research in this space continues to elucidate the functionality of grain proteins for developing healthy and tasty protein-rich foods.

Introduction to Grain Proteins

Plant protein markets are expected to experience a compounded annual growth rate of 8.1% from 2019 to 2025, with North America holding the largest share of the market (35). Interest in cereal and pulse proteins is largely driven by consumers' interest in health and well-being, as well as concerns over animal welfare and sustainability. From a population perspective, policy makers and non-governmental organizations (NGOs) have highlighted the need for increased reliance on plant proteins to sustain a growing population while preserving the environment and slowing climate change (3,61). As potential sources of plant proteins, grains hold the largest share of the plant protein market. Proteins derived from cereals (wheat, rice, and corn) and legumes (soy and pea) (35) continue to be popular ingredients for the development of high-quality, high-protein consumer-relevant foods (11,22,26). Nevertheless, incorporation of grains as a significant source of protein can present challenges during various stages of food development and can negatively affect the quality of food products, particularly when used as an alternative to animal proteins or in animal-free products (41,51).

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This review highlights prominent challenges experienced when developing foods with high levels of protein from grains at various stages of food development. Technological advances and strategies that have been used to address hedonic and functional issues often experienced when developing foods with grain proteins are also discussed.

Extraction of Grain Proteins

To use grain ingredients as sources of plant proteins, the proteins from raw ingredients are often extracted to provide a more concentrated product. Wet-extraction and dry-fractionation are both employed for the isolation of proteins from cereals and pulses. Industrial extraction of grains to attain isolate levels of protein typically utilizes wet-extraction methods. As illustrated in Figure 1, wet-extraction starts with subjecting finely milled (and defatted, dehulled and/or debranned, depending on the grain) flour to alkaline or acidic conditions to solubilize proteins (1). After centrifugation to remove insoluble material (e.g., starch and fiber), the solubilized proteins may be concentrated by isoelectric precipitation, washed, and centrifuged again to remove soluble material (e.g., sugars, soluble fibers, and fats). Proteins are then neutralized and dried to obtain protein isolates with high purity (90%) (38,54). However, the use of chemical solvents and thermal treatments in this process may affect protein functionality by altering the structure (24,64). In addition, this process requires high amounts of water and energy and generates high levels of waste products, which can negatively affect the environmental footprint of the ingredient and final food product (14,44). To overcome both functional and environmental drawbacks, several innovative pre- and postprocessing techniques have been developed (Table I).

Characteristics of Grain Proteins

Due to their high prevalence of consumption in the daily human diet cereals are valuable sources of proteins despite their low quality and digestibility. Gluten, zein, and rice proteins are the most commonly used proteins in food and beverage formulations because of their techno-functional properties. Gluten has a high concentration of sulfur-containing amino acids and plays an important role in the water absorption capacity, cohesiveness, viscosity, and elasticity of doughs (37). However, for consumers who are genetically predisposed, gluten is related to a wide spectrum of diseases, such as celiac disease and gluten sensitivity (49). Rice proteins contain all of the essential amino acids, with high amounts of cysteine and methionine, although their native forms have low solubility and emulsifying properties (18). Rice proteins are hypoallergenic and rich in bioactive peptides (5). Zein is a storage protein derived from corn, and although it is rich in sulfur-containing amino acids, it lacks sufficient amounts of tryptophan and lysine (16). Zein has low water solubility and high capacities in emulsion and foam stability and film forming (9,13,56).

Soy protein is the most marketed plant protein isolate and provides a relatively well-balanced amino acid composition along

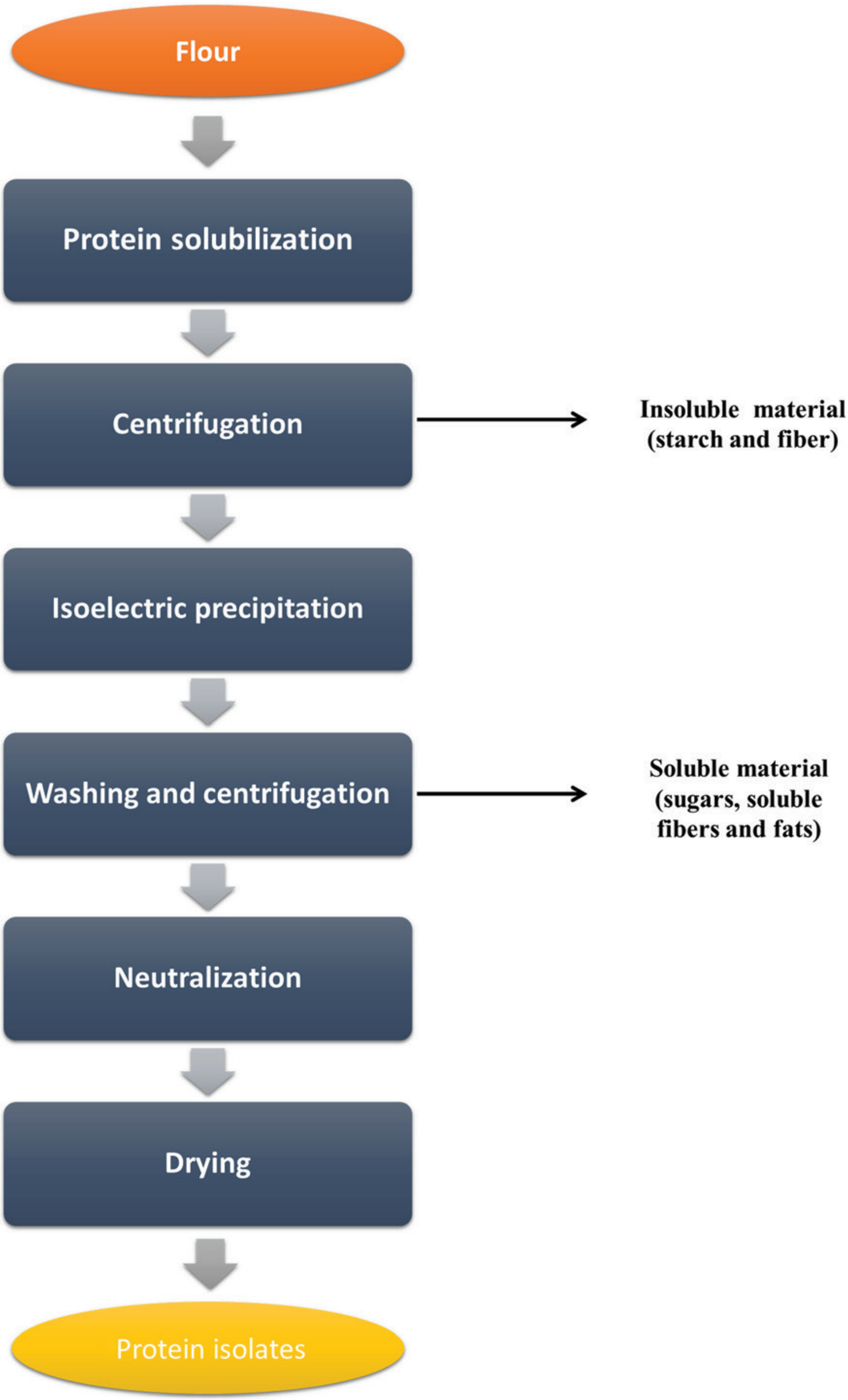

Fig. 1. Wet-extraction of grain protein (38,54).

Table I. Innovative processes for grain protein purification

Process	Advantages	References
Electro-acidification and ultrafiltration	Improves protein purity and protein isolate solubility	36
Single-frequency ultrasound	Improves rove protein isolate solubility and emulsifying capacity and stability	23, 31
Multi-frequency ultrasound	Improves rove protein structure and functionality and reduces extraction time	17, 47, 62
Supercritical carbon dioxide	Green technology; removes bitterness and carotenoid compounds; and lightens the color of protein	58
Enzymatic extraction assisted by microwave or vacuum processing	Improves protein functionality and bioactivity of antioxidant compounds	19
Lactic acid fermentation	Decreases flavor; reduces antinutrients; and increases bioactive peptides	12, 63
Solvent treatment	Enhances structure and decreases flavor retention	59
Acetylation and succinylation	Enhances structure and decreases flavor retention	60

with bioactive peptides (20). Soy proteins provide high gel-formation capabilities, as well as emulsifying, solvent holding, and film-forming capacities (6,29). Pea protein use is on the rise as a less allergenic alternative to soy protein, offering good emulsification and foaming properties (53). Other grain proteins are also gaining traction, including sweet lupin and fava proteins. Sweet lupin is a low-cost source of proteins with a protein content similar to that of soy, and its derived bioactive peptides are associated with several health-related benefits (e.g., hyperglycemia, hypertension, and cholesterol lowering) (7,8,27,33,39,48). Studies have been carried out to enhance lupin protein functionality (e.g., solubility, emulsification, and foaming activity) through the application of proteolytic enzymes in order to match that of soy (50). Fava is another sustainable and low-cost source of protein that is particularly rich in lysine and threonine and has high protein digestibility (42).

Enriching Foods with Grain Proteins: Opportunities and Challenges

In meat-analogue applications, soy and gluten play crucial roles in creating a fibrous structure due to their binding and film-forming capacities (51). Pea protein is increasingly being used as a substitute for soy protein due to consumer concerns about perceived issues, including genetic modification of crops and the presence of estrogen-like compounds. However, use of pea protein may result in a weaker structure, thereby requiring the addition of other ingredients (e.g., gluten) to reinforce and stabilize the fibrous structure of meat analogues (51).

The addition of grain proteins can increase total protein and amino acid contents in beverages (4). In infant formula, the partial substitution of whey protein with 50% grains proteins resulted in a beverage with protein digestibility similar to milk (42). However, the quality of the final product was closely associated with process parameters. Alternative dairy-free beverages enriched with soy and pea proteins are characterized by a distinct grassy or beany flavor (52,57). Additional studies will be useful for further product development to optimize processing to ensure quality and stability during storage based on the specific grain protein selected.

In bread, vital wheat gluten is commonly added to weak wheat flour (i.e., low-protein flour) to improve the strength of the protein network in the dough and, thereby, enhance the properties of the bread, including yield, volume, texture, color, and sensory properties (10). The incorporation of nongluten proteins at up to 10% has been found to improve both the protein quantity and quality of bread; however, incorporation at more than 15% weakened the gluten network of doughs and hindered bread quality (21,65). In gluten-free breads, the addition of protein at up to 2% enhanced dough rheological properties and bread quality (i.e., specific volume, sensory quality, nutritional quality, and digestibility) (34,45). However, protein additions at more than 10% resulted in breads with darker color, lower volume, and greater hardness than the control (46).

Gluten-free pasta enriched with grain proteins (up to 10%) had enhanced structure, texture, cooking quality, and sensory properties and reduced the digestibility of the final product (15,28,30,40,42). However, at more than 12% zein resulted in excessive water absorption and firmness (25).

Cookies made by substituting up to 30% wheat flour with grain proteins resulted in increased water absorption and spread, whereas up to 15% did not hinder texture and overall acceptability (55). Likewise, gluten-free biscuits formulated by substituting rice flour with soy or pea protein at levels up to 20% were well accepted by consumers; however, higher levels hampered the quality of biscuits (dark color and hard texture) and, thereby, lowered the overall acceptability of the enriched products (2,32).

Conclusions

The information provided in this article is a brief summary of the recently published research focused on formulating with grain proteins. Although plant proteins are becoming a desirable choice for consumers and food manufacturers, there are still challenges that arise when using these ingredients. Consumer interest in plant-based proteins and products is driving the development of novel solutions to enable the use of these higher protein ingredients. Breakthroughs in understanding off-flavor mechanisms and new manufacturing techniques will breed the next generation of ingredients to improve on current plant-based replacements for animal proteins. These improvements can lead the way in furthering consumer acceptance, leading to higher demand for additional plant-based products.

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