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The Role of Cereal and Pulse Constituents and Processing Technology in Flake Texture Development: a Review

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Abstract. To meet the rising consumer demand for higher nutrition foods and to increase flake nutritional value and functionality, it is possible to combine cereals with pulses. For consumers, one of the most important quality parameters along with appearance and taste, is texture. To produce the appropriate quality of flakes, the knowledge about the relationship between chemical composition, processing parameters, and texture is necessary. The aim of this study was to characterise the role of cereal and pulse constituents and processing technologies in flake texture development, which could be used in flake production for achieving the appropriate hardness and crunchiness of new products. The monographic method was used to characterise the constituent and processing technology`s role in cereal and pulse flake texture development. Information published from 2003 till 2022, in total 77 full text research articles, books and databases were analysed and summarised. Data analysed show if pulse and cereal nutritional information, mineral and vitamin content is known, it is possible to combine different cereals and pulses to provide a specific nutrient composition in the developed products. The main change in high starch products is a specific gelatinization and retrogradation behaviour of starch. Constituents such as lipids and proteins as well as processing technology and parameters, can significantly modify the properties and functionality of starch. Proteins can encapsulate starch granules, inhibit starch digestion and gelatinization, reduce starch structural order, and inhibit starch retrogradation.
Key words: cereal, chemical composition, flake texture, pulse, starch gelatinization.

Introduction

Breakfast cereals are processed foods usually produced from different cereal grains such as oats (*Avena sativa* L.), wheat (*Triticum aestivum* L.), rye (*Secale cereale* L.), rice (*Oryza sativa* L.), maize (*Zea mays* L.), and others. Ready to eat cereals are consumed with milk, milk alternatives or juice. One of their quality factors along with appearance and taste is the texture. Consumers appreciate crunchy and crispy products, whereas they reject too hard or soggy textures (Robin & Palzer, 2015). It is estimated that during the period from 2021 till 2026, the breakfast cereal market will have an annual growth rate of 4.78% (Mordor Intelligence, 2022). In addition, the demand for foods of high nutritional value is rising (Perdon, Poutanen, & Schonauer, 2020). For this reason, it is necessary to produce high quality, nutritious, and functional foods. To increase flake nutritional value and functionality, it is possible to combine cereals with pulses. Carbohydrate, fat, niacin, riboflavin, thiamine, and vitamin B_6 content is similar in cereal grains and pulses, whereas protein, folate, iron, magnesium, and zinc content in pulses are higher compared to cereals. Seeing that pulses have a beneficial nutrient composition, it is reasonable to combine and partly replace cereal grains with pulses (Marinangeli *et al.*, 2017).

To produce the appropriate quality of flakes, knowledge about the relationship between chemical composition, processing parameters, and texture is necessary. Processing can have either a positive or negative impact on flake texture. Fundamental changes can happen at microstructural and macrostructural levels (Huang & Perdon, 2020). Such constituents as starch, fibre, protein, fat, and moisture content influence cereal product texture (Salmenkallio-Marttila *et al.*, 2011). Product texture can be developed and changed during the flake processing steps such as steaming, cooking, flaking, drying, toasting, and extrusion. The aim of this study was to characterise the role of cereal

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and pulse constituents and processing technologies in flake texture development, which could be used in flake production for achieving the appropriate hardness and crunchiness of new products.

Materials and Methods

To characterise cereal and pulse constituent and the role of processing technologyin flake texture development, the monographic method was used. Information published from 2003 till 2022, in total 77 full text research articles, books and databases were analysed and summarised. For pulse and cereal nutrient and starch characteristics analysis FAO, FoodData Central and Fineli databases were used. To select and analyse full text research articles and books, Scopus, Web of Science, PubMed, ScienceDirect and ResearchGate research databases were used. The published data was used to compile available

Table 1

Proximate cereal and pulse composition

Nutrients	Cereals					Pulses		
	hulless oats	rye	wheat	white rice	maize	red kidney beans	red lentils	chickpeas
Carbohydrates, %	55.7-63.9 [1, 2]	57.1-76.3 [2, 6, 7]	52.9-61.3 [1, 2]	75.6-78.7 [1, 2]	62.2-83.8 [2, 10, 12]	35.6-64.8 [13, 14, 15, 17]	45.8-53.6 [2, 13]	46.4-49.5 [2, 13]
Starch, %	27.3-63.0 [3, 4, 5]	55.8-70.0 [2, 5]	50.3-58.2 [2, 5, 8]	70.8-75.2 [1, 2, 9]	53.2-83.2 [2, 5, 11]	25.0-45.0 [13, 16]	47.4-50.8 [2, 13]	36.4-43.8 [2, 13]
Total dietary fibre, %	9.0-30.2 [1, 2, 3, 4]	11.5-16.4 [2, 6]	9.9-13.3 [1, 2, 8]	1.3-2.3 [1, 2]	0.7-11.9 [2, 5, 10, 11, 12]	2.3-21.50 [13, 15, 17]	4.9-7.1 [2, 13]	10.7-12.2 [2, 13]
Protein, %	9.7-17.3 [1, 2, 3, 4]	9.6-12.9 [2, 6, 7]	12.9-13.2 [1, 2, 8]	6.1-7.1 [1, 2]	1.6-12.0 [2, 5, 10, 11, 12]	21.4-26.0 [13, 14, 15, 17]	23.8-25.3 [2, 13]	20.4-21.3 [2, 13]
Fats, %	5.2-12.4 [1, 2, 3, 4]	1.6-2.5 [2, 6, 7]	1.8-2.5 [1, 2, 8]	0.7-0.8 [1, 2]	1.4-5.7 [2, 5, 10, 11]	1.8-2.7 [13, 14, 15, 17]	1.3-2.0 [2, 13]	5.4-6.9 [2, 13]
Fe, mg 100 g^{-1}	4.7-5.5 [1, 2]	2.6-3.0 [2, 6, 7]	3.2-3.9 [1, 2, 8]	0.8-1.2 [1, 2]	0.9-2.7 [2, 12]	2.1-5.60 [13, 17]	5.5-7.6 [2, 13]	5.5-6.4 [2, 13]
Mg, mg 100 g^{-1}	160.0-177.0 [1, 2]	103.0-110.0 [2, 6]	121.0-137.0 [1, 2, 8]	25.0-34.0 [1, 2]	18.0-127.0 [2, 12]	140.0-164.0 [13, 18]	76.0-83.0 [2, 13]	130.0-160.0 [2, 13]
P, mg 100 g^{-1}	523.0-537.0 [1, 2]	298.0-332.0 [2, 6]	342.0-357.0 [1, 2, 8]	110.0-115.0 [1, 2]	60.0-210.0 [2, 12]	520.0-612.0 [13, 18]	320.0-360.0 [2, 13]	300.0-310.0 [2, 13]
Zn, mg 100 g^{-1}	4.0-4.1 [1, 2]	2.7-2.8 [2, 6]	2.6-3.0 [1, 2, 8]	1.1-1.3 [1, 2]	0.4-2.2 [2, 12]	0.8-3.3 [13, 17, 18]	2.7-3.1 [2, 13]	3.0-3.2 [2, 13]
Thiamine, mg 100 g^{-1}	0.3-0.8 [1, 2]	0.3-0.4 [2, 6]	0.4-0.5 [1, 2, 8]	0.05-0.07 [1, 2]	0.1-0.4 [2, 10, 12]	0.1-0.4 [13, 19]	0.4-0.5 [2, 13]	0.3-0.5 [2, 13]
Riboflavin, mg 100 g^{-1}	0.1-0.2 [1, 2]	0.1-0.3 [2, 6]	0.1-0.2 [1, 2, 8]	0.03-0.05 [1, 2]	0.1-0.2 [2, 10, 12]	0.2-0.3 [13, 19]	0.1-0.2 [2, 13]	0.1-0.3 [2, 13]
Niacin, mg 100 g^{-1}	0.8-1.0 [1, 2]	2.2-4.3 [2, 6]	5.0-5.1 [1, 2, 8]	1.6-2.8 [1, 2]	2.7-3.6 [2, 12]	2.3-3.0 [13, 20]	2.0-2.3 [2, 13]	1.5-1.9 [2, 13]
Vitamin B6, mg 100 g^{-1}	0.1-0.2 [1, 2]	0.3-0.4 [2, 6]	0.1-0.4 [1, 2, 8]	0.1-0.2 [1, 2]	0.1-0.6 [2, 12]	0.1-0.5 [13, 19]	0.5-0.6 [2, 13]	0.41 [2, 13]
Folate, µg 100 g^{-1}	38.7-56.0 [1, 2]	38.0-40.0 [2, 6]	44.0-87.0 [1, 2, 8]	8.0-20.0 [1, 2]	15.0-19.0 [2, 12]	130.0-394.0 [13, 18]	35.0-111.0 [2, 13]	180.0 [2, 13]

[1]Joint Research Centre, 2021; [2]Fineli, 2022; [3]Sterna, Zute, & Brunava, 2016; [4]Sterna et al., 2015; [5]Arendt & Zannini, 2013; [6]FoodData Central, 2019; [7]Nordlund et al., 2013; [8]Wieser Koehler, & Scherf, 2020; [9]Kumar et al., 2013; [10]Mühlbauer & Müller, 2020; [11]Michel et al., 2020; [12]Siyuan, Tomg, & Liu, 2018; [13]FAO, 2017; [14]Sarker, Chakraborty, & Roy, 2020; [15]Wani et al., 2017; [16]Punia et al., 2020; [17]Kambabazi et al., 2021; [18]Mullins & Arjmandi, 2021; [19]Margier et al., 2018; [20]Thani, Alu, & Yakubu, 2018

knowledge on the impact of such constituents as protein, starch, fat, and fibre and such processing technologies as steaming, cooking, flaking, drying, toasting, and extrusion on flake texture. To find relevant information, previously mentioned constituents and processing technologies as keywords in research databases were used.

Results and Discussion

To combine cereals with pulses, it is necessary to evaluate their nutritional value. Proximate chemical composition varies in the different most common cereals and pulses (Table 1).

Carbohydrate content in selected cereal grains varies from 52.9 till 83.8%, in pulses it varies from 35.6 till 53.6%. Cereal grains, especially maize, white rice, and rye, have the highest carbohydrate and starch content, compared to pulses. Pulses, especially red kidney beans (*Phaseolus vulgaris* L.) and red lentils (*Lens culinaris* L.), have the highest protein content. In pulses they vary from 20.4 till 26.0%, whereas cereal grains contain 1.6 till 17.3% of protein.

Fat content in selected cereal grains varies from 0.7 till 12.4%, whereas in pulses it varies from 1.8 till 6.9%. Oats and chickpeas (*Cicer arietinum* L.) have the highest fat content, whereas rice has the lowest fat content. The total dietary fibre, magnesium, phosphorus, and vitamin B content are highly variable in cereal grains and pulses. Compared to cereal grains, pulses have higher iron and folate content. If composition data is known, it is possible to combine different cereals and pulses to provide specific nutrient composition in the developed products. During processing, the physico-chemical properties of the constituents such as starch, proteins, lipids, and cell wall constituents change and they have a large effect on the texture of cereal products (Salmenkallio-Marttila *et al.*, 2011). Texture is an important quality factor not only for consumers but also for producers. Food texture can be described as expansion index, bulk density, hardness, crispiness, and crunchiness. A description of texture parameters and impact factors is summarized in Table 2.

The major constituent of cereal grains and pulses is **starch**, which is present in granule form. Starch granules are composed of systematically arranged amylopectin and amylose in various proportions (Huang & Perdon, 2020). During thermal treatment, starch interacts with lipids and proteins and undergoes structural changes that is the major determinant of flavour and texture of processed foods (Liu *et al.*, 2022). The processes of starch gelatinization and retrogradation are responsible for quality characteristics of high starch products (Chang *et al.*, 2021; Yan *et al.*, 2021). Gelatinization causes irreversible changes in starch properties due to a water-mediated disruption of molecular order in starch granules, amylose dissolution and diffusion. Starch gelatinization also involves an increase in viscosity, hydration and swelling, and a loss of crystallinity and birefringence. Intermolecular bonds in starch molecules are broken during gelatinization. The starch gelatinization temperature depends on the plant's origin, water amount, and salt concentration. The amount of water present in the system affects the integrity of starch granules during cereal processing. These changes determine the quality attributes of the finished product, especially its texture (Huang & Perdon, 2020). It can be seen that the level of starch gelatinization increases together with hardness (Taghinezhad *et al.*, 2016). On the other hand, the complex process of starch retrogradation starts after the gelatinized starch has cooled down. Then, due to a recombination of the high-energy disordered amylopectin and amylose chains into different structures which form crystals, a stable and ordered state is reached. Starch composition along with other ingredients such as water, proteins, lipids, and trace elements present in the matrix together with processing conditions, especially temperature, affect retrogradation time and patter. Three mechanisms: (a) the migration of amylopectin and amylose chains in the starch-water systems, (b) the water molecule redistribution, and (c) the recrystallization of gelatinized starch are responsible for the starch retrogradation process (Chang *et al.*, 2021). Retrogradation of amylose in processed starch-containing foods is important, such properties as an ability to absorb water, stickiness, and digestibility (Copeland *et al.*, 2009). The gelatinization temperature, granule size and amylose content of different cereal and pulse starches are shown in Table 3.

Another cereal and pulse constituent responsible for flake texture is **fibre**. Soluble dietary fibre, except gums and β-glucan, is known to have the lowest versatility for their impact on texture and lowest viscosity (R.S. Mehta & R. Mehta, 2014). Fibre reduces the expansion ratio, thus increasing the expanded product density and making it harder (Foschia *et al.*, 2013). Grain outer layer hydrolysis and softening can improve its flavour and texture, making bran more appealing to consumers. Such enzymes as cellulases, β-glucanases, and xylanases can depolymerise grain cell wall polysaccharides through hydrolyse (Poutanen, 2020).

The second major constituent of cereal grains and pulses is **protein**, which therefore, plays an important role on food quality. To meet rising the consumer demand for higher protein foods and to improve starchy food protein content and composition, cereals and pulses are combined. Plant proteins mainly consist

of globular proteins such as albumins, globulins, prolamins, and glutelins. In all pulses (>50%) and some pseudocereals such as quinoa (*Chenopodium quinoa* L.) and amaranth (*Amaranthus cruentus* L.), the main part is made of albumins and globulins. Wheat, barley, maize, and rye prolamins and wheat glutelins make up to 85% of cereal proteins. The high temperature causes the unfolding of proteins due to a hydrogen bond breakage. With a further increase in temperature, the intramolecular disulphide bonds are broken down, forming new intermolecular bonds such as hydrogen, disulphide or hydrophopic, which leads

Table 2

Description of texture parameters and impact factors

Texture parameter	Description	Effect of parameters and constituents
Crispiness	Can be defined as the force of the first distinct break on the deformation curve of flakes. It can be affected by water activity present in the material. [1]	• If water activity is higher than 0.3, a decrease of force is observed. [1] • Extruded cereal flours lose their crispy texture and shrink due to the moisture plasticisation. An addition of sugars would be expected to increase product crispiness. [6] • Toasting increases maize flake thickness and develops a porous microstructure. Sufficiently thick cell walls (20–50 μm) support large pores (up to 100 μm) during toasting, appearing to possess a crisp texture. [7]
Expansion	Can be characterised on cool and dimensionally stable products. Expansion parameters are derived from bubble growth up until maximum size and from the following contractions. During the food extrusion-cooking process, the extrudate expansion is fundamentally important. [2]	• Moisture is the main factor affecting extrudate expansion. [2] • Processing parameters such as die type, screw speed, and temperature have an important effect on extruded product expansion. [2] • Highest extruded pellet volume can be obtained with lowest feed moisture content (27%) and highest extrusion temperature. [8] • Increased protein and fibre content decrease extruded snack expansion ratio. [9] • Insoluble fibre significantly reduces extruded product expansion volumes, increase density and lead to harder texture. [10] • Soluble fibre leads to better expansion volumes and affect extruded product bulk density less than insoluble fibre constituent. [10]
Bulk density	A mass of the particulate product per unit volume, which they occupy. [3]	• Product density is mainly affected by product moisture content and processing parameters such as screw speed, temperature, and time. [2] • It is closely related to the hardness of cellular materials. This could be affected by amylase action on starch and changes in its crystallinity during cooling. The resulting network together with thermoset gluten contributes to the initial hardness of flakes. [4] • Physical properties as size influence flake volume. [11]
Hardness	Can be described as a maximum force on the deformation curve. [4]	• Flake hardness can be impacted by water activity. If water activity is above 0.5, an increase of force is observed. [1] • Increased fibre content can also increase product hardness. [6] • Product hardness variation correlates with starch-associated proteins. [12]
Crunchiness	Can be described as number of peaks on the deformation curve. [5]	• Mainly it depends on moisture content and water activity. The higher the moisture content and water activity in the product, the lower the crunchiness. [13] • Crispiness, hardness, and crunchiness are related. If extruded products have lower hardness and crunchiness, they have higher crispiness. [5, 14]

[1]Lewicki Marzec, & Kuropatwa, 2007; [2]Ajita, 2018; [3]Changmai & Purkait, 2021; [4]Lemmens et al., 2021; [5]Costantini et al., 2021; [6]Kaletunç & Breslauer, 2003; [7]Sumithra & Bhattacharya, 2008; [8]Zambrano et al., 2022; [9]Korkerd et al., 2016; [10]Robin, Schuchman & Palzer, 2012; [11]Rolls et al., 2014; [12]Autio & Salmenkallio-Marttila, 2003; [13]Tunick et al., 2013; [14]Smith, 2003

Table 3

Proximate gelatinization temperature, granule size and amylose content of different cereal and pulse starches

Starch characteristics	Cereals					Pulses		
	hulless oats	rye	wheat	white rice	maize	kidney beans	lentils	chickpeas
Gelatinization temperature, ˚C	53–67 [1, 2]	51–64 [1, 3, 4]	51–86 [1, 3, 5, 6]	68–83 [1, 5]	73–85 [5, 7]	64–79 [8, 9]	58–85 [5, 7, 9]	72–81 [7, 10, 11]
Starch granule size, µm	3–10 [1, 7, 12]	23-40 [1, 3, 4]	20–35 [1, 3, 9]	3–8 [1, 7]	7-20 [9, 13]	13-52 [14, 15]	14–32 [9, 14]	10–30 [10, 14]
Amylose, %	14–24 [9, 12]	22–25 [3, 4]	22–31 [5, 7]	17–24 [5, 9]	24–31 [5, 7, 9, 13]	17–37 [9, 15]	20–46 [5, 7, 9, 16]	28–35 [10, 11, 14]

[1]Delcour & Hoseney, 2010; [2]Kumar et al., 2022; [3]Gomand et al., 2011; [4]Autio & Eliasson, 2009; [5]Liu et al., 2019; [6]Kalnina, Rakcejeva, & Kunkulberga, 2015; [7]Ren et al., 2021; [8]Punia et al., 2020; [9]Zhou et al., 2013; [10]Zhang et al., 2019; [11]Kaur & Singh, 2007; [12]Berski et al., 2011; [13]Joshi et al., 2013; [14]Pelgrom, Boom, & Schutyser, 2015; [15]Demiate et al., 2016; [16]Lu et al., 2018

to protein aggregates (Sim *et al.*, 2021). An increased screw speed results in a gradual increase in expansion and softer extrudates possibly due to less protein aggregation and a larger fragmentation of protein, larger starch gelatinization, a higher starch content, and molecular fragmentation (Lee *et al.*, 2006). An interaction of starches and proteins having different functional properties in processed foods are often providing their structure. Proteins encapsulate starch granules, inhibit starch gelatinization and digestion, reduces starch structural order and inhibits starch retrogradation (Zhang *et al*., 2021). Van der Waals, electrostatic, hydrophobic, and hydrogen bonds are primarily regulating protein and starch interaction. Concentration, pH, molecular weight, ionic strength, macromolecule nature, and temperature affects the starch and protein system. The interaction of protein and starch is strengthened by gluten, whereas it is weakened by soybeans (*Glycine max* L.) and field beans (*Vicia faba* L.) possibly due to their hydrophilic nature, causing competition between the wheat protein and starch for water. Adding sucrose esters or surfactants can minimise this effect. Sugar and sugar alcohols may increase the enthalpy and gelatinization temperature. A large number of hydroxyl groups in molecular structures of trisaccharides and disaccharides contributing to starch interactions have a higher impact on the gelatinization temperature compared to monosaccharides (Quiroga Ledezma, 2018).

Amylose complexes with **lipids**, especially with monoacylglycerides, monoacylglycerides, and fatty acids can significantly change the functionality and properties of starch. The complex formation reduces water solubility of starch, decreases swelling capacity, resulting in a gelatinization temperature increase, retarded retrogradation, and a reduced susceptibility to enzymatic hydrolysis. The variation ability of

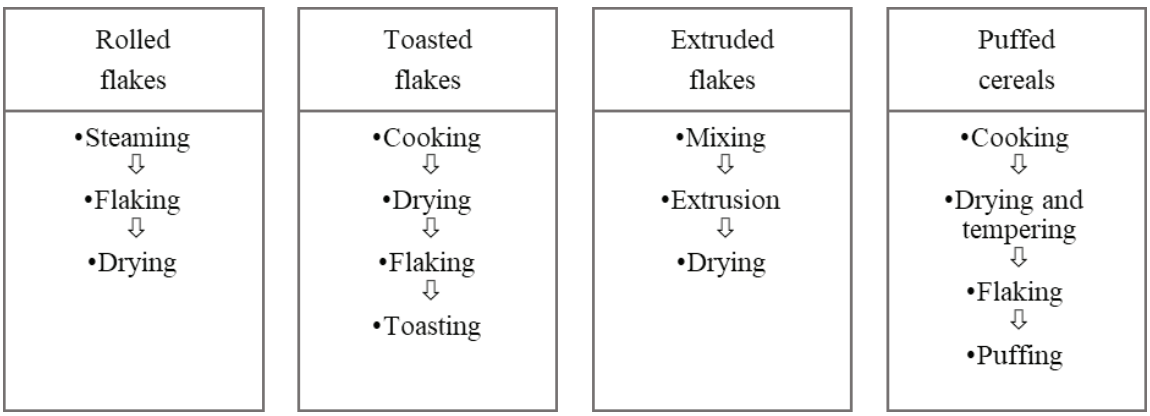


Figure 1. General overview of the main processing steps in flake production (Fast, Perdon, & Schonauer, 2020).

starch to bind lipids depends on the amylose to amylopectin ratio (Copeland *et al.*, 2009). The starch systems containing high lipid content possess higher a gelatinization temperature. During cooling and storage, the water holding capacity of processed foods and retrogradation of amylose and amylopectin undergo changes. However, it is diminished if lipids interact with crystallisation process in the system (Quiroga Ledezma, 2018).

There are different cereal and pulse flakes available in the market. They can be prepared using different technologies. A general overview of the main cereal and pulse flake processing operations can be seen in Figure 1.

Rolled, toasted flakes, and puffed cereals are produced from wholegrains. Extruded flakes are usually produced from flour mixes. Rolled flake production includes three main steps – steaming, flaking, and drying. After cleaning and de-hulling, grains are steamed at around 80 to 110 °C (Gates *et al*., 2008a) to ensure optimal product preparation prior to flaking. After steaming, grains are flaked and then dried to ensure required a moisture content of around 10 to 12%. Toasted flake production includes four main steps – cooking, drying, flaking, and toasting. Cleaned and dehulled grains are cooked with steam under pressure. Cooking is normally done at 1.0 till 0.125 MPa, for two hours with 1 to 4 rpm speed. The moisture content of cooked mass should not be more than 32%. During cooking, grains turn from chalky white, hard to light, soft and translucent due to starch gelatinization. Cooked grains are dried to their desired moisture content and then flaked. Later, flakes are toasted in a hot airstream and carried through the oven by a vibratory belt. The entering flakes should have a moisture content of around 10–14% to perform blistering and puffing of flakes during toasting. Usually, the moisture content of finished products ranges from 1.5 to 3% (Fast, Perdon, & Schonauer, 2020). The extruded flake production consists of three main steps – mixing, extrusion, and drying. The formation of extruded flakes consists of an extrusion of mixed flour ingredients through a die hole and cutting of at a certain length. After extrusion, flakes are dried to the desired moisture content. In the extrusion processes, products are treated for a short time (< 1 min) at a high temperature (~150 °C). The initial moisture content of dry material before the extrusion process is around 12%, which is increased to 20–25% in the hydration process, allowing the material to overcome the glass transition line. After extrusion product moisture content is below 10%. (Fast, Perdon, & Schonauer, 2020). Puffed cereal processing has four main steps – cooking, drying and tempering, flaking, and puffing. It starts with pressure cooking, followed by drying and tempering. At first, grains are dried and then tempered to achieve good moisture equilibration, which is followed by flaking grains through rolls to slightly flatten them, but making vary thin flakes is avoided. The last production step is puffing. It is done at an extremely high temperature (290–340 °C) and in a short time, about 90 seconds, to puff processed grains (Fast, Perdon, & Schonauer, 2020).

Before flaking, grains are exposed to **steam** to increase their temperature and moisture content. It results in a gelatinization of starch granules in the rolling process (Safaei & Yang, 2017). **Flaking** is used to flatten grain or grain mass into a specific shape, having a certain thickness and density, which is adjusted by the distance between flaking mill rolls. The appearance and texture of flakes is affected by the roll speed and size. Thickness variation also change the flake texture (George *et al.*, 2020).

The main objective of grain **cooking** is the gelatinization or melting of crystalline starch into a rubbery-state matrix to achieve the desired shape and size in the further processing steps, such as flaking or shredding (Huang & Perdon, 2020).

Drying is an important flake processing step, during which the desired moisture content can be achieved. Flake moisture content is an important flake quality parameter and has an important role in texture. If the moisture content is higher, products are less hard, less crispy, and chewier (Gates *et al.*, 2008b). During drying, water is removed, flake moisture content is decreased, and the texture and density are changed. Drying can be divided into three phases: (a) heating, (b) a constant drying rate, and (c) falling drying rate phases. If drying takes place at a very high temperature and low air humidity (improper drying), the high moisture gradient may cause stress cracking and/or a hardening of the surface. This may result in a temperature increase above the air wet bulb temperature due to reaching critical the moisture content when evaporation slows down. To prevent case hardening and stickiness, the air dry bulb temperature should be reduced (Breslin, 2020). Due to this, to produce flakes with a desired texture, it is important to produce flakes with an appropriate moisture content.

Toasting is the final stage of traditionally prepared grain flakes. Consumers appreciate such attributes as flavour, colour, and texture developed in the toasting process. Product movement through heating and drying phases allows reaching the conditions required for a Maillard reaction and caramelization, which are important in colour and flavour development (Breslin & Knott, 2020). The flakes are typically toasted in long, continuous conveyor ovens. The finished product moisture content ranges from 1.5 to 3% (Fast, Perdon, & Schonauer, 2020). During toasting, prepared flake

moisture content decreases and due to an expansion or shrinkage, the structural properties of the starch matrix are altered. At a certain pressure, the product expands, and vapour is released from the starch matrix. The expansion depends on the temperature increase rate (Breslin & Knott, 2020). Traditionally prepared toasted flakes show more irregular air cells in the stretched shapes of different sizes, having a less expanded microstructure, the cell wall matrix is present as oriented in irregularly distributed crazes (Kristiawan *et al.*, 2020). For maize flakes, to achieve maximum puffed thickness and appealing sensory parameters, the optimum moisture content should be 8.8–11.2%, the temperature in the range of 251 and 257 °C, and the time between 39 and 45 seconds (Sumithra & Bhattacharya, 2008).

It is possible to obtain flakes of desired texture and physical parameters directly off the **extruder**. In this process, due to expansion and shrinkage, the starch matrix structural properties are modified and the texture of the product changes (Breslin & Knott, 2020). When material flows through the die, there is a sudden pressure drop and the vaporisation of water causes expansion. Thus, extrude flakes obtain their porous structure, which provides a crispy texture and shape, which is characterised by their bulk density (ρ*). The mechanics of the constitutive material and distribution of air cell size and shape determine the mechanical properties of extruded flakes (Kristiawan *et al.*, 2020). Preconditioning improves extruded flake flavour and texture. The texture of extruded flakes in milk is determined by the physical form of starch being present in the cereal. If cereals contain mechanically over-treated starch with dispersed and/or depolymerised starch granules, producing dextrins, those may cause extensive tooth packing. Before mass is introduced into the shear-intensive environment of the extruded, grain particles that contain starch, they should be plasticized by the addition of water and steam through a preconditioning process. After preconditioning, the mass is more easily deformed in the extruder and quantity of mechanical energy applied is reduced (Caldwell *et al.*, 2020). Microstructures show that the extruded flakes present large, expanded bubbles that homogeneously distribute in the flake with thinner cell walls (Kristiawan *et al.*, 2020). High dietary fibre concentration reduces water evaporation at the die, decreasing the expansion and increasing the hardness (Brennan *et al.*, 2008).

Conclusions

Data analysed show if pulse and cereal nutritional information, mineral and vitamin content is known, it is possible to combine different cereals and pulses to provide a specific nutrient composition in the developed products. For example, by adding pulses to cereals, it is possible to increase the content of protein and folate in flakes.

Food texture can be described by the expansion index, bulk density, hardness, crispiness, crunchiness, and toughness. Fundamental changes can happen at microstructural and macrostructural levels. During processing and interaction with macronutrients as proteins and lipids, the physico-chemical properties of starch change and this has a significant effect on the texture of cereal and pulse products. The main change in high starch products is the specific gelatinization and retrogradation behaviour of starch. Constituents such as lipids and proteins as well as processing technology and parameters can significantly modify the properties and functionality of starch.

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