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Impact of Composite Flour on Nutritional, Bioactive and Sensory Characteristics of Pastry Foods: A Review

GBEMINIYI OLAMITI* and SHONISANI EUGENIA RAMASHIA

Faculty of Science, Engineering and Agriculture, Department of Food Science and Technology, University of Venda, Private Bag, Thohoyandou, South Africa.

Abstract

Pastry foods are popular worldwide due to their taste and convenience. However, traditional pastries made from refined wheat flour have received criticism for their high-calorie content, lack of essential nutrients, and limited availability in some areas. In pursuit of enhancing the nutritional composition of pastry products, nutritional science has turned to composite flours, which consist of a blend of various grain and non-grain flours. This review aims to evaluate the impact of composite flours on pastries' nutritional, bioactive, and sensory characteristics. Specifically, the focus is on how composite flours can increase the nutritional content of pastries while preserving their sensory qualities. The review synthesises findings from published research articles on composite flours, analysing macro and micronutrient profiles, dietary fibre content, antioxidant capacity, glycaemic index, and sensory evaluations of pastries made from these flours. The nutritional value of pastries is significantly enhanced by incorporating composite flours, which blend wheat flour with flours made from legumes, tubers, pseudocereals, and ancient grains. This review showcases improvements in mineral and vitamin content, including B vitamins, iron, zinc, and magnesium, as well as higher levels of unsaturated fatty acids and essential amino acids. The dietary fibre content similarly increases substantially, contributing to improved satiety and digestive health. In addition, pastries made with composite flours exhibit higher antioxidant activity, suggesting potential benefits in combating oxidative stress. These findings indicate composite flours enhance pastries' nutritional and bioactive profiles and maintain acceptable sensory properties. Incorporating alternative flours introduces new flavours and textures, enhancing consumer appeal while promoting a balanced diet. Therefore, composite flours offer a viable strategy for enhancing the nutritional quality

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CONTACT Gbeminiyi Olamiti gbeminiyi.olamiti@univen.ac.za Faculty of Science, Engineering and Agriculture, Department of Food Science and Technology, University of Venda, Private Bag, Thohoyandou, South Africa.

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of pastry foods. Their utilisation in the pastry industry could support public health initiatives to reduce non-communicable diseases associated with poor dietary choices. By carefully selecting and blending alternative flours, it is possible to produce healthier pastries that appeal to consumers.

Introduction

Pastry foods are a staple in diets globally, relished for their delicious taste and versatility. Traditionally, these delicacies were made mostly with refined wheat flour, sugar, and fats, which contributed significantly to their sensory appeal. Pastry foods such as bread, muffins, croissants, pies, and cookies have been produced. However, regularly consuming these foods has been associated with various health problems, such as obesity, type 2 diabetes, and cardiovascular diseases, mainly because of their high-calorie content and low nutritional value.[1] Additionally, the prevalence of gluten-related disorders has prompted researchers and consumers to seek alternative baking ingredients capable of delivering healthier pastry options.[2]

Composite flour is flour that is made by mixing two or more different varieties of flour, especially wheat flour mixed with other non-wheat flours from different indigenous crops such as cereals, legumes, tubers, and pseudocereals. This diversification of ingredients can enhance the nutritional profile by incorporating higher amounts of dietary fibres, proteins, minerals, and vitamins while introducing novel bioactive compounds like phenolic acids and flavonoids into the diet. Bioactive compounds are recognised for their antioxidant properties, which are capable of counteracting cellular damage and lowering the likelihood of chronic diseases.[3-4]

The rationale for incorporating composite flours into pastry production arises from the need to address the health concerns linked to traditional pastry consumption and to meet the increasing consumer demand for food products that promote a healthier and more sustainable lifestyle.[5-6] Research indicates that using composite flours not only improves the nutritional quality of pastries but also leverages underutilised crops, contributing to food security and encouraging agricultural biodiversity.[7] Furthermore, the usage of combined flours aligns with global sustainability goals by promoting the use of diverse crops that can thrive in various environmental conditions, thereby reducing dependency on wheat and other major grains.[8]

This review seeks to gather and integrate current scientific understanding of the nutritional and bioactive advantages of composite flours, and to explain their influence on the sensory attributes of pastry foods. It evaluates the potential of composite flours to serve as functional ingredients that can enrich the nutrient composition of pastry products. Moreover, this review intends to explore how composite flours can be effectively utilised in pastry production, considering sensory acceptability and consumer preferences, thus providing a comprehensive guide for both the food industry and the scientific community.

Composite Flours and Pastry Foods

Composite flours, which involve the combination of different flours derived from cereals, legumes, and tubers, have garnered interest due to their capacity to augment the nutritional, functional, and sensory attributes of bakery goods. The utilisation of these composite flours in the realm of baking presents a pioneering method for enhancing health advantages while preserving the desired texture, flavour, and overall quality of the end product. Pastry foods such as croissants, pies, scones, rusks, muffins and cupcakes are increasingly made with composite flours (Figure 1). These blends combine wheat with legume and tuber flours, resulting in products that maintain the desired texture and taste while offering improved nutritional profiles. Including legumes and tuber flours increases protein content, dietary fibre, and essential nutrients.[9]

Similarly, composite flours are used in cookies and biscuits, where oat, millet, or chickpea flour is added to wheat flour. This addition of alternative flours creates healthier options that are high in fibre and protein. These improvements in nutritional content contribute to enhanced satiety, digestive health, and glycaemic control.[10] Composite flours made by blending almonds, sorghum, or quinoa

with traditional wheat flour are also used in cakes. These composite flours result in cakes with improved texture, flavour, and nutritional value, especially regarding essential amino acids and micronutrients.[11] The use of composite flours enables the production of a variety of pastry foods worldwide (Table 1).

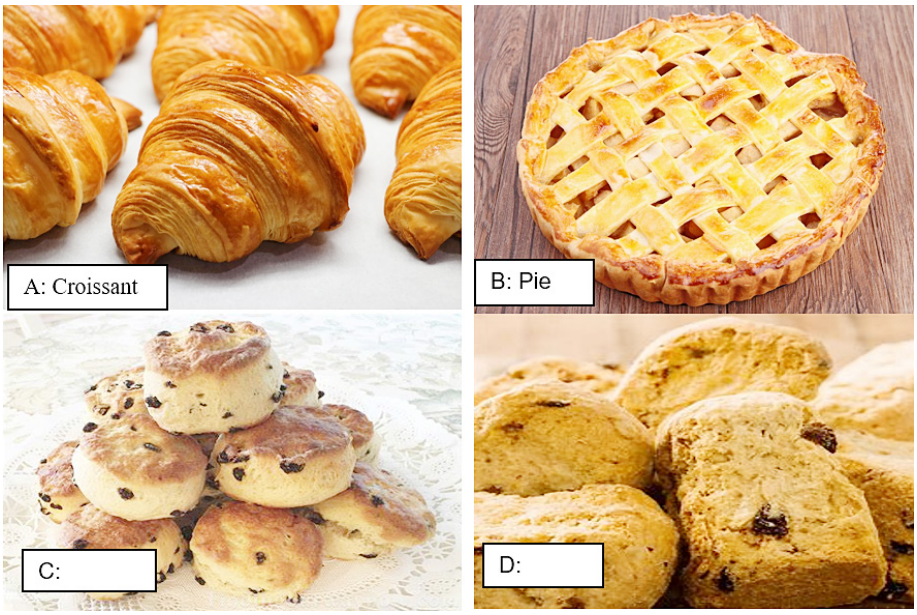

Fig. 1: Some pastry foods

Table 1: Composite pastry foods, nutrient contributions and country of consumption

Type	Composite	Nutrient Contributions	Pastry Foods	Country of Consumption
Grains	Sorghum, barley, millet	High in carbohydrates, B vitamins, and minerals (iron and magn -esium)[15-16]	Sorghum bread, barley muffins, millet cookies	USA, Nigeria, South Africa, India
Legumes	Chickpea, lentil, soy	Rich in protein, dietary fibre, essential amino acids, and minerals (calcium and zinc)[17-18]	Chickpea flour cookies, lentil scones, soy cakes	Middle East, South Asia, East Asia, South Africa
Tubers	Sweet potato, yam	Good source of complex carbohydrates, fibre, vitamins A and C, and antioxidants[19- 20]	Sweet potato pie, yam buns	USA, West Africa, South Africa, Southeast Asia
Pseudocereals	Quinoa, amaranth, buckwheat	High in protein, fibre, essential amino acids, and micronutrients (magnesium, zinc, and iron)[21,22,23]	Quinoa bread, amaranth biscuits, buckwheat pancakes	South America, Europe, South Africa, East Asia

Additionally, composite flours are used in the production of tarts and pies. By including rice, maise, and buckwheat in wheat flour, these pastries cater to the gluten-free market while maintaining comparable

sensory qualities to conventional products.[12] This is particularly beneficial for consumers with celiac disease or gluten intolerance. Doughnuts made from composite flours, which blend wheat with cassava, sweet potato, or plantains, offer soft and flavourful products with increased nutritional content, specifically vitamins and resistant starch. These nutrients enhance gut health by promoting the growth of beneficial gut bacteria, optimising digestion, augmenting the production of short-chain fatty acids, and facilitating bowel regulation, potentially reducing the susceptibility to colon-related diseases.[13] Croissants and other laminated pastry products can also be made using composite flours. Blending wheat with almond, oat, or spelt flour in these products results in foods with flakier textures, buttery flavour, and increased nutrient density.[14] Composite flours are made by combining wheat flour with alternative flours from various plant sources. Each of these alternative flours provides unique nutritional advantages. This not only improves the nutritional value of the final pastry product but also expands the dietary options available to consumers. The availability of composite flours, including in sub-Saharan Africa, supports diverse and nutritious food production, enhances food security, and promotes agricultural biodiversity. Grains, such as barley, millet, sorghum, oats, and maise, are often added to increase food's soluble fibre and beta-glucan content.

These compounds are known for their ability to lower cholesterol levels.[24] For example, millet contains high levels of phenolics and fibre, which have been found to reduce oxidative stress and modulate inflammation.[16] Sorghum is rich in dietary fibre and bioactive compounds that help reduce the risk of chronic diseases. The dietary fibre in sorghum improves digestive health, promotes satiety, and aids in weight management, which is crucial for preventing obesity-related conditions. In addition, sorghum contains bioactive substances like polyphenols, which act as antioxidants to fight cellular damage and decrease the likelihood of chronic diseases such as heart disease, diabetes, and certain cancers.[25]

Legume flours, such as chickpea, lentil, and soybean flour, are highly regarded for their abundance of high-quality protein and essential amino acids. Adding chickpea flour to baked goods not only improves the protein quality but also increases dietary fibre, which promotes weight management and digestive health. Chickpea flour, in particular, is rich in protein and essential amino acids, making it a valuable ingredient in various food products.[17] Lentil flour, known for its nutty flavour, is an excellent source of iron, folate, and antioxidants, which contribute to maintaining blood health and reducing oxidative stress. Therefore, lentil flour is a valuable addition to enhance the nutritional content of foods while providing essential micronutrients.[26] Soybean flour is a significant source of isoflavones, compounds associated with a lower risk of hormone-related cancers and improved cardiovascular health. Incorporating soybean flour into diets can offer substantial health benefits due to its bioactive compounds and high-quality protein content.[26] In addition, tubers such as sweet potato, yam, and cassava are commonly used in composite flours. Sweet potato flour is particularly rich in beta-carotene, a nutrient that promotes eye health and immune function. In the body, beta-carotene from sweet potatoes is converted into vitamin A, which is vital for maintaining optimal vision and a strong immune system. Sweet potato flour is also an excellent source of fibre, which supports digestive health and reduces the risk of chronic diseases.[27] Yam flour, known for its smooth texture, contains significant amounts of dietary fibre and antioxidants. These properties contribute to improved digestive health and reduced inflammation, potentially benefiting conditions such as heart disease and certain cancers. Additionally, the high fibre content of yam flour promotes gut health by supporting the growth of beneficial gut bacteria.[28] Cassava flour, a gluten-free alternative, adds a smooth consistency to baked goods and provides a reliable source of carbohydrates and essential minerals. It is particularly beneficial for individuals with gluten intolerance or celiac disease, as it offers a versatile ingredient that meets energy requirements while delivering necessary nutrients.[29]

The inclusion of composite flours in pastry products is an effective strategy for enhancing their nutritional composition and bioactive properties. By combining wheat with various non-wheat flours derived from legumes, tubers, pseudocereals, and grains, composite flours significantly enhance the nutritional profile by increasing protein, fibre, vitamins, and minerals. They also introduce important bioactive

compounds such as phenolic acids, flavonoids, carotenoids, and phytosterols, which provide health benefits such as antioxidants, anti-inflammatory properties, and cholesterol-lowering effects.[30-31] Staple grains such as sorghum and millet are well-known for being high in carbohydrates, making them valuable sources of energy. They are also rich in B vitamins necessary for energy metabolism and nerve function.[32] In addition, minerals like iron and magnesium play crucial roles in muscle function and the transportation of oxygen.[1] Legumes, which include chickpeas, lentils, and soybeans, are excellent sources of plant-based protein, making them essential components of vegetarian and vegan diets. They also provide essential minerals like calcium and zinc, which promote bone health and immune function. Furthermore, they contain dietary fibre and vital amino acids that are necessary for protein synthesis.[1]

Tubers, such as sweet potatoes and yams, are highly regarded for their complex carbohydrates, which provide a steady release of energy. They are also rich in dietary fibre, which promotes digestive health, and contain significant amounts of vitamins A and C. These vitamins act as antioxidants that support immune function and maintain healthy skin.[33] Pseudocereals, such as buckwheat, amaranth, and quinoa, although not true grains are appreciated for their high protein and fibre content. These pseudocereals contain all essential amino acids, making them complete proteins.[34] Additionally, pseudocereals play essential roles in various biochemical processes, including enzyme function and immune response, due to their micronutrients like magnesium, zinc, and iron. The use of composite flours in these pastries showcases the versatility of these ingredients in meeting the growing demand for nutritious and diverse food choices while maintaining desirable sensory characteristics and increasing overall nutritional value.

Macro and Micronutrient Profiles of Composite Flours

Composite flours offer an enhanced macronutrient profile by blending different flour types to increase the protein, fibre, and complex carbohydrate content, making them suitable for a balanced diet. The micronutrient profile of composite flours is also significantly improved (as indicated in Table 2), providing essential vitamins and minerals such as iron, magnesium, calcium, and vitamins A and C, which support several body processes, such as immunological response and bone health.[1,35] Additionally, the inclusion of phytochemicals like phenolic acids, flavonoids, and carotenoids contributes to the antioxidant and anti-inflammatory properties of composite flours, offering further health benefits.[23]

Table 2: Nutrient Contributions of Wheat Flour and Composite Flour for Making Pastry Food

Nutrient Benefits	Composite Flour	References
Carbohydrates	Maize-cassava	1, 35
Proteins and improved amino profiles	Wheat-soy, sorghum-cowpea	1, 36, 37
Increase fibre	Rice-millet, barley-oat	1, 38
Improve vitamins	High (B-vitamins, A, C)	1, 37, 39
Improve minerals	High (iron, zinc, magnesium, calcium)	1, 37, 38

According to[40] wheat flour, the main ingredient in composite flour, has a significant amount of carbohydrates per 100 g. In comparison, composite flour contains slightly less, about 70 g. This decrease in carbohydrate content in combined flour is owing to the inclusion of grains and other flours with lower carbohydrates and higher fibre. The increased fibre content in composite flour contributes to better glycaemic control and digestive health, lowering the chance of type 2 diabetes and supporting healthy weight maintenance.[1,35] Additionally, the lower glycemic index of composite flour can effectively help manage blood sugar levels.

Composite flour has a higher protein content, providing 15 g of protein per 100 g compared to 10 g per 100 g in wheat flour.[41] This increase primarily comes from including legumes and pseudocereals

in composite flours. These components are known for their high protein content, making composite flour a valuable protein source, especially for vegetarian and vegan diets. Certain pseudocereals, like quinoa, contain all essential amino acids, making composite flours an excellent choice for improving the overall protein quality of baked goods.[1,37] The higher protein content also supports muscle repair and growth, contributing to overall improved health.

The fat content in bread made with composite flour is slightly higher (2 g/100 g) compared to wheat flour (1 g per 100 g), as stated by.[42] This increase is due to the inclusion of legumes and seeds, which have higher amounts of beneficial fats. Fats are essential for supplying vital fatty acids and aiding in the absorption of fat-soluble vitamins (A, D, E, and K), which are necessary for various bodily functions, including brain health and anti-inflammatory processes. The presence of beneficial fats in composite flour can also promote better cardiovascular health by reducing harmful cholesterol levels. Composite flour contains a significantly higher fibre content (8g/100g) compared to wheat flour (2g/100g).[43] This increased fibre content is due to the inclusion of whole grains, legumes, and pseudocereals, all of which are abundant in dietary fibre. A high-fibre diet is linked with several health values, involving improved digestive health, lowered risk of cardiovascular disease, improved weight management, and lowered cholesterol levels.[1,38] Dietary fibre also supports a balanced gut microbiome, which is essential for immunological function and overall well-being. Composite flour is known for its higher vitamin content than wheat flour, specifically B-vitamins, and vitamins A and C. This enrichment is ascribed to the advantages of various botanical sources used in the creation of composite flour. Each botanical ingredient, such as grains, legumes, tubers, and pseudocereals, contributes distinct vitamins, thereby enhancing the overall nutritional value of the composite flour.[1,37,39] The creation of red blood cells, nervous system function, and energy metabolism all depend on B vitamins. Vitamins A and C act as antioxidants and are essential for maintaining immune health and skin integrity. The enhanced vitamin content of composite flours can help prevent deficiencies and support overall well-being.

In addition to their superior vitamin content, composite flours also excel in their mineral composition, containing higher amounts of iron, zinc, magnesium, and calcium contrasted to wheat flour. The diverse grains, legumes, and pseudocereals used in composite flours are excellent sources of these essential minerals. Iron is important for oxygen transfer and the prevention of anaemia, while zinc helps support immune function and wound healing. Magnesium shows a significant function in muscle and nerve function, and calcium is necessary for maintaining strong bones.[1,37-38] Adequate consumption of these minerals is necessary for complete health and the prevention of chronic diseases. Composite flours offer a well-balanced macronutrient profile, with substantial amounts of carbohydrates, proteins, and fats, along with an enhanced micronutrient composition. This combination helps address the nutritional deficiencies commonly associated with refined wheat flour. Composite flours are particularly abundant in essential minerals for instance iron, zinc, magnesium, and calcium. Moreover, they hold elevated levels of B-vitamins, vitamin A, and vitamin C, further enhancing their nutritional value.[37,39]

Bioactive Compounds and Health Implications in Composite Flours

Combined flours, created by mixing wheat flour with various non-wheat flours such as legumes, tubers, pseudocereals, and grains, which are abundant in bioactive substances (as indicated in Table 3). These compounds include phenolic acids, flavonoids, carotenoids, saponins, and phytosterols. Each type of flour contributes unique bioactive components that enhance the overall nutritional profile of the composite flour.z[44-45]

Legume flours, such as those made from chickpeas, lentils, and cowpeas, are rich in protein and fibre, which help enhance satiety and support digestive health.[17] They also contain substantial quantities of isoflavones and other polyphenols, which have been associated with several health advantages, including antioxidant and anti-inflammatory properties46. Isoflavones found in legumes are known to reduce the risk of hormone-related cancers, such as breast and prostate cancer, by replicating the effects of estrogen in the body. Additionally, they promote heart

health by reducing blood pressure and cholesterol levels[47]

Tubers like sweet potatoes and yams contribute substantial amounts of carotenoids, particularly beta-carotene, a compound that the body converts into vitamin A. This addition can enhance the visual appeal and nutritional content of baked goods and other food products made from composite flours.[58] Carotenoids are vital for eye health and immune function. Beta-carotene is transformed into vitamin A in the body, which plays a crucial role in supporting healthy vision, particularly in low-light conditions.[59-60] It also supports skin health and boosts the immune system's capacity to defend against infections.[59,61]

Table 3: Composite flour bioactive compounds and health benefits

Type of composite flour	Bioactive compounds	Health Benefits
Legumes (e.g., Chickpeas, Soy)	Isoflavones, saponins	Rich in protein and dietary fibre, enhancing satiety and digestive health, Isoflavones, with estrogenic activity, may decrease the risk of cancers and cardiovascular diseases by imitating estrogen, lowering the risk of breast and prostate cancers, and improving cardiovascular health by reducing blood pressure and cholesterol.[48-49,50]
Pseudocereals (e.g., Quinoa, Amaranth)	Phenolic acids, flavonoids	They are gluten-free, provide a complete protein profile with all basic amino acids, and offer antioxidant and anti-inflammatory benefits. Phenolic acids act as antioxidants to neutralise free radicals and reduce inflammation, while flavonoids enhance cardiovascular health by improving endothelial function and lowering blood pressure[23, 51-52]
Tubers (e.g., sweet potato, yam)	Carotenoids, polyphenols	They are rich in beta-carotene, which supports eye health, immune function, and shields the skin from UV harm. Additionally, their polyphenols and carotenoids provide antioxidant properties, which reduce the danger of cancerous diseases.[53,54,55]
Grains (e.g., barley, millet)	Phytosterols, beta-glucans	They contain phytosterols and beta-glucans that contribute to heart health. Phytosterols lower total and LDL cholesterol levels by inhibiting cholesterol absorption in the intestines. Beta-glucans regulate blood sugar concentrations and promote the increase of beneficial gut bacteria through their prebiotic effects[55, 56, 57]

Grains like quinoa, amaranth, and buckwheat are notable for their high levels of fully balanced proteins, which include all essential amino acids. These flours also offer a rich supply of flavonoids and saponins, bioactive compounds known for their anti-carcinogenic and cholesterol-lowering effects.[23,62] Phenolic acids and flavonoids in pseudocereals exhibit anti-inflammatory and anticancer properties. These compounds function as antioxidants, neutralising free radicals and shielding cells from oxidative damage, a process that can contribute to the development of chronic diseases like cancer, cardiovascular diseases, and neurodegenerative disorders.[22,58] Additionally, flavonoids can enhance the body's immune response and decrease the chance of contracting infections.[22,59]

Grains such as millet and sorghum make significant contributions to dietary fibre, minerals, and unique phenolic compounds that provide antioxidant benefits.[63-64] These grains are particularly beneficial for individuals with gluten intolerances or celiac disease, as they naturally do not contain gluten[65-66] The presence of phytosterols derived from grains helps reduce cholesterol levels by impeding the absorption of cholesterol in the intestines. Consequently, this can reduce overall and bad (LDL) cholesterol levels, thereby improving cardiovascular health.[67-68] Consistent consumption of foods rich in phytosterols has been connected to a decreased danger of coronary heart disease.[63,69]

Furthermore, beta-glucans present in grains like barley and oats have been shown to improve blood sugar control and enhance immune function. Beta-glucans can also promote gut health by serving as prebiotics, fostering the growth of beneficial gut bacteria.[70-71]

Considering the health-promoting compounds and nutritional advantages of composite flour, the incorporation of these diverse flours into blends not only boosts the nutritional value but also optimises the sensory qualities of food items. Studies have shown that composite flours enhance the texture, flavour, and shelf life of bakery products while offering health benefits beyond those of products made solely from wheat flour.[72]

Overall, composite flours provide a versatile and nutrient-rich alternative to traditional wheat flour, making them an excellent option for improving the nutritional value and sensory qualities of various food products. The diverse array of phytochemicals in composite flours delivers substantial health advantages, such as lowering the risk of chronic diseases, promoting cardiovascular health, strengthening immune function, and enhancing overall well-being.

Effects of Processing on the Health-Promoting Compounds in Composite Flours

Processing methods such as milling, baking, and extrusion can impact the bioactive compounds in composite flours. Milling can diminish the content of phenolic compounds as a result of the removal of bran, which is rich in these bioactive (Table 4). The reduction of phenolic acids and flavonoids during milling can lower the antioxidant capacity of the flour.[67,73]

During processing, baking and extrusion can lead to the breakdown of heat-sensitive bioactive compounds like carotenoids and flavonoids. High temperatures and long processing times can lead to the oxidation and thermal decomposition of these compounds, reducing their nutritional benefits[74,75,76.76] reported that beta-carotene and other carotenoids can degrade, diminishing their effectiveness in supporting eye health and immune function.

However, some processes can enhance the bioavailability of certain bioactive compounds by breaking down cell walls and releasing bound phytochemicals.

Heat treatments like baking can increase the extractability and digestibility of some phytochemicals. For example, the bioavailability of phenolic acids can be improved through heat treatments, which may break ester bonds and release bound phenolics.[77] Fermentation is another processing method that can positively affect bioactive compounds. It can increase the levels of certain phytochemicals, such as isoflavones in soy products, by converting glycosides to aglycones, which are more bioavailable and have greater biological activity.[82,83]

Additionally, germination of grains and legumes can enhance the content and absorption of health-promoting compounds. This process can enhance the levels of vitamins, phenolic acids, and flavonoids by activating endogenous enzymes that synthesise these compounds.[85]

Overall, while some processing methods can lead to the loss of bioactive compounds, others can enhance their availability and efficacy, contributing to the health benefits of composite flours.

Development and Derived Foods from Composite Flour

Composite flours, which are blends of different types of flours such as wheat, legumes, tubers, pseudocereals, and grains, have been widely used to improve the nutritional value, sensory attributes, and functional qualities of a variety of food products. Foods derived from composite flours are not only nutritionally superior but also meet the growing

demand for healthier and more functional foods. This literature review explores the development, nutritional benefits, sensory attributes, and consumer acceptance of foods derived from composite flours. The creation of foods using composite flours aims to leverage the complementary nutritional and functional properties of different flour types. Composite flours are frequently employed in producing bread, pastries, pasta, snacks, and gluten-free products.[88] reported that the inclusion of legume flours such as chickpeas and lentils in bread and pastries enhances protein content and improves the balance of essential amino acids, often lacking in wheat alone. Additionally, pseudocereals such as quinoa and amaranth are incorporated into bakery products to provide essential micronutrients and enhance the overall nutritional quality.[21]

Table 4: Effects of Processing on the Health-Promoting Compounds in Composite Flours

Processing method	Influence on Bioactive Compounds
Milling	Reduces phenolic compounds due to the removal of bran, a major source of antioxidants and fibre. Milling also decreases the content of vitamins and minerals located in the outer layers of the grain.[67,73]
Baking	Degrades heat-sensitive compounds such as carotenoids, flavonoids, and some vitamins. It can enhance the bioavailability of some phytochemicals by breaking down cell walls and releasing bound phenolics.[75,77] It can also induce the Maillard reaction, which forms beneficial antioxidant compounds.[78]
Extrusion	Degrades some compounds, particularly heat-sensitive vitamins and phytochemicals, due to high temperature and pressure. It can increase the bioavailability of some bioactive compounds by disrupting the food matrix and releasing bound phytochemicals.[79-80] Extrusion can also increase the digestibility and functional properties of proteins and starches..[81]
Fermentation	Increases levels of health-promoting compounds like isoflavones, phenolic acids, and B-vitamins. Fermentation can also enhance antioxidant activity and the bioavailability of these compounds by breaking down complex molecules.[82-83] It enhances probiotic content, which contributes to gut health.[84]
Sprouting	Enhances the content and bioavailability of health-beneficial compounds, including vitamins, phenolic acids, and flavonoids, by activating endogenous enzymes. Sprouting can also improve protein quality and reduce antinutrients.[85]
Microwave Processing	Retains more heat-sensitive bioactive compounds relative to traditional heating methods. Microwave treatment can boost the extraction of polyphenols and antioxidants due to its rapid heating.[86,87]

Foods derived from composite flours offer significant nutritional benefits. Legume flours are abundant in protein, fibre, vitamins, and minerals, which contribute to improved satiety, digestive health, and overall nutritional adequacy. For example, incorporating chickpea flour into snacks and baked goods increases their protein and fibre content, which can help in weight management and improve gut health.[46] Gluten-free pseudocereals like quinoa and amaranth offer high levels of protein, fibre, and various health-promoting compounds with antioxidant and anti-inflammatory effects.[23]

Tubers like sweet potatoes and yams add significant amounts of dietary fibre, vitamins (especially vitamin A), and antioxidants to derived foods. These

nutrients support immune function and eye health and help mitigate the risk of chronic diseases.

Grains such as millet and sorghum are abundant in phenolic compounds, exhibiting antioxidant and anti-cancer properties.[16] According to[32] the inclusion of diverse ingredients in composite flours helps address micronutrient deficiencies, such as iron, zinc, and calcium, particularly in populations with limited access to a variety of foods.

Sensory Attributes of Pastry Products from Composite Flour

The incorporation of non-wheat flours can significantly alter the taste and flavour profile of pastry products from composite flour. Table 5 provides some pastry products from composite flour and their sensory attributes. Legumes such as chickpeas and lentils add a nutty and earthy flavour, which can enhance the taste of baked goods and snacks.[89] However,[90] stated that some legume flours may introduce a beany or bitter taste, which can be mitigated by processing methods such as roasting. Additionally, the soaking and germination of legumes can further reduce these undesirable flavours while enhancing the nutritional profile.[91] Pseudocereals like quinoa and amaranth contribute a mildly sweet and nutty flavour, making them suitable for both sweet and savoury applications.[21]

Table 5: Pastry products from composite flour with sensory attributes

Sensory attribute	Description	References
Taste and Flavour	Legumes like chickpeas and lentils add a nutty and earthy flavour, enhancing baked goods and snacks; Mitigating beany or bitter taste can be achieved through roasting or fermentation; Pseudocereals like quinoa and amaranth provide a mildly sweet and nutty flavour suitable for both sweet and savoury applications.	21, 102, 103
Texture	Legume flours improve the moisture content and crumb softness of baked products; Tubers like sweet potato and yam create a soft and tender texture due to high starch content; Extrusion and baking enhance textural properties by improving water-holding capacity and reducing hardness.	20, 79,102
Colour	Carotenoids in tubers impart an orange or yellow hue, making products visually appealing and indicating vitamin A content; Grains like sorghum and millet add a colour spectrum from white to red and brown; Phenolic compounds in pseudocereals can contribute to a darker appearance.	16, 21, 76
Aroma	Roasting legume flours enhances their nutty aroma, improving appeal in baked goods and snacks; Fermentation modifies aroma by breaking down complex compounds into simpler, more volatile compounds, enhancing sensory appeal.	83, 102
Consumer Acceptance	Optimising sensory qualities through techniques such as consumer panels and descriptive analysis ensures that composite foods meet consumer expectations; The use of electronic nose and tongue can objectively measure aroma and taste profiles.	100, 101

Texture is a critical sensory attribute that affects the mouthfeel and overall eating experience. The inclusion of legume flours can improve the texture of baked products by increasing their moisture content

and crumb softness.[89] Tubers like sweet potato and yam provide a soft and tender texture owing to their elevated starch content, which makes them perfect for creating soft and moist baked goods.[92] The starches in tubers undergo gelatinisation during baking, contributing to a desirable texture. Extrusion and baking processes can enhance the textural properties of composite flours by improving their water-holding capacity and reducing hardness89,93. Additionally, the use of hydrocolloids and enzymes in composite flour formulations can further improve texture and mouthfee.[92]

The colour of pastry products from composite flour is influenced by the pigments found in the various types of flours used. Carotenoids found in tubers, such as sweet potatoes, can give products an attractive orange or yellow hue and also indicate their vitamin A content.[58,95] Grains like sorghum and millet can contribute a variety of colours, from white to red and brown, depending on the specific variety and processing methods used.[58,64] Additionally, the presence of phenolic compounds in pseudocereals can affect the colour, potentially resulting in a darker appearance in certain cases.[58,95] It is also worth noting that the Maillard reaction during baking can enhance the colour and flavour complexity of composite foods.[94, 96]

Aroma is an essential component of flavour perception and can significantly influence consumer preference. Composite flours can introduce diverse aromatic profiles to food products. For instance, the roasting of legume flours enhances their nutty aroma, making them more appealing in baked goods and snacks.[97] Fermentation processes can also modify the aroma by breaking down complex compounds into simpler, more volatile aroma compounds, enhancing the overall sensory appeal.[83] The use of specific strains of yeast and bacteria in fermentation can further refine the aroma profile.[98]

The acceptance of pastry products from composite flour is largely determined by their sensory attributes. Studies have shown that consumers are generally receptive to composite flours, especially when the sensory qualities are optimised.[99] Sensory evaluation techniques, including consumer panels and descriptive analysis, are essential for assessing the sensory attributes and ensuring that pastry products from composite flour meet consumer expectations.[100] Techniques such as electronic nose and tongue can also be employed to measure aroma and taste profiles[101] objectively.

Conclusion

Incorporating composite flours into pastry foods offers an effective strategy to improve these widely consumed products' nutritional and bioactive profiles. Composite flours, which blend wheat with various non-wheat flours such as legumes, tubers, pseudocereals, and grains, significantly enhance nutritional value by boosting protein, fibre, vitamins, and mineral content. They also introduce essential health-promoting compounds, such as phenolic acids, flavonoids, carotenoids, and phytosterols, which provide a range of health benefits, including antioxidant, anti-inflammatory, and cholesterol-lowering effects.

Furthermore, composite flours positively impact pastry foods' sensory attributes, including taste, texture, colour, and aroma. For instance, legumes add a nutty flavour, tubers contribute to a soft texture, and grains enhance visual appeal with a diverse colour spectrum. Sensory evaluations indicate that consumers generally accept and prefer pastries made with moderate levels of composite flours, especially when processing methods such as roasting or fermentation are applied to mitigate any undesirable flavours.

Overall, the integration of composite flours in pastry production addresses the growing consumer demand for healthier food options and aligns with global sustainability goals by promoting the use of diverse crops. Future research should continue exploring innovative combinations of flours and advanced processing techniques further to enhance composite flours' nutritional value and sensory qualities, ensuring their broad acceptance and utilisation in the food industry.

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Conflict of Interest
The authors declare no conflicts of interest.
Data Availability statement
This statement does not apply to this article.

Ethics Statement
This research did not involve human participants, animal subjects, or any material that requires ethical approval.

Informed Consent Statement
This study did not involve human participants, and therefore, informed consent was not required.

Clinical Trial Registration
This research does not involve any clinical trials.

Author Contributions
- **Gbeminiyi Olamiti:** conceptualisation, initial drafting, as well as the subsequent review and editing.
- **Shonisani Eugenia Ramashia:** Supervision process and engaging in writing activities such as reviewing and editing.

References

1. Johnson J, Wallace T. C. Whole Grains and Their Bioactives: Composition and Health. John Wiley & Sons; 2019.
2. Cabanillas B. Gluten-related disorders: celiac disease, wheat allergy, and nonceliac gluten sensitivity. *Crit Rev Food Sci Nutr.* 2020;60(15):2606-2621. https://doi.org/10.1080/10408398.2019.1651689
3. Jiménez-Moreno N, Esparza I, Ancín-Azpilicueta C. Antioxidant properties of bioactive compounds in fruit and vegetable waste. *Foods.* 2023;12(8):1647. https://doi.org/10.3390/antiox12081647
4. Liu RH. Health-promoting components of fruits and vegetables in the diet. *Adv Nutr.* 2013;4(3):384S-392S. https://doi.org/10.3945/an.112.003517
5. Duque-Soto C, Ruiz-Vargas A, Rueda-Robles A, Quirantes-Piné R, Borrás-Linares I, Lozano-Sánchez J. Bioactive potential of aqueous phenolic extracts of spices for their use in the food industry—a systematic review. *Foods.* 2023;12(16):3031. https://doi.org/10.3390/foods12163031
6. Villarino CBJ, Jayasena V, Coorey R, Chakrabarti-Bell S, Johnson SK. Nutritional, health, and technological functionality of lupin flour addition to bread and other baked products: benefits and challenges. *Crit Rev Food Sci Nutr.* 2016;56(5):835-857. https://doi.org/10.1080/10408398.2013.814044
7. Olaoye OA, Ade-Omowaye BI. Composite flours and breads: potential of local crops in developing countries. In: Preedy VR, Watson RR, Patel VB, eds. Flour and Breads and Their Fortification in Health and Disease Prevention. *Elsevier*; 2011:183-192. doi:10.1016/B978-0-12-380886-8.10017-0.
8. Zeng F, Guo H, Liu G. Processing and utilisation technology of root and tuber food. *Foods.* 2024;13(8):2082. https://doi.org/10.3390/foods13132082
9. Aleman RJS. Physicochemical properties of high protein rice flours and application in a cupcake. (Master's thesis). Louisiana State University; 2021. Available at: https://digitalcommons.lsu.edu/gradschool_theses/5173. Accessed September 2024.
10. Virk A, Kaur M, Thakur P, Chauhan D, Rizvi Q. Development and nutritional evaluation of multigrain gluten-free cookies and pasta products. *Curr Res Nutr Food Sci J.* 2019;7(3):842-853. https://dx.doi.org/10.12944/CRNFSJ.7.3.23
11. Peñalver R, Ros G, Nieto G. Development of functional gluten-free sourdough bread with pseudocereals and enriched with Moringa oleifera. *Foods*. 2023;12(21):3920. https://doi.org/10.3390/foods12213920
12. Siddiqui SA, Zannou O, Karim I. Avoiding food neophobia and increasing consumer acceptance of new food trends—a decade of

research. *Sustainability.* 2022;14(16):10391. https://doi.org/10.3390/su141610391

13. Oduro-Obeng H, Plahar WA. Development, quality evaluation and estimated contribution of composite flour snack foods to nutrient requirements of young children aged 2 to 6 years. Council for Scientific and Industrial Research Ghana; 2017. Available at: https://csirspace.foodresearchgh.site/handle/123456789/1307. Accessed August 22, 2024.
14. Ooms N, Pareyt B, Brijs K, Delcour JA. Ingredient functionality in multilayered dough-margarine systems and the resultant pastry products: a review. *Crit Rev Food Sci Nutr.* 2016;56(13):2101-2114. https://doi.org/10.1080/10408398.2014.928259
15. Brennan CS, Cleary LJ. The potential use of cereal (1→3, 1→4)-β-D-glucans as functional food ingredients. *J Cereal Sci.* 2005;42(1):1-13. https://doi.org/10.1016/j.jcs.2005.01.002
16. Mawouma S, Condurache NN, Turturică M, Constantin OE, Croitoru C, Rapeanu G. Chemical composition and antioxidant profile of sorghum (*Sorghum bicolor* (L.) Moench) and pearl millet (*Pennisetum glaucum* (L.) R. Br.) grains cultivated in the far-North region of Cameroon. *Foods.* 2022;11(14):2026. https://doi.org/10.3390/foods11142026
17. Begum N, Khan QU, Liu LG, Li W, Liu D, Haq IU. Nutritional composition, health benefits and bio-active compounds of chickpea (*Cicer arietinum L.*). *Front Nutr.* 2023; 10:1218468. https://doi.org/10.3389/fnut.2023.1218468
18. Kose BE, Tacer-Caba Z, Nilufer-Erdil D. Simulated digestion of the pigmented legumes' (Black chickpea Cicer arietinum L. and brown lentil Lens culinaris Medikus) phenolics to estimate their bioavailability. *Plant Foods Hum Nutr.* 2022;77(4):584-590. https://doi.org/10.1007/s11130-022-01006-w
19. Brown AC, Walter JM, Beathard K. Understanding Food: Principles and Preparation. Cengage Learning; 2015.
20. Johnson JB, Budd C, Mani JS, Brown P, Walsh KB, Naiker M. Carotenoids, ascorbic acid and total phenolic content in the root tissue from five Australian-grown sweet potato cultivars. *New Zealand Journal of Crop and Horticultural Science*. 2022;50(1):32-47. https://doi.org/10.1080/01140671.2021.1895230
21. Agregán R, Guzel N, Guzel M, Bangar SP, Zengin G, Kumar M, Lorenzo JM. The effects of processing technologies on nutritional and anti-nutritional properties of pseudocereals and minor cereals. *Food and Bioprocess Technology*. 2023;16(5):961-986. https://doi.org/10.1007/s11947-022-02936-8
22. Shahbaz M, Raza N, Islam M. The nutraceutical properties and health benefits of pseudocereals: a comprehensive treatise. *Crit Rev Food Sci Nutr.* 2023;63(29):10217-10229. https://doi.org/10.1080/10408398.2022.2071205
23. Tang Y, Li X, Zhang B, Chen PX, Liu R, Tsao R. Characterisation of phenolics, betanins and antioxidant activities in seeds of three Chenopodium quinoa Willd. *genotypes. Food Chem.* 2015; 166:380-388. https://doi.org/10.1016/j.foodchem.2014.06.018
24. Petrova P, Petrov K. Lactic acid fermentation of cereals and pseudocereals: ancient nutritional biotechnologies with modern applications. *Nutrients*. 2020;12(4):1118. https://doi.org/10.3390/nu12041118
25. Aguiar EV, Santos FG, Krupa-Kozak U, Capriles VD. Nutritional facts regarding commercially available gluten-free bread worldwide: recent advances and future challenges. *Crit Rev Food Sci Nutr.* 2023;63(5):693-705. https://doi.org/10.1080/10408398.2021.1952403
26. Boye J, Zare F, Pletch A. Pulse proteins: processing, characterisation, functional properties and applications in food and feed. *Food Res Int.* 2010;43(2):414-431. https://doi.org/10.1016/j.foodres.2009.09.003
27. Oleas Lopez JM, Bravo Avalos F, Vásconez–Barrera L. Sweet potato and amaranth chips and their economic analysis. *J Surv Fish Sci.* 2023;10(3S):385-403. https://doi.org/10.17762/sfs.v10i3S.43
28. Khol M, Ma F, Lei L, Liu W, Liu X. A frontier review of nutraceutical Chinese yam. *Foods.* 2024;13(10):1426. https://doi.org/10.3390/foods13101426
29. Abu MS. Comparative evaluation of cassava composite flours and bread. *Asian J Nat Prod Biochem.* 2023;21(1). https://doi.org/10.13057/biofar/f210103
30. Kaur P, Purewal SS, Sandhu KS, Kaur M,

Salar RK. Millets: a cereal grain with potent antioxidants and health benefits. *J Food Meas Charact.* 2019; 13:793-806. https://doi.org/10.1007/s11694-018-9992-0

31. Waisundara VY, Grichar WJ. Pseudocereals: recent advances and new perspectives. In: *Agricultural Sciences.* Vol 5. IntechOpen; 2024:10.
32. Gibson RS, Bailey KB, Gibbs M, Ferguson EL. A review of phytate, iron, zinc, and calcium concentrations in plant-based complementary foods used in low-income countries and implications for bioavailability. *Food Nutr Bull.* 2010; S134-S146. https://doi.org/10.1177/15648265100312S206
33. Chandrasekara A. Roots and tubers as functional foods. In: Bioactive Molecules in Food. *Reference Series in Phytochemistry.* Springer; 2018. doi:10.1007/978-3-319-78030-6_73.
34. Li L, Lietz G, Seal CJ. Phenolic, apparent antioxidant and nutritional composition of quinoa (*Chenopodium quinoa* Willd.) seeds. *Int J Food Sci Technol.* 2021;56(7):3245-3254. https://doi.org/10.1111/ijfs.14962
35. Okpala L, Okoli E. Nutritional evaluation of cookies produced from pigeon pea, cocoyam and sorghum flour blends. *Afr J Biotechnol.* 2011;10(3): 433-438. Doi: 10.5897/AJB10.1318
36. Olagunju AI, Ekeogu PC, Bamisi OC. Partial substitution of whole wheat with acha and pigeon pea flours influences rheological properties of composite flours and quality of bread. *Br Food J.* 2020;122(11):3585-3600. https://www.emerald.com/insight/0007-070X.htm
37. Olakanmi SJ, Jayas DS, Paliwal J. Implications of blending pulse and wheat flours on rheology and quality characteristics of baked goods: a review. *Foods*. 2022;11(20):3287. https://doi.org/10.3390/foods11203287
38. Dhingra D, Michael M, Rajput H, Patil R. Dietary fibre in foods: a review. *J Food Sci Technol.* 2012; 49:255-266. Doi 10.1007/s13197-011-0365-5
39. Rashwan AK, Yones HA, Karim N, Taha EM, Chen W. Potential processing technologies for developing sorghum-based food products: an update and comprehensive review. *Trends Food Sci Technol.* 2021; 110:168-182. https://doi.org/10.1016/j.tifs.2021.01.087
40. Ficco DBM, Borrelli GM. Nutritional components of wheat-based food: composition, properties, and uses. *Foods.* 2023;12(21):4010. https://doi.org/10.3390/foods12214010
41. Oyeyinka SA, Bassey IAV. Composition, functionality, and baking quality of flour from four brands of wheat flour. *J Culin Sci Technol.* 2023:1-21. https://doi.org/10.1080/15428052.2023.2191874
42. Aslam HKW, Raheem MIU, Ramzan R, Shakeel A, Shoaib M, Sakandar HA. Utilisation of mango waste material (peel, kernel) to enhance dietary fibre content and antioxidant properties of biscuit. *J Glob Innov Agric Soc Sci*. 2014;2(2):76-81. Doi: 10.17957/JGIASS/2.2.533
43. Adebayo TK, Daramola AS, Abdulraheem IA, Jimoh KA. Effect of inclusion of velvet bean on the proximate composition and functional properties of the wheat-plantain flour blends. *World J Adv Res Rev.* 2023;20(3):562-573. https://doi.org/10.30574/wjrr.2023.20.3.2474
44. Awika JM. Major cereal grains production and use around the world. In: Advances in Cereal Science: Implications to Food Processing and Health Promotion. ACS Publications; 2011:1-13.
45. Shahidi F, Chandrasekara A. Millet grain phenolics and their role in disease risk reduction and health promotion: a review. *J Funct Foods*. 2013;5(2):570-581. https://doi.org/10.1016/j.jff.2013.02.004
46. Mudryj AN, Yu N, Aukema HM. Nutritional and health benefits of pulses. *Appl Physiol Nutr Metab*. 2014;39(11):1197-1204. https://doi.org/10.1139/apnm-2013-0557
47. Sánchez-Chino XM, Jiménez Martínez C, León-Espinosa EB. Protective effect of chickpea protein hydrolysates on colon carcinogenesis associated with a hypercaloric diet. *J Am Coll Nutr.* 2019;38(2):162-170. https://doi.org/10.1080/07315724.2018.1487809
48. Juárez-Chairez MF, Meza-Márquez OG, Márquez-Flores YK, Jiménez-Martínez C. Potential anti-inflammatory effects of legumes: a review. *Br J Nutr.* 2022;128(11):2158-2169. Doi:10.1017/S0007114522000137
49. Kumar GA, Kumar S, Bhardwaj R. Recent

advancements in multifaceted roles of flavonoids in plant–rhizomicrobiome interactions. *Front Plant Sci*. 2024; 14:1297706. https://doi.org/10.3389/fpls.2023.1297706

50. Yanni AE, Iakovidi S, Vasilikopoulou E, Karathanos VT. Legumes: a vehicle for transition to sustainability. *Nutrients.* 2023;16(1):98. https://doi.org/10.3390/nu16010098
51. Agarwal A, Rizwana, Tripathi AD, Kumar T, Sharma KP, Patel SKS. Nutritional and functional new perspectives and potential health benefits of quinoa and chia seeds. *Antioxidants.* 2023;12(7):1413. https://doi.org/10.3390/antiox12071413
52. Kenari RE, Azizkhani M. Quinoa and its antioxidant and nutritional properties and application in the food industry. In: Pseudocereals-Recent Advances and New Perspectives. IntechOpen; 2024. Doi:10.5772/intechopen.111646
53. Nguyen HC, Chen CC, Lin KH, Chao PY, Lin HH, Huang MY. Bioactive compounds, antioxidants, and health benefits of sweet potato leaves. *Molecules.* 2021;26(7):1820. https://doi.org/10.3390/molecules26071820
54. Olivas-Aguirre F, Quintero-Vargas J, Escobar-Puentes A, Wall-Medrano A. Bioactive compounds and biological activities of sweet potato (*Ipomoea batatas* (L.) Lam.). *Bioactive Compounds in the Storage Organs of Plants.* 2024;877.
55. Niazi MK, Saeed Z, Imran S, Hassan F. Therapeutic effect of barley on cardiovascular diseases. In: Frontiers in Clinical Trials. *IntechOpen*; 2023. Doi:10.5772/infotechopen.108060
56. Raj R, Shams R, Pandey VK, Dash KK, Singh P, Bashir O. Barley phytochemicals and health-promoting benefits: a comprehensive review. *J Agric Food Res*. 2023; 14:100677. https://doi.org/10.1016/j.jafr.2023.100677
57. Schmidt M. Cereal beta-glucans: an underutilised health endorsing food ingredient. *Crit Rev Food Sci Nutr.* 2022;62(12):3281-3300. https://doi.org/10.1080/10408398.2020.1864619
58. Magalhães D, Gonçalves R, Rodrigues CV, Rocha HR, Pintado M, Coelho MC. Natural pigments recovery from food by-products: health benefits towards the food industry. *Foods.* 2024;13(14):2276. https://doi.org/10.3390/foods13142276
59. Bas TG. Bioactivity and bioavailability of carotenoids applied in human health: technological advances and innovation. *Int J Mol Sci*. 2024;25(14):7603. https://doi.org/10.3390/ijms25147603
60. Wu J, Cho E, Willett WC, Sastry SM, Schaumberg DA. Intakes of lutein, zeaxanthin, and other carotenoids and age-related macular degeneration during 2 decades of prospective follow-up. *JAMA Ophthalmol.* 2015;133(12):1415-1424. doi:10.1001/jamaophthalmol.2015.3590
61. Bozdemir M, Gümüş T, Altan Kamer DD. Technological and beneficial features of lactic acid bacteria isolated from Boza, a cereal-based fermented beverage. *Food Biotechnology*. 2022;36(3):209-233. https://doi.org/10.1080/08905436.2022.2092128
62. Repo-Carrasco-Valencia RA-M, Serna LA. Quinoa (Chenopodium quinoa, Willd.) as a source of dietary fibre and other functional components. *Food Sci Technol.* 2011; 31:225-230. https://doi.org/10.1590/S0101-20612011000100035
63. Simnadis TG, Tapsell LC, Beck EJ. Effect of sorghum consumption on health outcomes: a systematic review. *Nutr Rev*. 2016;74(11):690-707. https://doi.org/10.1093/nutrit/nuw036
64. Xiong Y, Zhang P, Warner RD, Fang Z. Sorghum grain: From genotype, nutrition, and phenolic profile to its health benefits and food applications. *Compr Rev Food Sci Food Saf.* 2019;18(6):2025-2046. https://doi.org/10.1111/1541-4337.12506
65. Dykes L, Rooney L. Phenolic compounds in cereal grains and their health benefits. *Cereal Foods World.* 2007;52(3):105-111. Doi:10.1094/CFN-52-3-0105
66. Pontieri P, Mamone G, De Caro S. Sorghum, a healthy and gluten-free food for celiac patients as demonstrated by genome, biochemical, and immunochemical analyses. *J Agric Food Chem.* 2013;61(10):2565-2571. https://doi.org/10.1021/jf304882k
67. Kraithong S, Gao J, Theppawong A, Bunyameen N, Rungraeng N, Huang R. Phyto-nutritional components and health-promoting aspects of pigmented sorghum.

In: Pigmented Grains. *Academic Press;* 2024:157-197. https://doi.org/10.1016/B978-0-443-15906-0.00007-3

68. Medeiros D, Vazquez-Araujo L, Chambers E. Sorghum: the forgotten grain. *Food Technol* (Chicago). 2011;65(6):52-60. Doi/full/10.5555/20113201160
69. Taguchi C, Kishimoto Y, Fukushima Y, Kondo K, Yamakawa M, Wada K and Nagata C. Dietary intake of total polyphenols and the risk of all-cause and specific-cause mortality in Japanese adults: the Takayama study. *Eur J Nutr.* 2020; 59:1263-1271. https://doi.org/10.1007/s00394-019-02136-9
70. Vetvicka V, Novak M. Biological action of β-glucan. *Biol Chem Beta Glucan.* 2011; 1:10-18.
71. Wood PJ. Cereal β-glucans in diet and health. *J Cereal Sci*. 2007;46(3):230-238. https://doi.org/10.1016/j.jcs.2007.06.012
72. Tortoe C, Akonor P, Hagan L, Kanton R, Asungre P, Ansoba E. Assessing the suitability of flours from five pearl millet (*Pennisetum americanum*) varieties for bread production. *Food Res J.* 2019;26(1):329-336. http://www.ifrj.upm.edu.my
73. Slavin J. Fiber and prebiotics: mechanisms and health benefits. *Nutrients.* 2013;5(4):1417-1435. https://doi.org/10.3390/nu5041417
74. Cazzonelli CI. Carotenoids in nature: insights from plants and beyond. *Funct Plant Biol.* 2011;38(11):833-847. https://doi.org/10.1071/FP11192
75. Ndolo VU, Beta T. Distribution of carotenoids in endosperm, germ, and aleurone fractions of cereal grain kernels. *Food Chem*. 2013;139(1-4):663-671. https://doi.org/10.1016/j.foodchem.2013.01.014
76. Sandesh GM, Saran Kumar C, Bharathi P, Dhasarathan M, Karthikeyan A, Meenakshi V, Thangaraj K, Vellaikumar S, Baskaran V, Senthil N. β-carotene bioavailability and retention in biofortified maize (*Zea mays L.*) after processing and preparation of Indian foods. *Vegetos*. 2018; 68-74. Doi:10.5958/2229-4473.2018.0009.4
77. Zalewska M, Marcinkowska-Lesiak M, Onopiuk A. Application of different drying methods and their influence on the physicochemical properties of tomatoes. *European Food Research and Technology.* 2022;248(11):2727-2735. https://doi.org/10.1007/s00217-022-04081-0
78. Tang Y, Luo J, Luo F, Lu X, Hu J, Li W, Fu F, Gao J. Endogenous ascorbic acid prevents fresh-cut potato from browning. *International Journal of Food Science & Technology.* 2023;58(11):5885-5895. https://doi.org/10.1111/ijfs.16691
79. Hernández-Santos B, Juárez-Barrientos JM, Torruco-Uco JG, Ramizez-Rivera ED, Bautista-Viazcan VO, Rodriguez-Miranda J. Physicochemical properties of extruded ready-to-eat snack from unripe plantain blends, pineapple by-products and stevia. *Nova Scientia*. 2021;13(27). https://doi.org/10.21640/ns.v13i27.2842
80. Brennan C, Brennan M, Derbyshire E, Tiwari BK. Effects of extrusion on the polyphenols, vitamins and antioxidant activity of foods. *Trends Food Sci Technol.* 2011;22(10):570-575. https://doi.org/10.1016/j.tifs.2011.05.007
81. Mahasukhonthachat K, Sopade P, Gidley M. Kinetics of starch digestion and functional properties of twin-screw extruded sorghum. *J Cereal Sci.* 2010;51(3):392-401. https://doi.org/10.1016/j.jcs.2010.02.008
82. Hur SJ, Lee SY, Kim YC, Choi I, Kim GB. Effect of fermentation on the antioxidant activity in plant-based foods. *Food Chem.* 2014; 160:346-356. https://doi.org/10.1016/j.foodchem.2014.03.112
83. Duhan J, Kumari N, Singh M, Garg B. General overview of composition, use in human nutrition, process of sprouting, change in composition during sprouting, parameters affecting nutritional quality during sprouting, benefits of sprouts, nutritional value and food safety issues of cereals/pseudo cereal sprouts. In: Advances in Plant Sprouts: *Phytochemistry and Biofunctionalities*. 2023:1-28. https://doi.org/10.1007/978-3-031-40916-5_1
84. Marco ML, Heeney D, Binda S. Health benefits of fermented foods: microbiota and beyond. *Curr Opin Biotechnol.* 2017; 44:94-102. https://doi.org/10.1016/j.copbio.2016.11.010
85. Tian B, Xie B, Shi J. Physicochemical changes of oat seeds during germination. *Food Chem.* 2010;119(3):1195-1200. https://

doi.org/10.1016/j.foodchem.2009.08.035

86. Bayana D, İçier F. Effects of process conditions on drying of tomato pomace in a novel daylight simulated photovoltaic-assisted drying system. *Food and Bioprocess Technology*. 2024:1-23.https://doi.org/10.1007/s11947-024-03411-2
87. Zhang LL, Wang YM, Wu DM, Xu M, Chen JH. Microwave-assisted extraction of polyphenols from Camellia oleifera fruit hull. *J Agric Food Chem.* 2011;59(15):8134-8141.
88. Park J, Kim HS. Rice-based gluten-free foods and technologies: a review. *Foods.* 2023;12(22):4110. https://doi.org/10.3390/foods12224110
89. Kaur B, Ranawana V, Henry J. The glycemic index of rice and rice products: a review, and table of GI values. *Crit Rev Food Sci Nutr.* 2016;56(2):215-236. https://doi.org/10.1080/10408398.2012.717976
90. Aung T, Kim BR, Kim S, Shin EC, Kim MJ. Comparative volatiles, amino acids, and phenolic compounds and characteristics of roasted germinated wheat (*Triticum aestivum L*.) during beverage preparation. *LWT.* 2023; 173:114412. https://doi.org/10.1016/j.lwt.2022.114412
91. Razzak A, Mahjabin T, Khan MRM, Hossain M, Sadia U, Zzaman W. Effect of cooking methods on the nutritional quality of selected vegetables at Sylhet City. *Heliyon.* 2023;9(11). https://doi.org/10.1016/j.heliyon.2023.e21709
92. Guiné RPF. Textural properties of bakery products: a review of instrumental and sensory evaluation studies. *Appl Sci.* 2022;12(17):8628. https://doi.org/10.3390/app12178628
93. Zhang Y. Investigating dough rheology and texture properties of bakery products containing soy or pulse flours. [dissertation]. Manhattan, KS: Kansas State University; 2021. Accessed 10th September, 2024 from: https://hdl.handle.net/2097/41422
94. Wannasin D, Grossmann L, McClements DJ. Optimising the appearance of plant-based foods using natural pigments and colour matching theory. *Food Biophys.* 2024;19(1):120-130. https://doi.org/10.1007/s11483-023-09809-3
95. Khoo HE, Azlan A, Tang ST, and Lim SM. Anthocyanidins and anthocyanins: colored pigments as food, pharmaceutical ingredients, and the potential health benefits. *Food Nutr Res*. 2017;61(1):1361779. https://doi.org/10.1080/16546628.2017.1361779
96. McClements DJ, Grossmann L. Next-generation plant-based foods. *Next-Generation Plant-Based Foods*. 2022. Available from: https://doi.org/10.1007/978-3-030-96764-2
97. Bi S, Wang A, and Lao F. Effects of frying, roasting and boiling on aroma profiles of adzuki beans (*Vigna angularis*) and potential of adzuki bean and millet flours to improve flavour and sensory characteristics of biscuits. *Food Chem.* 2021; 339:127878. https://doi.org/10.1016/j.foodchem.2020.127878
98. Liu SQ. Flavors and food fermentation. In: Handbook of Plant-Based Fermented Food and Beverage Technology. 2012:23-34.
99. Feyera M. Proximate, anti-nutrients and sensorial acceptability of some cereal and legume based composite biscuits*. Food Sci Qual Manag.* 2020; 98:18-25. Doi: 10.7176/FSQM/98-03
100. Civille GV, Carr BT, Osdoba KE. Sensory Evaluation Techniques. Taylor and Francis Group, UK: CRC Press; 2024.
101. Rodríguez-Méndez ML, De Saja JA, González-Antón R. Electronic noses and tongues in wine industry. *Front Bioeng Biotechnol.* 2016; 4:81. https://doi.org/10.3389/fbioe.2016.00081
102. Jati IRA, Darmoatmodjo LM, Suseno TI, Ristiarini S, Wibowo C. Effect of processing on bioactive compounds, antioxidant activity, physicochemical, and sensory properties of orange sweet potato, red rice, and their application for flake products. *Plants.* 2022;11(3):440. https://doi.org/10.3390/plants11030440
103. Paucar-Menacho LM, Simpalo-López WD, Castillo-Martínez WE, Esquivel-Paredes LJ, Martínez-Villaluenga C. Reformulating bread using sprouted pseudocereal grains to enhance its nutritional value and sensorial attributes. *Foods*. 2022;11(11):1541. https://doi.org/10.3390/foods