

Research progress on lentil-based composite flours: physicochemical, techno-functional properties, and high-performance food applications

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Abstract

As the global population continues to grow, there is an increasing need to explore alternative nutrition sources that are sustainable, affordable, and environmentally friendly. Lentils, from leguminous crops, are a promising option because of their high protein content and numerous health benefits. The Food and Agriculture Organization (FAO) has recommended the development of composite flours as an effective way to incorporate local, nutritious grains into food products. Composite flours are mixtures of different flours, often combining traditional grains with healthier alternatives like lentils. These flours are cost-effective, quick to produce, and improve food quality. While many studies explore lentil-based composite flours, few provide comprehensive reviews of their physicochemical and technological properties. Understanding these properties—such as water absorption, binding capacity, and effects on food texture and flavor—is crucial for predicting their quality and potential applications in various food systems. By reviewing the techno-functional and physicochemical characteristics of lentil-based composite flours, this study aims to fill that gap and provide insights that could promote the commercialization of food products made with these flours. Ultimately, this could help make healthier, sustainable food options more accessible to a larger population.

Keywords: composite flour, lentil, physicochemical properties, functional properties, farinograph

Introduction

The global population is projected to reach 10 billion by 2050; consequently, there will be a need to increase food production by 70% to meet demand. In response,

scientists have been exploring sustainable protein alternatives, particularly plant-based proteins, which have been extensively studied in food research. The plant-based options are generally more cost-effective, environmentally friendly, and protein-dense (Yekta *et al.*, 2023).

In addition, plant-based proteins are favored for ethical and consumer preference rationale compared to animal and insect proteins. A class of legumes (*Fabaceae* family) known as lentil (*Lens culinaris*) has gained wide attention as an excellent source of sustainable and low-cost animal protein alternatives. Lentil is free from gluten (an allergen) and contains slowly digestible carbohydrates and dietary fiber that lead to satiety (Didinger and Thompson, 2022). The lens-shaped edible lentil seeds are identified as Adas, Mercimek, Masoor, Messer, and Heramame in different parts of the world. Red and green lentils are more widely consumed because of their higher global production, availability, and incorporation into traditional dishes, while yellow and Spanish brown lentils are less common because of limited production and regional preference (Kaale *et al.*, 2023).

Global lentil production has increased substantially (Figure 1) over the past two decades. The lentil production recorded for 2022 is approximately 66.56×10^5 tonnes, and the major producers of lentils are Canada, India, Australia, and Turkey (FAO, 2022a). Traditionally, lentil seeds are the primary ingredient in homemade dishes, while lentil flour is used for commercially prepared snacks, both fried and extruded varieties. However, with the growing interest in protein-rich foods, research is exploring the development of a wider range of lentil-based applications across various food categories, including bread (Gallo *et al.*, 2022; Portman *et al.*, 2018), cheese analogs (Moradi *et al.*, 2021), biscuits (Turfani *et al.*, 2017), noodles (Bayomy and Alamri, 2022), extruded snacks (Ahmed *et al.*, 2024; Li *et al.*, 2022), and puffed snacks (Sinaki *et al.*, 2021). In addition, lentil applications are being explored in pet food (Pattanaik and Kore, 2022). Despite these studies, lentil flour-based products are not commercialized like products obtained from commercial cereal grains such as wheat, rice, and corn. This could be because most of the studies were

considerably focused on the characterization of lentil-based products. However, a few studies have explored the physicochemical properties of lentil-based composite flours and the products prepared. It must be considered that the applications of flours are mainly dictated by the findings of their physicochemical and techno-functional properties. Therefore, this review aims to offer a comprehensive insight into the research discoveries regarding the physicochemical and technological properties of composite flours containing lentil flour. The idea is to highlight this essential aspect of lentil-based composite as there is no recent and even old review (to the best of our knowledge based on an extensive literature review) that compiles the functional and physicochemical characterization of composite flours prepared using lentil flour.

Composite flours and their significance

Wheat crop (*Triticum aestivum* L.) is an important staple source of energy for countries in temperate zones, and its requirement is increasing in countries undergoing urbanization and industrialization, such as Pakistan, Nigeria, Tajikistan, Zimbabwe, etc. (Joshi *et al.*, 2014). Wheat flour when combined with other conventional or non-conventional flours to prepare a blend of flours is usually termed composite flour. The composite flours developed from various flour blends are extensively studied by scientists around the globe because of their significant importance in alerting nutritional profile, cost-effectiveness, development of specialty flour for celiac patients, utilization of indigenous crops, and contribution to food security (Moin *et al.*, 2024). For instance, in 2021–2022, Pakistan and Zimbabwe imported 248.6×10^4 and 172.7×10^3 tonnes of wheat, respectively (FAO, 2022a). The huge imports may affect the depleting foreign reserves of developing countries. Therefore, developing composite

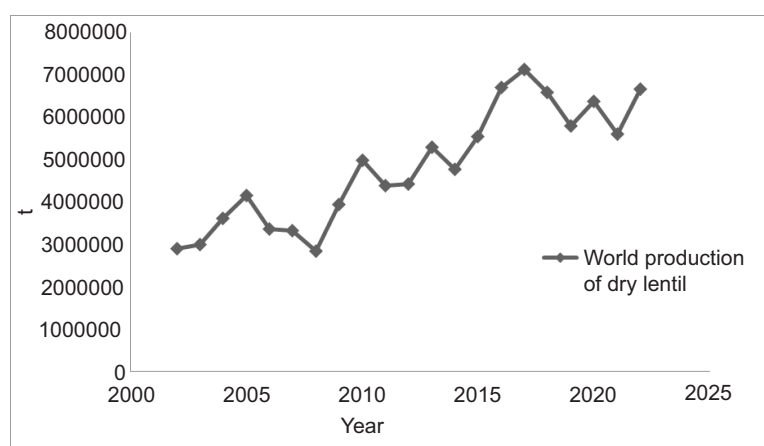


Figure 1. World production of lentils (2002–2022) based on FAO data (FAO, 2022b).

flours is crucial for human nutrition and economic stability. To target these global issues, FAO initiated a composite flour program in 1964, promoting the substitution of wheat flour with indigenous crops such as legumes, root crops, and millet (Banu *et al.*, 2021).

Lentils as a constituent of composite flour

Because of their rich protein profile, lentils are popular among populations with low financial resources and vegetarian dietary preferences. The higher protein (24–30%) and phenolic content of lentils compared to other legumes and commercial cereals make them a promising ingredient in the food industry (Kaur and Sandhu, 2010a). Lentils typically contain about twice as much protein as most cereals and a protein content comparable to meat. The essential amino acid content of lentil protein is 39.3 g/100 g. The lysine content in lentils ranges between 362 and 481 mg/g of lentil protein, while it is deficient in tryptophan and threonine (sulfur-containing amino acids) (Joshi *et al.*, 2017). On the contrary, cereal proteins are limited to essential amino acid lysine but have enough sulfurous amino acids. Therefore, blending lentil flour with other cereal flour to prepare composite flour provides all essential amino acids (Hera *et al.*, 2012). Subsequently, lentil composite flours, in view of their nutritional profile, seem to be the ideal flour for inclusion in food products (Figure 2). In literature, a number

of studies reported the inclusion of lentils in different ratios with staple crops like wheat (Bouhlal *et al.*, 2019), rice (Ghavidel and Prakash, 2010), corn (Ahmed *et al.*, 2024), and nonconventional crops such as millet (Waleed *et al.*, 2017), taro (Shongwe *et al.*, 2024), and chickpea (Bayomy and Alamri, 2022) to formulate composite flours. Different hydrocolloids (xanthan, carrageenan, guar, and Arabic gum) may be added in composite flours to overcome the processing hurdles because of low or no gluten content (Benkadri *et al.*, 2020).

It must be considered that the sugar profile is also altered in composite flours through the introduction of complexed and nonreducing sugars from nonwheat sources. Regardless of lentil quality, extrusion treatment, and blending proportion, the incorporation of lentil flour introduced the raffinose family oligosaccharides to the wheat–lentil blends (Portman *et al.*, 2018; Portman, *et al.*, 2020a; Portman, *et al.*, 2020b). Wheat flour predominantly contains fructose, glucose, sucrose, and maltose but no α -galacto oligosaccharides. The stachyose, sucrose, pinitol digalactoside ciceritol, verbascose, fructose, glucose, and raffinose (mentioned in descending order) were reported in the wheat–lentil blend (60:40) prepared with Lentil cv. Northfield and wheat variety cv. Elmore (Portman *et al.*, 2018). These raffinose family oligosaccharides are deemed to be anti-nutritional for monogastric species and human beings because of inadequate α -galactosidase enzymes (Sengupta *et al.*, 2015)

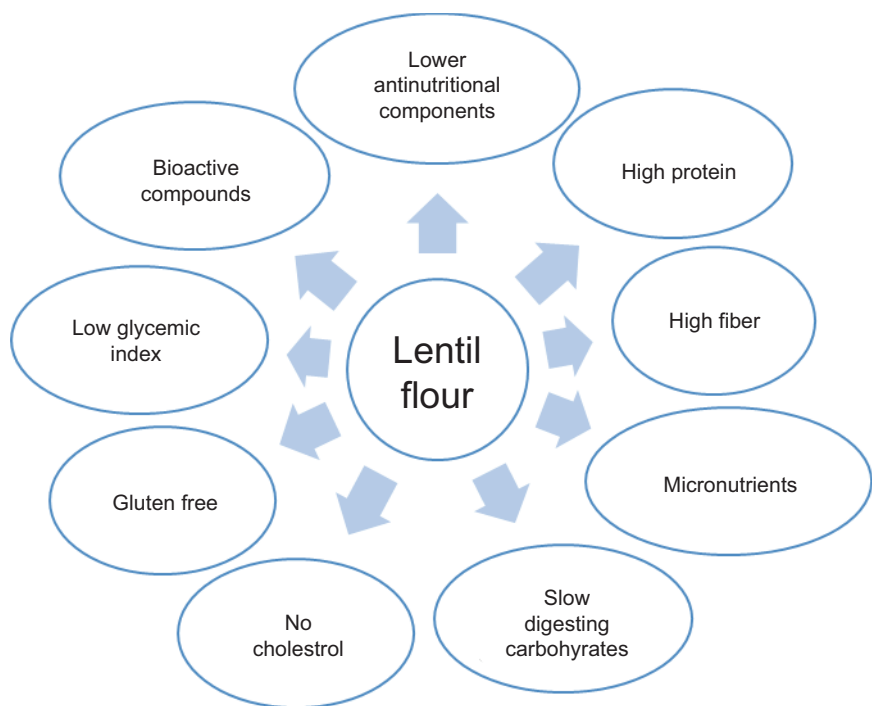


Figure 2. Health and nutritional significance of lentil flour.

and could cause irritable bowel syndrome (Siva and Thavarajah, 2018). However, there is evidence of their role as prebiotics and ultimately contributing to improved gut health after partial fermentation in the large intestine (Raman *et al.*, 2019). Considering the technological aspect, the development of high-quality yeast-leavened products is based on the availability of fermentable sugars. Portman *et al.* (2018) reported that wheat–lentil composites exhibited lower concentrations of fructose and glucose than wheat flour, leading to reduced yeast activity in the wheat–lentil blend.

Characterization of lentil-based composites flours

The success of composite flours in food applications depends on their functional properties. For instance, in baking, good water absorption helps handle the dough, while for products like ground meat, doughnuts, and pancakes, the ability to absorb oil is key (Mepba *et al.*, 2007). Therefore, to employ lentil-based composites in various food applications such as soups, extruded snacks, salad dressing, baked products, dairy, gluten-free (GF) foods, and other innovative food products, the lentil composite flours have been characterized. However, there is a lack of extensive studies on the characterization of lentil blends. Some of the most studied physicochemical and technological parameters of lentils and their composites with wheat and other nonconventional flours are discussed below.

Swelling power (SP)

SP reflects the ability of starch chains to interact with water and expand within the granule's crystalline and amorphous regions. The SP varies significantly across sources and cultivars because of differences in granule structure, amylose content, lipid content, and surrounding factors (Moin *et al.*, 2017). Moreover, temperature, pH, and solvent type also influence water–starch interactions, while the polymer network's crosslinking density and chain hydrophilicity determine the degree of swelling (Jia *et al.*, 2023). Understanding these factors allows tailoring flour or starch properties for desired textures and functionalities in various applications. The SP of red lentil flour was found to be dependent on the particle size of flour components and temperature. The lower particle size fractions (less than 100 μm) exhibited significantly higher SP than the whole and coarser fractions. Moreover, the SP of lentil flour increased with the rising temperature from 60°C to 80°C, and then it remained constant at 90°C (Marchini *et al.*, 2021). The swelling behaviors of lentil-based composite flours at different experimental conditions are summarized in

Table 1. In the wheat–taro–lentil composite, an increment in swelling was observed with the increase in taro flour proportion (0.85–1.41 mL/g), while reduced swelling was observed with an increase in black lentil flour proportions (1.41–0.45 mL/g). This could be attributed to the development of starch–protein complexes, which decreased the swelling capacity of the composite containing lentil flour in higher amounts as the protein content of lentils is relatively higher than taro (Shongwe *et al.*, 2024). Moreover, the swelling of the wheat–lentil (70:30) composite was significantly lower than that of wheat flour. On the contrary, Waleed *et al.* (2017) observed an insignificant difference in the swelling capacity of wheat flour (0.99 mL/g) and the composite flour containing wheat–lentil–millet flour (0.98 mL/g). Furthermore, for refined wheat flour and lentil flour composite, enhancement of SP with the increase in lentil flour ratio (10–50%) was reported by other researchers (Ashraf *et al.*, 2012). Similarly, Badia-Olmos *et al.* (2024) investigated the impact of fermentation and drying methods on lentil flour's swelling behavior. Their findings showed that raw lentil flour exhibited the lowest SP (2.50 mL/g), whereas fermentation combined with lyophilization significantly increased SP to 3.30 mL/g. In contrast, fermentation followed by hot air drying resulted in a moderate increase to 2.75 mL/g, suggesting that lyophilization was more effective in enhancing swelling capacity. These results highlight the influence of processing techniques on the functional properties of lentil flour, further emphasizing the role of starch structure modification and hydration behavior in composite flour applications. The proportion, hydrophilicity, number of composite flour components, the diversity of lentils and wheat cultivars, and the particle size of the flours, along with varied analysis conditions such as soaking time and temperature, could have contributed to the variation observed for the water absorption capacity of lentil composite flours. Recent studies have provided further insights into the SP of lentil-based flours, particularly regarding the role of lentil variety, starch structure, and thermal processing. Ahmed (2024) found that SP is strongly dependent on lentil variety and temperature conditions. Lentil flour from Matilda, Digger, and Cobber varieties exhibited SP ranging from 2.1 to 2.5 g water/g sample at 25°C, demonstrating moderate hydration potential at ambient conditions. However, when gradually heated from 25°C to 95°C at a rate of 5°C per minute, SP increased significantly to 5.8–6.3 g water/gram sample for lentil flour and 7.4–8.5 g water/gram sample for isolated lentil starch, highlighting the gelatinization behavior of starch under high temperatures.

The particle size of lentil flour also played a key role in hydration behavior, with finer fractions demonstrating higher swelling capacity because of greater surface area and water absorption potential. In addition, fermentation

Table 1. Swelling behavior of lentil flours and their composites.

Flours	Ratio in composite flour	Variety	Process conditions	Swelling power	Reference
Fermented-Lyophilized Lentil	100	<i>Lens culinaris</i> var. <i>variabilis</i>	Fermentation (14 days) + Lyophilization (-45°C, 48h)	3.30 mL/g	(Badia-Olmos et al., 2024)
Fermented, Lyophilized Lentil	100	<i>L. culinaris</i> var. <i>variabilis</i>	Fermentation (14 days) + Hot air drying (60°C)	2.75 mL/g	(Badia-Olmos et al., 2024)
Lentil Flour	100	Matilda, Digger, Cobber	25°C (Ambient)	2.1–2.5 g/g	(Ahmed, 2024)
Lentil Flour	100	Matilda, Digger, Cobber	Heated from 25°C to 95°C (5°C/min)	5.8–6.3 g/g	(Ahmed, 2024)
Lentil Starch	100	Matilda, Digger, Cobber	Heated from 25°C to 95°C (5°C/min)	7.4–8.5 g/g	(Ahmed, 2024)
Wheat:Lentil	90:10, 80:20, 70:30, 60:40, 50:50	Not specified	Heated at 85°C for 30 min	Increased from 80 to 300	(Ashraf et al., 2012)
Lentil	100%	Renka	Flour was soaked in distilled water for 18 h at room temperature	2.90 ± 0.13 (mL/g)	(Kohajdová et al., 2013)
Whole Wheat:Wheat: Lentil:Millet	42:24:22.5:11.5	Not specified	Flour was soaked in distilled water for 18 h at room temperature	1.02 ± 0.01 (mL/g)	(Waleed et al., 2017)
Wheat:Lentil	70:30	Black lentil	Flour was soaked in distilled water for 4 h at room temperature	0.85 ± 0.03 (mL/g)	(Shongwe et al., 2024)
Wheat:Taro:Lentil	70:10:20 70:15:15 70:20:10	Black lentil	Flour was soaked in distilled water for 4 h at room temperature	1.20 ± 0.01 (mL/g) 1.27 ± 0.09 (mL/g) 1.35 ± 0.03 (mL/g)	(Shongwe et al., 2024)
Raw Lentil	100	<i>L. culinaris</i> var. <i>variabilis</i>	Room temperature (23°C) for 20 h	2.50 mL/g	(Badia-Olmos et al., 2024)

and drying techniques influenced SP, with lyophilization enhancing hydration properties more than traditional drying methods. This suggests that processing techniques can be optimized to modify the hydration and swelling behavior of lentil-based ingredients for improved functionality in food formulations (Ahmed, 2024).

These results align with earlier findings on wheat–lentil composites, where higher lentil flour content led to lower swelling capacity because of protein–starch interactions. The formation of starch–protein complexes in high-protein lentil formulations could restrict starch granule expansion, as previously observed in black lentil flour–based mixtures (Shongwe et al., 2024). In addition, processing techniques such as fermentation and drying could further modify the hydration capacity of lentil starch, influencing the overall SP of composite flours (Ahmed, 2024; Badia-Olmos et al., 2024).

Overall, the swelling behavior of lentil-based composite flours is influenced by multiple factors, including flour composition, particle size, wheat and lentil cultivars, protein–starch interactions, and processing conditions.

The significant reduction in SP observed in sprouted lentil flour formulations suggests that sprouting alters the starch matrix, impacting dough hydration properties and the final texture of bakery products. The findings from the Ahmed (2024) study reinforce that lentil starch swells significantly more than whole lentil flour, emphasizing the role of starch purity and processing techniques in hydration behavior. These insights are critical for formulating functional composite flours with modified swelling capacities, particularly in applications requiring controlled starch gelatinization and hydration behavior.

Water absorption capacity

Water absorption capacity usually refers to the quantity of water absorbed per gram of a sample and estimates the availability of water-binding sites (Moin et al., 2016). Understanding the interaction of flour with water is a crucial parameter throughout the processing and storage of food products. This knowledge facilitates stabilizing and modifying the food’s textural attributes to meet consumer preferences (Lutfi et al., 2023). Along with

various other intrinsic factors, lentil flour processing also impacts the water absorption capacity. The water absorption capacity of lentil composite flours prepared with whole wheat, refined wheat, taro, and millet flours at different experimental conditions are summarized in Table 2. Gandhi *et al.* (2022) studied the functional properties of two lentil varieties (LL1373 and LL931) and found significantly enhanced water absorption capacity for both lentil varieties after boiling (46.63–53.52%) and germination (26.44–30.05%), respectively. In the lentil composite system, the findings of Shongwe *et al.* (2024) suggested that the proportions of flour blends significantly affect the water absorption capacity. They observed that water absorption capacity was enhanced with a rise in the ratio of lentil flour. In contrast, it was reduced with a rise in the ratio of the taro flour in the

wheat–taro–lentil composite. Legume flours contain some hydrophilic components, such as polysaccharides, and generally exhibit higher water absorption capacity. Furthermore, the protein quality of legume flours also impacts their water absorption capacity (Kaur and Singh, 2005). Findings from Dragomir *et al.* (2025) further confirmed that the addition of lentil flour influences water absorption capacity in wheat-based doughs. Their study on composite wheat–black lentil flours and wheat-sprouted lentil flours demonstrated that water absorption was higher in composite flours than in wheat flour alone. Wheat flour exhibited a water absorption capacity of 59.9%, whereas the inclusion of 10–20% non-sprouted black lentil flour increased absorption slightly to 60.1%. A similar trend was observed in sprouted lentil flour formulations, where water absorption varied between 56.9%

Table 2. Water absorption capacity of lentil composite flours and their composites.

Flour	Ratio in composite flour	Variety	Process conditions	Water absorption capacity	Reference
Raw Lentil	100	<i>Lens culinaris</i> var. <i>variabilis</i>	Room temperature (23°C) for 20 h	1.80 g/g	(Badia-Olmos <i>et al.</i> , 2024)
Fermented, Lyophilized Lentil	100	<i>L. culinaris</i> var. <i>variabilis</i>	Fermentation (14 days) + Lyophilization (−45°C, 48 h)	2.40 g/g	(Badia-Olmos <i>et al.</i> , 2024)
Fermented, Dried Lentil	100	<i>L. culinaris</i> var. <i>variabilis</i>	Fermentation (14 days) + Hot air drying (60°C)	2.10 g/g	(Badia-Olmos <i>et al.</i> , 2024)
Wheat:Lentil Flour	10–20 Lentils	Black lentil	Milled without soaking or sprouting	59.9–60.1%	(Dragomir <i>et al.</i> , 2025)
Wheat:Lentil Sprout	10–20 Lentils	Black lentil	Sprouted before milling	56.9–58.6%	(Dragomir <i>et al.</i> , 2025)
Wheat:Lentil	70:30	Black lentil	Distilled water and flour mixture was vortexed for 30 s, then left for 30 min at 25°C, followed by centrifugation at 3000 rpm for 25 min	1.23 ± 0.04 mL/g	(Shongwe <i>et al.</i> , 2024)
Wheat:Taro:Lentil	70:10:20 70:15:15 70:20:10	Black lentil	Distilled water and flour mixture was vortexed for 30 s, then left for 30 min at 25°C, followed by centrifugation at 3000 rpm for 25 min	1.15 ± 0.07 mL/g 1.11 ± 0.04 mL/g 0.99 ± 0.03 mL/g	(Shongwe <i>et al.</i> , 2024)
Whole Wheat: Wheat: Lentil: Millet	24:22.5:11.5	Not specified	Composite blended with distilled water, incubated for 30 min at 30 °C, followed by centrifugation at 3500 rpm for 25 min	188.48%	(Waleed <i>et al.</i> , 2017)
Wheat:Lentil	100:0, 90:10, 80:20	Not specified	Standard milling	55.20%, 57.40%, 70.20%	(Koubaier <i>et al.</i> , 2015)
Wheat:Lentil	90:10, 80:20, 70:30, 65:35, 60:40, 55:45, 50:50	Not specified	Farinograph analysis, mixed with water until 500 BU consistency	Decreased from 61.1% (control) to 58.6% at 10% lentil, then increased to 61.9% at 50% lentil substitution	(Ashraf <i>et al.</i> , 2012)

and 58.6% depending on the proportion used. These results align with previous studies indicating that lentil flours, particularly in nonsprouted form, contribute to an increased water retention capacity because of their higher protein and fiber content. In the study by Waleed *et al.* (2017), water absorption for composite flour containing whole wheat, wheat, lentil, and millet (42:24:22.5:11.5) was 188.48%, while wheat flour exhibited significantly lower water absorption (171.5%). Composite flours exhibiting higher water absorption capacity are advantageous for bakery, meat, and dairy product formulation applications. The enhanced water absorption is likely linked to increased amylose leaching and solubility, along with a breakdown in the crystalline structure of the starch (Hasmadi *et al.*, 2020). Moreover, the impact of fermentation and drying methods on lentil flour's water absorption was investigated by Badia-Olmos *et al.* (2024). Their findings showed that raw lentil flour had the lowest water absorption capacity (1.80 g/g), whereas fermented lyophilized lentil flour exhibited the highest absorption capacity (2.40 g/g). Fermentation followed by hot air drying resulted in a moderate increase (2.10 g/g), indicating that lyophilization enhanced water-holding capacity more effectively than conventional drying methods. These findings emphasize the role of processing techniques in modifying hydration properties, which is particularly relevant when incorporating lentil-based flours into composite flour systems. Further supporting these findings, the Koubaier *et al.* (2015) study demonstrated that water absorption capacity increases with a higher proportion of lentil flour in composite blends, reinforcing lentil flour's role in enhancing hydration properties. Their results showed that 100% wheat flour had a water absorption capacity of 55.20%, whereas incorporating 10% lentil flour increased water absorption to 57.40%. A more substantial increase was observed with higher lentil content, where 15% lentil flour raised water absorption to 67.50%, and 20% lentil flour resulted in the highest absorption capacity of 70.20%. These findings confirm that lentil flour's high fiber and protein content contribute to its superior water-binding ability, making it particularly suitable for dough-based products requiring higher hydration levels. The significant improvement in water absorption with increasing lentil flour ratio aligns with previous studies that highlight the importance of legume proteins and starch interactions in modifying flour hydration properties.

Oil-holding capacity

The capacity to hold oil refers to the quantity of oil that a food product could absorb during different cooking processes. Oil-holding capacity is a key attribute for the development of edibles where fat absorption is desirable for palatability, retention of flavors, and

extension of shelf-life (Adebowale and Lawal, 2004). Shongwe *et al.* (2024) reported that the proportion of lentils in the composite flour (containing wheat, lentil, and taro) significantly influenced the capacity to hold oil, and there was an increase in oil-holding capacity with an increment in the amount of lentil flour. Oil absorption is mainly associated with hydrophobic proteins in the flour (Manyatsi *et al.*, 2020). Also, the physical interaction of oil with proteins through capillary action could lead to increased oil-holding capacity (Katunzi-Kilewela *et al.*, 2023). Furthermore, treatments such as the germination of lentils also significantly enhance the oil-holding capacity of flour (Oskaybaş-Emlek *et al.*, 2021). In addition, the particle size of lentil flour could affect oil absorption. The oil absorption capacity of Indian and Turkish split red lentil seeds was studied and for each fraction, the oil absorption enhanced with a reduction in particle size from 210 to 105 μm ; however, the quantity reduced after that for the smallest particle size (74 μm) (Ahmed *et al.*, 2016). The functional uses of lentil flour associated with oil absorption capacity are enhancement in texture, better cooking quality, improved sensory acceptability, and increment of shelf life (Romano *et al.*, 2021).

Oil emulsion capacity

Emulsifying ability is another imperative physicochemical trait that may directly affect the application of lentil flour in food formulations. The functional uses of lentil flour associated with their emulsification behavior are control of creaming, coalescence, flocculation, and sedimentation (Romano *et al.*, 2021). Du *et al.* (2014) compared whole legume flours and reported that lentils (*L. culinaris* M.) exhibited a higher ability to form an emulsion than chickpeas (*Cicer arietinum* L.), lima beans (*Phaseolus vulgaris* L.), and mung bean (*Vigna radiate* L.). Waleed *et al.* (2017) reported whole wheat–wheat–lentil–millet (42:24:22.5:11.5) blend exhibited enhanced (52.98%) emulsifying capacity while it was found to be 32.9% for wheat flour. This is attributed to the proteins present in lentils having hydrophobic sites. They lower interfacial tension and form a thin film around oil droplets in an aqueous medium (Romano *et al.*, 2021). Moreover, the emulsion-forming capacity of lentil varieties, namely, Maxim, Invincible, and Greenland, was found to be impacted by flour processing; for instance, roasting of flour reduced the emulsion ability while germination enhanced it (Najib *et al.*, 2023). Conclusively, the improved emulsification ability, emulsion stability, and lipid binding of composite flours during food processing are primary functional properties of the proteins in food products like plant-based meat, value-added salad dressings, frozen desserts, and sauces such as mayonnaise (Hasmadi *et al.*, 2020).

Bulk density

The bulk density of a flour sample describes its heaviness (Oladele and Aina, 2007). Technically, it quantifies the mass of a material in a unit volume, together with the volume of all inter-particle spaces. The estimation of the bulk density of flour is necessary for designing, procuring, or selecting suitable equipment required for the transportation, packaging, and storage of flour (Ahmed *et al.*, 2022). Legume flour bulk density is critical in food formulation for different consumer groups. Lower bulk density flours are advantageous for weaning food formulation as they allow for the incorporation of greater nutrient content without compromising portion size or feeding volume. Conversely, flours with higher bulk density are better suited for applications requiring structure and stability, such as in various liquid, semi-solid, and solid food preparations (Hasmadi *et al.*, 2020). Du *et al.* (2014) compared 10 legumes, namely, pinto bean, lima bean, red kidney bean, black bean, navy bean, small red bean, black eye bean, mung bean, lentil, and chickpea, and found that the highest bulk density was exhibited by lentil flour (0.816 ± 0.01 g/mL), suggesting that it is heavier than other legume flours (Du *et al.*, 2014). The bulk density of lentil flour is reported to differ with variety and particle size (Ahmed *et al.*, 2016). The recent review concluded that the bulk density of composite flour increased with an increment in the proportion of different flours with wheat flour (Hasmadi *et al.*, 2020). An increment in bulk density with the increase in the ratio of lentil flour in the wheat–taro–lentil blend was reported by others (Shongwe *et al.*, 2024). In contrast, bulk density is reduced for the composite of lentil, millet, and whole wheat flour (Waleed *et al.*, 2017). This contrast in bulk density of lentil-based composite flour could be because of the difference in ratios of components (presence of taro flour in the former and millet in the later composite flour), particle size of flours, type of mill used for flour production (disk, stone, cyclone, centrifugal or hammer mill), and mill settings (presence or absence of screen) (Fernando and Manthey, 2021).

Dough rheology

A farinograph is generally employed to study the rheology of dough prepared with wheat flour and its blends. The parameters frequently studied are consistency, degree of softening, water absorption, dough development time, dough stability, and farinograph quality number (Ahsan *et al.*, 2023). For wheat–green lentil (Turfani *et al.*, 2017), whole wheat–wheat–lentil–millet (Waleed *et al.*, 2017), and wheat–lentil (Bouhlal *et al.*, 2019) composites, the dough development time was lengthened, and stability was reduced. Longer dough development time could be elucidated because of the

interactions of nonwheat proteins and fiber with gluten, leading to a delay in hydration and the formation of a gluten network in the presence of these ingredients (Dhinda *et al.*, 2012). Moreover, significantly reduced dough stability and development time were also observed for a 5–40% blend of wheat–lentil (gray seed coat with orange–red cotyledon) (Portman *et al.*, 2018) and refined wheat flour and lentils (*Lens esculenta* L., var. Renka) (Kohajdová *et al.*, 2013). The dough stability corresponds to dough strength, and elevated values indicate that the dough is well-built and exhibits tolerance and flexibility in mixing and blending operations. The primary reasons for the reduced dough stability of lentil composite flours are the weakening of the gluten network and the dilution of the gluten by lentil proteins (Hasmadi *et al.*, 2020). On the contrary, Ashraf *et al.* (2012) reported insignificant changes in dough development time and stability for 20% to 50% lentil and refined wheat flour blends. Water absorption in farinographic assessment reflects the water required to produce dough with optimum consistency. In general, water absorption is enhanced after the incorporation of lentil flour (Bouhlal *et al.*, 2019; Turfani *et al.*, 2017; Waleed *et al.*, 2017). However, Ashraf *et al.* (2012) have observed insignificant change in the amount of absorbed water at higher substitution levels (40–50%) of lentil flour. Moreover, Portman *et al.* (2018) reported reduced water absorption for lentil composites containing more than 10% lentil proportion. A farinographic water absorption study of composite flours prepared with red lentil cotyledon flour (var. Northfield) and wheat flour (var. Elmore) revealed that vital wheat gluten powder increased water absorption. Specifically, water absorption increased significantly at 10% lentil flour proportion without gluten powder and up to 20% lentil flour proportion after the addition of wheat with gluten powder in wheat–lentil composite (Portman *et al.*, 2018). The blend of wheat flour (var. Khadija) and lentil (var. Bakria) showed increased farinographic water absorption from 58.6% to 61.9% when the lentil proportion increased from 10% to 50% (Bouhlal *et al.*, 2019).

The degree of softening indicates the mixing tolerance of flour before fermentation, and it is calculated 12 min. after the dough has attained maximum consistency. The degree of softening increased with the increased ratio of lentil flour in the composite (Ashraf *et al.*, 2012; Bouhlal *et al.*, 2019). This could be because of lesser gluten content and a weaker protein network in the composite dough. The divergence observed in the farinographic findings of lentil-containing composite flours in the studies as mentioned earlier could be because of the difference in lentil flour proportion, presence or absence of seed coat, type of wheat flour (whole, refined, or durum), and added components such as gluten or other flours. The seed coat and fiber present in whole wheat flour could impact the water absorption of composite flour.

Pasting properties

Pasting properties are the most evaluated technological characteristics for cereal-based flours. Pasting study details the cooking performance of starches/flours during heating and cooling cycles. Brabender viscoamylograph, rheometer, and rapid visco analyzer are frequently employed to scrutinize the pasting characteristics. Pasting attributes (pasting temperature, peak viscosity, time to attain maximum viscosity, setback, breakdown, hot paste and cold paste viscosities) have proven to be a reliable predictor of flour quality, consequently proving to be one of the deciding factors of flour applications. Waleed *et al.* (2017) studied the pasting profile of lentil composite flour containing whole wheat, wheat, lentil, and millet (42:24:22.5:11.5) and compared it with whole wheat–refined wheat composite flour (65.5:34.5) and refined wheat flour. Lentil flour (22.5%) containing composite flour exhibited lower peak viscosity, final viscosity, breakdown, and setback than refined wheat flour and the mixture of wheat and whole-wheat flour. This could be because of the dilution of gluten and enhancement of the protein content of lentil-based composite flour. Jabeen *et al.* (2018) studied a blend of barley, lentil, and pumpkin flour prepared to develop extruded snacks in which pumpkin content was kept constant (7.5%) in all the batches. Barley content varied from 50 to 90%, lentil flour content ranged from 2.5 to 42.5%, and it was distributed in five batches. Pasting temperature increased with the decline in the lentil flour concentration, that is, from 73.45 to 85.50°C. Similar observations were made for peak, final, and setback viscosity from 1197 to 1369 cP, 1852 to 2350 cP, and 794–1087 cP, respectively. However, the opposite trend was observed for breakdown viscosity, suggesting the increment in lentil percentage would lead to lower shear stability of the gel. This attribute is essential, especially in lentil composite–based soups, gravies, and condiments, if product processing involves pressure-cooking, pumping, and high-speed mixing operations.

Color

Color is a significant marketing factor and a primary quality attribute of food processing and product development (Zhang *et al.*, 2014). The color of food components and processed foods is usually studied in terms of L^* , a^* , and b^* values. The L^* value corresponding to 100 indicates white color while the zero L^* value depicts black color. The positive a^* value indicates redness, and the negative a^* value represents the greenness of the sample. Furthermore, the positive b^* value indicates yellowness, while the negative b^* value correlates with the blueness of the sample (Ahsan *et al.*, 2023). Bouhlal *et al.* (2019) reported that whiteness values (L^*) of wheat–lentil

mixtures decreased significantly as the lentil flour incorporation ratio increased, and the same trend was obtained for the yellow–blue chromatic component (b^*). The results also indicated that the L^* value of the wheat–lentil–taro blend decreased with an increase in lentil flour proportion and enhanced with an increment in the ratio of taro flour (Shongwe *et al.*, 2024). The reduction in the whiteness of flour composites containing lentil flour as a component could be because of the broad range of colors (yellow, orange, red, and green) of lens-shaped lentil cotyledon. Moreover, the seed coat could also contribute to the overall hue of lentil composite flour. Nevertheless, it is reported that the color values of lentils vary with cultivars (Kaur and Sandhu, 2010b; Saleem *et al.*, 2019), particle size (Ahmed *et al.*, 2016; Lazou, 2024), seed size (Saleem *et al.*, 2019), and processing interventions like germination (Gandhi *et al.*, 2022; Oskaybaş-Emlek *et al.*, 2021), soaking, and boiling (Gandhi *et al.*, 2022).

Applications of Lentil-Based Composites

Food products

Lentils, renowned for their rich nutrient profile, serve as a foundation for the development of a myriad of food products (Figure 3). Known for their high levels of protein, carbohydrates, and energy, along with a wealth of essential minerals, vitamins, phytochemicals, and fiber, lentils stand out as a prime ingredient for enhancing the nutritional value of gluten-free (GF) and various other edibles.

Researchers have delved into incorporating lentils into diverse products, recognizing their potential to elevate the healthfulness of offerings available to consumers (Table 3). In this context, Saleem *et al.* (2019) developed protein-enriched biscuits using lentil seed flour and wheat flour. These biscuits were intended to serve as a source of protein, dietary fiber, and essential nutrients. Various combinations of wheat flour and lentil flour were utilized, including ratios of 100:0, 93:7, 86:14, 79:21, and 72:28%. The findings revealed a significant increase in protein concentration and energy value upon partial substitution of wheat flour with lentil flour, particularly at levels of 21% and 28%, which exhibited the highest protein content. In addition, the sensory evaluation indicated that including lentil flour yielded the most favorable sensory attributes, especially at a 21% level. Hence, researchers recommend incorporating 21% lentil flour in biscuit formulations to offer value-added products to consumers and effectively address protein deficiency. Furthermore, Lazou (2024) investigated the formulation of different ratios of chickpea or lentil flours, ranging from 0 to 30%, in combination with *Triticum dicoccum* whole flour. Furthermore, they examined the



Figure 3. Lentils, their various types, and their applications in different food products.

utilization of oligofructose at 50% and 100% ratios as a substitute for sugar. These substitutions significantly impacted various quality characteristics, encompassing physicochemical properties like moisture content, water activity, color, sorption behavior, structural and textural attributes, and sensory properties. The study concluded that highly satisfactory legume-based biscuits with alternative sweeteners could be developed, particularly with a 50% oligofructose substitution and incorporation of legume flour (either chickpea or lentil) up to 30% (Lazou, 2024). In their study, Hajas *et al.* (2022b) explored the formulation of GF cookies utilizing green and red lentils (29.7–47.6%) in various proportions. They tested different combinations of whey protein (0–11.9%),

inulin as dietary fiber (0–6%), and xylitol as a sweetener (0–27.9%). The lentil-based cookies exhibited consistent textural attributes, with the addition of inulin resulting in increased hardness of cookies. Moreover, all cookies containing xylitol were less crumbly than the controls (lentil flour alone), resulting in crumblier, less hard, and crunchier products. In a study by Hajas, *et al.* (2022a), the potential of five different colored lentils (black, brown, green, red, and yellow) in developing GF cookies, with rice flour as a benchmark, was investigated. The findings revealed that depending on the specific parameter under consideration—whether it be physicochemical (such as protein content or antioxidant properties), morphological (geometry, texture), or sensory—each of

Table 3. Applications of lentil-based composites in different food products.

Food products	Flours	Ratio (%)	Lentil variety	Reference
Biscuits	Wheat/lentil	100:0, 93:7, 86:14, 79:21, 72:28	Masoor-93 and NIA-Masoor, Masoor, 2004 and Punjab Masoor	(Saleem <i>et al.</i> , 2019)
Biscuits	Wheat/lentil/chickpea	100:0:0, 90:10:0, 90:0:10, 70:30:0, 70:0:30, 70:15:15	Not specified	(Lazou, 2024)
Biscuits	Wheat/lentil	100:0, 75:25, 50:50, 0:100	Premium and frost affected red lentil	(Portman <i>et al.</i> , 2020b)
Gluten-free cookies	Lentil/xylitol/inulin/whey protein	29.7–47.6: 0–27.9: 0–6: 0–11.9	Green and red lentil	(Hajas, <i>et al.</i> , 2022b)
GF cookies	Rice/lentil	100:0, 0:100	Black, brown, green, red, and yellow	(Hajas, <i>et al.</i> , 2022a)
Bread	Lentil/wheat	6:94, 12:8, 24:76	Green lentil	(Turfani <i>et al.</i> , 2017)
Spaghetti	Durum wheat semolina/lentil	100:0, 60:40	Commercial lentil, ragusa lentil	(Di Stefano <i>et al.</i> , 2020)
Pasta	Durum wheat semolina/Lentil	100:0, 95:5, 90:10	Red, green, and black lentil	(Levent <i>et al.</i> , 2023)
Pasta	Lentil	100	Yellow lentil	(Bresciani <i>et al.</i> , 2021)
Pasta	Semolina/green pea/red lentil/grass pea	100:0:0:0, 95:5:0:0, 90:10:0:0, 85:15:0:0, 80:20:0:0, 95:0:5:0, 90:0:10:0, 85:0:15:0, 80:0:0:20	Red lentil	(Tetrycz <i>et al.</i> , 2020)
Pasta	Wheat/lentil	31.25:31.25, 25:37.5, 27.5:25	Not specified	(Yesenia <i>et al.</i> , 2023)
Instant noodles	Durum wheat flour/chickpea/yellow lentil	100:0:0, 85:15:0, 80:20:0, 75:25:0, 85:0:15, 80:0:20, 75:0:25	Yellow lentil	(Bayomy and Alamri, 2022)
Extruded snakes	Pumpkin/lentil/quinoa	25:75/50:50/75:25,50,50	Not specified	(Eftekharizyazdi <i>et al.</i> , 2024)
Extruded snakes	Corn/soybean/lentil	100:0:0, 60:40:0, 80:15:5, 85:7.5:7.5, 90:7:3	Not specified	(Gomes <i>et al.</i> , 2023)
Extruded snacks	Barely/lentil	45:55, 60:40	Green lentil	(Li <i>et al.</i> , 2022)
Extruded snacks	Wheat/lentil	100:0, 90:10, 60:20, 0:100	Premium and frost affected red lentil	(Portman <i>et al.</i> , 2020a)
Puffed snacks	Lentil	100	Red lentil	(Guillermic <i>et al.</i> , 2021)
Crackers	Maize/lentil	85:15, 70:30	Red lentil	(Abd El Sabor <i>et al.</i> , 2023)
Cakes	Wheat/lentil	100:0, 50:50, 0:100	Yellow and orange lentils	(Hera <i>et al.</i> , 2012)
Scones	Wheat/taro/lentil	70:10:20, 70:15:15, 70:20:10	Black lentils	(Shongwe <i>et al.</i> , 2024)
Wafer sheers	Wheat/lentil	100:20	Not specified	(Tufan <i>et al.</i> , 2020)
Tarhanas	Lentil	100	Red, green, and yellow lentils	(Göncü and Çelik, 2020)

these lentil flours displayed promising characteristics as raw materials for GF bakery items. They demonstrated nutritional and sensory attributes surpassing those of cookies made with rice. Consequently, lentils are poised to assume an increasingly pivotal role in creating novel

GF products, including cookies, offering nutritionally advantageous alternatives for individuals with celiac disease. Moreover, Abd El Sabor *et al.* (2023) studied GF crackers, prepared by the combination of maize and red lentil flour in two ratios (70:30 and 85:15, respectively).

They reported enhanced nutritional values and sensory properties of lentil composite crackers when compared to maize crackers.

Turfani *et al.* (2017) examined the impact of varying levels of green lentil flour (6–24%) on the development of functional wheat bread. They observed that blends containing lentil flour exhibited comparable water absorption to the control sample of wheat flour, while the dough displayed decreased stability and strength. Despite this, bread volumes from blends containing 6–12% lentil flour were similar to or even higher than wheat bread, improving the bread's nutritional profile by increasing dietary fiber and bioactive substances and enhancing its antioxidant capacity (Turfani *et al.*, 2017). Stefano *et al.* developed and characterized fortified spaghetti by incorporating lentil flours of various origins, including a commercial variety and a Sicilian local population, at 40% (w/w). Chemical analyses revealed that the incorporation of lentils into semolina notably increased the levels of lysine and threonine. Moreover, an augmentation in essential and branched-chain amino acids was observed. However, contrary to expectations, no increase in mono- and polyunsaturated fatty acids was observed in the fortified spaghetti, likely because of their loss during cooking (Stefano *et al.*, 2020). Levent *et al.* (2023) conducted a study exploring the impacts of substituting wheat semolina with red lentil flour, green lentil flour, and black lentil flour at varying ratios (0–10%) in pasta formulation. Their investigation revealed notable distinctions among the lentil varieties examined: black lentil flour displayed the highest levels of ash, crude fat, and phytic acid, while green lentil flour showcased superior antioxidant activity and total phenolic content. Regarding texture, pasta samples enriched with green lentil flour exhibited heightened firmness compared to those incorporating red and black lentil flour. This increased firmness was particularly evident at the highest incorporation ratio of lentil flour. However, it is worth mentioning that samples containing 10% lentil flour experienced higher cooking loss values compared to the control group. Furthermore, the supplementation of lentil flour substantially improved the nutritional composition of pasta samples, augmenting their protein, ash, total phenolic content, and antioxidant activity, as well as calcium, magnesium, zinc, and iron content. These findings suggest the feasibility of producing nutritionally enhanced pasta by integrating up to 10% green and black lentil flour while preserving satisfactory technological attributes (Levent *et al.*, 2023). Bresciani *et al.* (2021) conducted a study focusing on the impact of extrusion conditions on the cooking quality of 100% yellow lentil pasta. They also explored the relationship between processing conditions and starch properties in pulse pasta. The study demonstrated the feasibility of producing pasta from native yellow lentils using conventional extrusion or extrusion-cooking processes.

Contrary to findings regarding GF cereals, the researchers found that yellow lentils can be processed into dry pasta even without a pre-gelatinization step. Notably, pasta produced through extrusion cooking exhibited enhanced stability during cooking and resistance to overcooking, leading to firmer pasta than conventional extrusion methods. However, the acceptability of yellow lentil pasta still requires validation through sensory analysis. This step is crucial for confirming consumer preferences and ensuring product marketability. Overall, the study sheds light on the potential of yellow lentils as a viable ingredient for pasta production, offering insights into processing techniques and product quality (Bresciani *et al.*, 2021). Teterycz *et al.* (2020) investigated the potential of various legume flours as natural coloring agents in durum wheat semolina pasta. They fortified pasta formulations with 0–20% green pea, red lentils, and grass pea flours, employing lamination technology. The research underscored the capacity of legume flours to augment the color and amino acid composition of pasta products, notably identifying red lentil flour as the most effective coloring agent. Moreover, incorporating legume flour significantly enriched the pasta's protein and dietary fiber content, including total dietary fiber. Notably, the lysine content, a crucial amino acid limited in wheat products, exhibited a remarkable increase of 60–88% in pasta samples fortified with 15% legume flour. Integrating selected legume flours, particularly red lentil flour, into durum semolina pasta formulations holds promise for enhancing pasta color intensity, bolstering consumer acceptance, and improving its nutritional profile. This research suggests a viable avenue for fortifying pasta products with legume flours to meet aesthetic and nutritional demands (Teterycz *et al.*, 2020).

Yesenia *et al.* (2023) developed a lentil and turmeric-based pasta, scrutinizing three formulations with varying ratios of wheat flour to lentil flour (31.25:31.25, 25:37.5, 27.5:25%). Sensory evaluations revealed that the blend comprising 37.5% lentil and 25% wheat flour garnered the highest favor among panelists, displaying attributes akin to commercial pasta. In addition, microbiological and physicochemical analyses validate adherence to regulatory criteria. Notably, the resultant product exhibited an augmented protein content compared to traditional pasta formulations (Yesenia *et al.*, 2023).

Bayomy and Alamri (2022) investigated the enrichment of instant noodles with selected legume flours, namely, chickpea or yellow lentils, at substitution rates of 15, 20, and 25% to enhance their nutritional value. Enriching durum wheat flour with either lentil or chickpea flour improves protein, crude fat, ash, and crude fiber while reducing carbohydrate and energy content. The study observed increases in the total essential amino acids with

higher substitution ratios. They suggested that replacing durum wheat flour with 25% chickpea flour or 20% lentil flour could enhance the nutritional profile of instant noodles without compromising rheological properties, cooking characteristics, or sensory qualities.

Eftekhariyazdi *et al.* (2024) developed lentil–quinoa–pumpkin extruded snacks and explored the impact of extrusion conditions on their characteristics. The snacks were formulated with a blend of lentil and quinoa flours in a 50:50 ratio, along with pumpkin flour in varying proportions (25:75, 50:50, and 75:25%). Their findings revealed that incorporating 44.2% pumpkin flour in conjunction with lentil–quinoa (50:50%) resulted in an optimized product boasting a high fiber content of approximately 15%, protein content of 17.3%, and significant antioxidant properties. These attributes position the snacks as potential staples in the snack food market or as plant-based alternatives.

Gomes *et al.* (2023) evaluated an extruded protein snack by replacing corn flour with lentil flour and soybean protein. They tested various formulations with different ratios of corn, soybean, and lentil flour: 100:0:0, 60:40:0, 80:15:5, 85:7.5:7.5, and 90:7:3%. The study found a significant increase in protein content in all formulations, indicating the efficiency of replacing corn with textured soy and lentil protein, which could produce value-added foods. However, formulations with higher substitution rates experienced more significant changes in physical parameters and appearance. Li *et al.* (2022) investigated the extrusion of whole barley and green lentil flours at different blending ratios (45:55, 60:40%) to optimize fiber and protein-enriched snacks' physical and microstructural qualities. They found that the blend of barley and green lentils at a ratio of 45:55 exhibited the highest extrudate expansion and lowest hardness, followed by the 60:40% blend. The significance and novelty of the study lie in the potential of blending cereal and pulse flours in snack food applications to develop fiber and protein-enriched options that are not only nutritious but also texturally and structurally appealing. This approach offers a promising avenue for the development of healthier snack alternatives.

Hera *et al.* (2012) explored the addition of lentil flour to both layer and sponge cakes, examining varying concentrations (0, 50, and 100%) and assessing its effects on batter characteristics and the final product. They found that lentil flour could be integrated into cake recipes, offering a nutritional boost. However, the impact of lentil flour differed depending on the cake type, with layer cakes showing more pronounced effects than sponge cakes. The quality of the lentil flour, particularly its fineness, significantly influenced its batter performance. Finer lentil flours were preferred because of their better

integration and distribution. Furthermore, the choice of lentil cultivar could affect the color of the cake, adding another dimension to the selection process for optimal results. In addition, the lentil flour has also been incorporated in wafer sheets (Tufan *et al.*, 2020), puffed snacks (Guillermic *et al.*, 2021), scones (Shongwe *et al.*, 2024), and tarhanas (Göncü and Çelik, 2020).

Research has also explored the incorporation of frost-damaged lentils into baked and extruded products to mitigate food waste and enhance food security. Studies have demonstrated that replacing up to 25% of wheat flour with either premium or frost-affected lentil flour in biscuit formulations significantly improves nutritional value and functional properties without compromising quality (Portman *et al.*, 2020a). Similar findings were reported in extruded products (Portman *et al.*, 2020b), reinforcing the potential of utilizing downgraded lentils as a cost-effective alternative to premium-grade counterparts. These insights highlight the feasibility of integrating underutilized frost affected lentil into food production systems, promoting sustainability and resource efficiency.

Nonconventional products

Lentil protein isolates or flour have been examined for application in numerous nonconventional formulations, including meat-extender, lentil milk-like products, and extruded puffed snacks. At a 10% supplementation level, Serdaroğlu *et al.* (2005) evaluated the impact of lentil flours on proximate composition, cooking parameters, color, and sensory features of low-fat meatballs. The lentil flour resulted in the highest cooking yields, at 93.2%, fat and moisture retention, and a lighter product (highest L^* at 43.4). Using a 9-point hedonic scale, the scores are appearance (7.0), texture (7.0), flavor (7.3), and overall palatability (7.5). Baugreet *et al.* (2016) studied the impact of lentil flour at 3 and 7% inclusion in beef patty. Lentil flour samples were softer than controls, provided good textural features, and did not improve the protein content. In this sense, lentil flour augmented the tendency to hold moisture and fat during the cooking route and lower cook loss compared with controls, therefore applying a practical impact on beef patties' textures. In addition, the polysaccharides presented in lentil flour, alone or in combination with proteins, can create a network that traps water and avoids its release (Baune *et al.*, 2022). Jeske *et al.* (2019) prepared a novel lentil-based milk substitute (BMSs)-based protein (3.3% w/w) and sunflower oil (3.3%). The emulsion was homogenized with a two-stage high-pressure homogenizer at 180 bars. The newly developed milk product presented comparable organoleptic and textural profiles with commercial plant-based milk substitutes. Particularly, the hedonic scores were alike for

all the samples and “slightly liked” overall, except for the hemp-BMS. Physically, the lentil-milk analog had a relatively small mean droplet size (500 μm) and remained stable without separation for over 21 days. Boeck *et al.* (2022) prepared a yogurt alternative (YA) from lentil protein isolate and fermented it with three lactic acid bacteria, *Lc. citreum* TR116, *Lc. pseudomesenteroides* MP070, and *L. paracasei* FST 6.1. These authors pointed out that lentil base substrate, supported by typical acidification, was a proper environment for fermented strains (Boeck *et al.*, 2022). Texturally, the YA exhibited the behavior of typical nonstirred yogurts, elevated water-holding capacity, and a high acceptance score. Morales *et al.* (2015) produced a GF 100% pulse-based cracker snack using green and red lentils. The acceptance of the products presented higher scores by consumers. Remarkably, the good crispness of crackers containing red lentil flour was perceived. Nevertheless, the developed products exhibited a beany flavor, and their GF nature produced an unversed texture for many consumers. Cai *et al.* (2001) prepared bean curds from diverse protein fractions of six legumes. Textural analysis demonstrated that curds from lentils displayed the lowest values of cohesiveness, springiness, and hardness. In the Ryland *et al.* (2010) study, a snack bar was developed by micronized flaked lentils (MFL), and a proper mathematical model was predicted to link consumer acceptance and purchase intent. It should be noted that the sweet, grainy flavors of lentils are of the highest importance to consumers in this snack bar. Three of the six MFL formulations gained great mean acceptability values. At the same time, external preference mapping noted that lentil hardness, cohesiveness, cohesiveness of mass, and moistness had the most significant impact on consumer acceptability. To establish acceptable formulations for the fabrication of GF snack-type products, Morales *et al.* (2015) evaluated the variation provided by the extrusion cooking on phytochemicals and antioxidant activity in products reinforced with lentil flours. In this line, extrusion supported an expansion of soluble fiber, total phenolic, hydroxybenzoic, and hydroxycinnamic acids. Likewise, the antioxidant was enhanced. In addition, lentil-based snacks contribute to 27–41% of daily fiber intake. These authors concluded that the novel pulse-based flours could contribute to snack-type products with a stable nutritional/antioxidant composition.

Ma *et al.* (2013) examined the impact of lentil addition on color; physical stability; and rheological, microstructural, and sensory properties of salad dressings supplemented with raw and thermally treated lentil flour. In this study, the developed food product presented higher consistency coefficient (m) and apparent viscosity (η_{ap}) values than the control samples, which indicates the enhancement of the viscosity of these emulsion systems. In addition, salad dressing samples supplemented with lentils improved the

instrumental total color intensity and had higher scores for sensory firmness.

Lentils and their products could be a promising candidate to replace animal proteins since they prove to be an excellent source of protein and can affect nutritional value (Al-Attar *et al.*, 2022; Kaur and Sandhu, 2010b; Ladjal-Ettoumi *et al.*, 2016; Pastrana-Pastrana *et al.*, 2025; Quintero *et al.*, 2022; Shen *et al.*, 2024; Tang *et al.*, 2024). Lentil flour has a high content of proteins (ca 23–24%), fiber (ca 11–14%) (Romano *et al.*, 2021; USDA, 2018) and minerals like Fe, Zn, Ca, Mg, and K (Ramírez-Ojeda *et al.*, 2018). However, caution needs to be exercised since lentil flour, like most legume flours, can contain variable amounts of anti-nutritional factors (ANFs), including phytic acid, tannins, trypsin inhibitors, and oligosaccharides (Cimini *et al.*, 2024), which can be removed by pretreatments (soaking, cooking, extrusion, microwaving). As reported by Liberal *et al.* (2024), cooking and germination were the most effective methods for reducing ANFs and improving the physicochemical profile of lentils. More developed nonheat traditional processing techniques include high processing, irradiation, ultrasonication, ultrafiltration, and isoelectric precipitation, which can retain the quantity and quality of nutrients and anti-nutrients (Baik and Han, 2012; Bubelová *et al.*, 2018; Fouad and Rehab, 2015; Patterson *et al.*, 2017; Yadav *et al.*, 2018). Moreover, Carboni *et al.* (2024) showed that lentil flour could favor water incorporation and show more resistance to enzymatic digestion than rice flour. Adding lentil flour formulations demonstrated an improvement in specific volume and alveolar parameters. Higher values of particular volume ($3.2 \text{ cm}^3 \text{ g}^{-1}$) were reported by Gularte *et al.* (2012) following the evaluation of GF cakes with lentil flour compared to the control ($2.7 \text{ cm}^3 \text{ g}^{-1}$).

Another critical factor that should be considered is particle size, which affects pasting, gelling, and other physicochemical attributes of flours and, hence, lentil flours, and this affects their roles as thickeners, gelling agents, binders, and stabilizers in food systems (Lee *et al.*, 2024). So, pulse flours show higher pasting viscosities and lower starch gelatinization temperatures if they display a finer particle size generally in comparison with the corresponding coarse flours (Ai *et al.*, 2017; Bourré *et al.*, 2019; Kaiser *et al.*, 2019; Kerr *et al.*, 2000; Tinus *et al.*, 2012). In this context, as the particle size increased, the strength of lentil flour gels strength, as reported by Cheng *et al.* (2023). Moreover, Yuan *et al.* (2021) stated that lentil flour required a cooking temperature $\geq 120^\circ\text{C}$ to display the maximum peak viscosities. There are no standards regarding the particle size requirements of pulse flours in the industry (Bourré *et al.*, 2019). Lentil flour can be considered as an alternative source of protein (Bravo-Núñez and Gómez, 2023), since chickpeas, beans, and lentils

contain 20–30% protein (Shevkani *et al.*, 2019). On the other hand, the foaming, emulsifying, and gelling capacity properties of concentrates and isolates depend on pH and ionic strength, as reported by Moussaoui *et al.* (2024) who reported that lowering the pH improved the viscosity of the flour paste. Finally, pulse flours can be added to the enrichment of bakery products, snacks, baby foods, and sports foods (Escobedo and Mojica, 2021; Maia *et al.*, 2021; Patrascu *et al.*, 2017; Rachwa-Rosiak *et al.*, 2015; Romero and Zhang, 2019).

Conclusions and Future Trends

Many approaches have been introduced to the food industry to prepare a wholesome cereal-based food product. However, the development of composite flour appears relatively more straightforward, economical, and sustainable. Applications of individual flours and their composite flours are primarily dictated by the findings of their physicochemical and techno-functional properties, which are influenced by the composition, structure, and ratio of composite flour components. Therefore, the extensive exercise of compiling and comparing the functional behavior of lentil flour-based composite would be a steppingstone to explore further and employ the full potential of lentils in the flour composite. Subsequently, affordable and healthy food products preferred by financially constrained, vegan, gluten intolerant, and protein-enriched foods demanding consumers will be developed. Moreover, a deep understanding of the formulation and processing affecting gelling, emulsifying, or foaming properties will be vital in developing new plant-based alternatives, specifically lentil-based ones. As the need for sustainable foods, precisely protein sources, is growing, the need to characterize widely cultivated and wild lentil varieties in combination with other locally available cereals is emerging. Therefore, a systematic database with information about the essential functional characteristics of flour combinations is needed for widespread commercial use of lentil flour and its composites.

Author Contributions

A.M. did the conceptualization; A.M., E.H., S.S., and T.V. took care of methodology; E.H. was responsible for software; A.M. and E.H. did validation, managed resources, and took care of writing—review and editing; S.S. was in charge of formal analysis; X.X. did the investigation; A.M., E.H., S.S., and T.V. did data curation; A.M., E.H., S.S., and T.V. concentrated on writing—original draft preparation; T.V. was responsible for visualization, supervision, funding acquisition; A.M. was responsible for project administration. All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

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References

- Abd El Sabor R.G.E.R., Ahmed Sadeek R. and Sayed K.M. 2023. Development of functional and rheological properties of bakery products from maize, lentil, and chickpea flours. *مجلة البحوث في مجالات التربية النوعية* 9(48), 163–195. <https://doi.org/10.21608/JEDU.2023.237838.1938>
- Adebowale K.O. and Lawal O.S. 2004. Comparative study of the functional properties of bambarra groundnut (*Voandzeia subterranean*), jack bean (*Canavalia ensiformis*) and mucuna bean (*Mucuna pruriens*) flours. *Food Research International* 37(4): 355–365.
- Ahmed J. 2024. A comprehensive review of the rheological properties of lentil flour and starch for food applications. *Legume Science* 6(3): e255. <https://doi.org/10.1002/LEG3.255>
- Ahmed J., Giri B.R., Reza M.A., et al. (2024). Twin-screw extrusion of vitamin D3/iron-blend granules in corn and lentil composite flours: Stability, microstructure, and interaction of vitamin D3 with human osteoblast cells. *Journal of Food Science* 89(1): 435–449.
- Ahmed J., Mulla M.Z., Siddiq, et al. 2022. Micromeritic, thermal, dielectric, and microstructural properties of legume ingredients: A review. *Legume Science* 4(1): e123.
- Ahmed J., Taher A., Mulla M.Z., et al. 2016. Effect of sieve particle size on functional, thermal, rheological and pasting properties of Indian and Turkish lentil flour. *Journal of Food Engineering* 186: 34–41.
- Ahsan M., Moin A., Ashraf H., et al. 2023. Technological, quality and nutritional characteristics of Ramen noodles with wheat flour partially substituted by water chestnut flour. *Italian Journal of Food Science* 35(4): 136–146.
- Ai Y., Jin Y., Kelly J.D., et al. 2017. Composition, functional properties, starch digestibility, and cookie-baking performance of dry bean powders from 25 Michigan-grown varieties. *Cereal Chemistry* 94(3): 400–408. <https://doi.org/10.1094/CCHEM-04-16-0089-R>
- Al-Attar H., Ahmed J. and Thomas L. 2022. Rheological, pasting and textural properties of corn flour as influenced by the addition of rice and lentil flour. *LWT* 160: 113231. <https://doi.org/10.1016/J.LWT.2022.113231>
- Ashraf S., Ghufra Saeed S.M., Sayeed S.A., et al. 2012. Impact of lentil fortification on physical, chemical and instrumental properties of dough and its influence on overall quality of cookies. *Arab Gulf Journal of Scientific Research* 30: 125–134.
- Badia-Olmos C., Sánchez-García J., Laguna L., et al. 2024. Flours from fermented lentil and quinoa grains as ingredients with new

- technofunctional properties. *Food Research International* 177. <https://doi.org/10.1016/j.foodres.2023.113915>
- Baik B.K. and Han I.H. 2012. Cooking, roasting, and fermentation of chickpeas, lentils, peas, and soybeans for fortification of leavened bread. *Cereal Chemistry* 89(6): 269–275. <https://doi.org/10.1094/CCHEM-04-12-0047-R>
- Banu M.T., Kaur J., Bhadariya V., et al. 2021. Role of consumption of composite flour in management of lifestyle disorders. *Plant Archives* (09725210), 21(2).
- Baugreet S., Kerry J.P., Botineştean C., et al. 2016. Development of novel fortified beef patties with added functional protein ingredients for the elderly. *Meat Science* 122: 40–47. <https://doi.org/10.1016/J.MEATSCI.2016.07.004>
- Baune M.C., Terjung N., Tülbek M.Ç., et al. 2022. Textured vegetable proteins (TVP): Future foods standing on their merits as meat alternatives. *Future Foods* 6: 100181. <https://doi.org/10.1016/J.FUFO.2022.100181>
- Bayomy H. and Alamri E. 2022. Technological and nutritional properties of instant noodles enriched with chickpea or lentil flour. *Journal of King Saud University-Science* 34(3): 101833.
- Benkadri S., Salvador A., Sanz T., et al. 2020. Optimization of xanthan and locust bean gum in a gluten-free infant biscuit based on rice-chickpea flour using response surface methodology. *Foods* 10(1): 12.
- Boeck T., Ispiryan L., Hoehnel A., et al. 2022. Lentil-based yogurt alternatives fermented with multifunctional strains of lactic acid bacteria-techno-functional, microbiological, and sensory characteristics. *Foods (Basel, Switzerland)*. 11(14): 2013. <https://doi.org/10.3390/FOODS11142013>
- Bouhlal O., Taghouti M., Benbrahim N., et al. 2019. Wheat-lentil fortified flours: Health benefits, physicochemical, nutritional and technological properties. *Journal of Materials and Environmental Science* 10(11): 1098–1106.
- Bourré L., Frohlich P., Young G., et al. 2019. Influence of particle size on flour and baking properties of yellow pea, navy bean, and red lentil flours. *Cereal Chemistry* 96(4): 655–667. <https://doi.org/10.1002/CCHE.10161>
- Bravo-Núñez Á. and Gómez M. (2023). Enrichment of cakes and cookies with pulse flours. A review. *Food Reviews International* 39(5): 2895–2913. <https://doi.org/10.1080/87559129.2021.1983591>
- Bresciani A., Giuberti G., Cervini M., et al. 2021. Pasta from yellow lentils: How process affects starch features and pasta quality. *Food Chemistry* 364. <https://doi.org/10.1016/J.FOODCHEM.2021.130387>
- Bubelová Z., Sumczynski D. and Salek, R.N. 2018. Effect of cooking and germination on antioxidant activity, total polyphenols and flavonoids, fiber content, and digestibility of lentils (*Lens culinaris* L.). *Journal of Food Processing and Preservation* 42(1): e13388. <https://doi.org/10.1111/JFPP.13388>
- Cai R., Klamczynska B. and Baik B.K. 2001. Preparation of bean curds from protein fractions of six legumes. *Journal of Agricultural and Food Chemistry* 49(6): 3068–3073. <https://doi.org/10.1021/JF0013398>
- Carboni A.D., Puppo M.C. and Ferrero C. 2024. Gluten-free lentil cakes with optimal technological and nutritional characteristics. *Journal of the Science of Food and Agriculture* 104(10): 6298–6310. <https://doi.org/10.1002/JSFA.13459>
- Cheng F., Ding K., Yin H., et al. (2023). Milling and differential sieving to diversify flour functionality: A comparison between pulses and cereals. *Food Research International* 163. <https://doi.org/10.1016/j.foodres.2022.112223>
- Cimini A., Poliziani A., Morgante L., et al. 2024. Antinutrient removal in yellow lentils by malting. *Journal of the Science of Food and Agriculture* 104(1): 508–517. <https://doi.org/10.1002/JSFA.12950>
- de la Hera E., Ruiz-París E., Oliete B., et al. 2012. Studies of the quality of cakes made with wheat-lentil composite flours. *LWT* 49(1): 48–54.
- Dhinda F., A. J.L., Prakash J., et al. 2012. Effect of ingredients on rheological, nutritional and quality characteristics of high protein, high fibre and low carbohydrate bread. *Food and Bioprocess Technology* 5(8): 2998–3006. <https://doi.org/10.1007/S11947-011-0752-Y/FIGURES/4>
- Di Stefano V., Pagliaro A., Del Nobile M.A., et al. 2020. Lentil fortified spaghetti: Technological properties and nutritional characterization. *Foods* 10(1): 4. <https://doi.org/10.3390/FOODS10010004>
- Didinger C. and Thompson H.J. 2022. The role of pulses in improving human health: A review. *Legume Science* 4(4): e147.
- Dragomir C., Dossa S., Jianu C., et al. 2025. Composite flours based on black lentil seeds and sprouts with nutritional, phytochemical and rheological impact on bakery/pastry products. *Foods (Basel, Switzerland)* 14(2): 319. <https://doi.org/10.3390/FOODS14020319>
- Du S., Jiang H., Yu X., et al. 2014. Physicochemical and functional properties of whole legume flour. *LWT-Food Science and Technology* 55(1): 308–313.
- Eftekhariyazdi M., Zenoozian M.S., Milani E., et al. 2024. Optimization of the extrusion parameters for the production of lentil-quinoa extrudates enriched with pumpkin. *Food Science and Technology International = Ciencia y Tecnología de Los Alimentos Internacional* 10820132241243240. <https://doi.org/10.1177/10820132241243240>
- Escobedo A. and Mojica L. 2021. Pulse-based snacks as functional foods: Processing challenges and biological potential. *Comprehensive Reviews in Food Science and Food Safety* 20(5): 4678–4702. <https://doi.org/10.1111/1541-4337.12809>
- FAO 2022a. Agricultural crops production and trade data. FAOSTAT.
- FAO 2022b. Lentil production data from 2002 to 2022. FAOSTAT.
- Fernando S. and Manthey F.A. 2021. Milling method affects the physical properties of black bean flour. *Cereal Chemistry* 98(3): 749–758.
- Fouad A.A. and Rehab F.M.A. 2015. Effect of germination time on proximate analysis, bioactive compounds and antioxidant activity of lentil (*Lens culinaris* Medik.) sprouts. *Acta Scientiarum Polonorum. Technologia Alimentaria* 14(3): 233–246. <https://doi.org/10.17306/J.AFS.2015.3.25>
- Gallo V., Romano A., Ferranti P., et al. 2022. Properties and in vitro digestibility of a bread enriched with lentil flour at different leavening times. *Food Structure* 33: 100284.

- Gandhi H., Toor B.S., Kaur A., et al. 2022. Effect of processing treatments on physicochemical, functional and thermal characteristics of lentils (*Lens Culinaris*). *Journal of Food Measurement and Characterization* 16(6): 4603–4614.
- Ghavidel R.A. and Prakash J. 2010. Composite weaning mixes: Formulation and quality characteristics. *Food Science and Technology Research* 16(1): 65–70.
- Gomes K.S., Berwian G.F., Tiepo, et al. 2023. Development and evaluation of extruded protein snacks added. *Food Science and Technology* 43. <https://doi.org/10.5327/FST.1123>
- Göncü A. and Çelik İ. 2020. Investigation of some properties of gluten-free tarhanas produced by red, green and yellow lentil whole flour. *Food Science and Technology* 40: 574–581. <https://doi.org/10.1590/FST.34919>
- Guillermic R.M., Aksoy E.C., Aritan S., et al. 2021. X-Ray microtomography imaging of red lentil puffed snacks: Processing conditions, microstructure and texture. *Food Research International* 140: 109996. <https://doi.org/10.1016/J.FOODRES.2020.109996>
- Gularte M.A., Gómez M. and Rosell C.M. 2012. Impact of legume flours on quality and in vitro digestibility of starch and protein from gluten-free cakes. *Food and Bioprocess Technology* 5(8): 3142–3150. <https://doi.org/10.1007/S11947-011-0642-3>
- Hajas L., Benedek C., Csajbókné Csobod É., et al. 2022a. Development of protein- and fiber-enriched, sugar-free lentil cookies: Impact of whey protein, inulin, and xylitol on physical, textural, and sensory characteristics. *Foods* 11(23): 3819. <https://doi.org/10.3390/FOODS11233819/S1>
- Hajas L., Sipos L., Csobod C., et al. 2022b. Lentil (*Lens culinaris* Medik.) flour varieties as promising new ingredients for gluten-free cookies. *Foods* 11(14): 2028. <https://doi.org/10.3390/FOODS11142028/S1>
- Hasnadi M., Noorfarahzilah M., Noraidah H., et al. 2020. Functional properties of composite flour: A review. *Food Research* 4(6): 1820–1831.
- Jabeen A., Hassan S., Masoodi L., et al. 2018. Physico-chemical composition and functional properties of blended flour obtained from lentil, pumpkin and barley for development of extrudates. *Journal of Food Processing & Technology* 9(1): 1–9.
- Jeske S., Bez J., Arendt E.K., et al. 2019. Formation, stability, and sensory characteristics of a lentil-based milk substitute as affected by homogenisation and pasteurisation. *European Food Research and Technology* 245(7): 1519–1531. <https://doi.org/10.1007/S00217-019-03286-0>
- Jia R., Cui C., Gao L., et al. (2023). A review of starch swelling behavior: Its mechanism, determination methods, influencing factors, and influence on food quality. *Carbohydrate Polymers* 121260.
- Joshi M, Aldred P, Panozzo J.F, et al. 2014. Rheological and microstructural characteristics of lentil starch–lentil protein composite pastes and gels. *Food Hydrocolloids* 35: 226–237.
- Joshi Matina, Timilsena Y. and Adhikari B. 2017. Global production, processing and utilization of lentil: A review. *Journal of Integrative Agriculture* 16(12): 2898–2913. [https://doi.org/10.1016/S2095-3119\(17\)61793-3](https://doi.org/10.1016/S2095-3119(17)61793-3)
- Kaale L.D., Siddiq M. and Hooper, S. 2023. Lentil (*Lens culinaris* Medik) as nutrient-rich and versatile food legume: A review. *Legume Science* 5(2): e169.
- Kaiser A.C., Barber N., Manthey F., et al. 2019. Physicochemical properties of hammer-milled yellow split pea (*Pisum Sativum* L.). *Cereal Chemistry* 96(2): 313–323. <https://doi.org/10.1002/CCHE.10127>
- Katunzi-Kilewela A., Rweyemamu L.M.P., Kaale L.D., et al. 2023. Proximate composition, pasting and functional properties of composite flour blends from cassava and chia seeds flour. *Food Science and Technology International* 29(3): 217–227.
- Kaur M. and Sandhu K.S. 2010a. Functional, thermal and pasting characteristics of flours from different lentil (*Lens culinaris*) cultivars. *Journal of Food Science and Technology* 47: 273–278.
- Kaur M. and Sandhu K.S. 2010b. Functional, thermal and pasting characteristics of flours from different lentil (*Lens culinaris*) cultivars. *Journal of Food Science and Technology* 47(3): 273–278. <https://doi.org/10.1007/S13197-010-0042-0>
- Kaur M. and Singh N. 2005. Studies on functional, thermal and pasting properties of flours from different chickpea (*Cicer arietinum* L.) cultivars. *Food Chemistry* 91(3): 403–411. <https://doi.org/10.1016/J.FOODCHEM.2004.06.015>
- Kerr W.L., Ward C.D.W., McWatters K.H., et al. 2000. Effect of milling and particle size on functionality and physicochemical properties of cowpea flour. *Cereal Chemistry* 77(2): 213–219. <https://doi.org/10.1094/CCHEM.2000.77.2.213>
- Kohajdová Z., Karovičová J. and Magala M. 2013. Effect of lentil and bean flours on rheological and baking properties of wheat dough. *Chemical Papers* 67: 398–407.
- Koubaier H.B.H., Snoussi A., Essaidi I., et al. 2015. Cake quality evaluation made of wheat–lentil flour blends. *Journal of New Sciences*. <https://www.jnsociences.org/agri-biotech/40-volume-special-journees-scientifiques-de-l-inat/198-cake-quality-evaluation-made-of-wheat-lentil-flour-blends.html>
- Ladjal-Ettoumi Y., Boudries H., Chibane M., et al. 2016. Pea, chickpea and lentil protein isolates: Physicochemical characterization and emulsifying properties. *Food Biophysics* 11(1): 43–51. <https://doi.org/10.1007/S11483-015-9411-6>
- Lazou A.E. 2024. Properties, structure, and acceptability of innovative legume-based biscuits with alternative sweeteners. *International Journal of Food Science* (1): 8216796. <https://doi.org/10.1155/2024/8216796>
- Lee D.J., Cheng F., Li D., et al. 2024. Important roles of coarse particles in pasting and gelling performance of different pulse flours under high-temperature heating. *Food Chemistry* 447: 138896. <https://doi.org/10.1016/J.FOODCHEM.2024.138896>
- Levent H., Kurt, E. and Şeref B. 2023. Investigation of the effects of red, green and black lentil flours on the physicochemical and technological quality of pasta. *Harran Tarım ve Gıda Bilimleri Dergisi* 27(4): 477–488. <https://doi.org/10.29050/HARRANZIRAAT.1318769>
- Li X., Guillermic R., Nadimi M., et al. 2022. Physical and microstructural quality of extruded snacks made from blends of barley and green lentil flours. *Cereal Chemistry* 99(5): 1112–1123.
- Liberal Â., Fernandes Â., Ferreira I.C.F.R., et al. 2024. Effect of different physical pre-treatments on physicochemical and techno-functional properties, and on the antinutritional factors of lentils (*Lens culinaris* spp). *Food Chemistry* 450: 139293. <https://doi.org/10.1016/J.FOODCHEM.2024.139293>

- Lutfi Z., Kalim Q. and Moin A. 2023. Characterization of water chestnut starch–xanthan gum complexes influenced by the addition of sucrose at different levels. *Journal of Raw Materials to Processed Foods* 4(2): 23–37.
- Ma Z., Boye J.L., Fortin J., et al. 2013. Rheological, physical stability, microstructural and sensory properties of salad dressings supplemented with raw and thermally treated lentil flours. *Journal of Food Engineering* 116(4): 862–872. <https://doi.org/10.1016/j.JFOODENG.2013.01.024>
- Maia L.C., Nano R.M.W., Santos W.P.C. dos, et al. 2021. Evaluation of the nutritional quality of cereal bars made with pulse flours using desirability functions. *Food Science and Technology International* 27(8): 702–711. <https://doi.org/10.1177/1082013220983080>
- Manyatsi N.T., Solomon W.K. and Shelembe J.S. 2020. Optimization of blending ratios of wheat-maize-sprouted mungbean (*Vigna radiata* L.) composite flour bread using D-optimal mixture design. *Cogent Food & Agriculture* 6(1): 1824304.
- Marchini M., Carini E., Cataldi N., et al. 2021. The use of red lentil flour in bakery products: How do particle size and substitution level affect rheological properties of wheat bread dough? *Lebensmittel-Wissenschaft & Technologie* 136: 110299.
- Mepba H.D., Eboh L. and Nwaojigwa S.U. 2007. Chemical composition, functional and baking properties of wheat-plantain composite flours. *African Journal of Food, Agriculture, Nutrition and Development* 7(1).
- Moin A., Ali T. M. and Hasnain A. 2016. Effect of succinylation on functional and morphological properties of starches from broken kernels of Pakistani Basmati and Irri rice cultivars. *Food Chemistry* 191. <https://doi.org/10.1016/j.foodchem.2015.03.119>
- Moin A., Ali T.M. and Hasnain A. 2017. Characterization and utilization of hydroxypropylated rice starches for improving textural and storage properties of rice puddings. *International Journal of Biological Macromolecules* 105: 843–851.
- Moin Abeera, Zaid M., Moin M., et al. 2024. Consumer acceptance and sensory properties of wheat-millet composite biscuits fortified with moringa oleifera and camellia sinensis leaves powder. *Current Research in Nutrition and Food Science Journal* 12(2): 686–698.
- Moradi D., Ziarati P. and Sawicka B. 2021. Physicochemical and rheological properties of lentil milk/inulin blend—A feta cheese analogue. *Legume Science* 3(4): e80.
- Morales P., Cebadera-Miranda L., Cámara R.M., et al. 2015. Lentil flour formulations to develop new snack-type products by extrusion processing: Phytochemicals and antioxidant capacity. *Journal of Functional Foods* 19: 537–544. <https://doi.org/10.1016/j.JFF.2015.09.044>
- Moussaoui D., Chaya C., Badia-Olmos C., et al. 2024. Effect of pH and calcium on the techno functional properties of different pulse flours, pastes, and gels. *Food and Bioprocess Technology* 17(8): 2292–2303. <https://doi.org/10.1007/S11947-023-03264-1>
- Najib T., Heydari M.M., Tu K., et al. 2023. Protein structural changes in lentil flour during soaking/germination and thermal treatments: Indication of nutritional and functional properties. *Food Chemistry Advances* 3. <https://doi.org/10.1016/j.focha.2023.100475>
- Oladele A.K. and Aina J.O. 2007. Chemical composition and functional properties of flour produced from two varieties of tigernut (*Cyperus esculentus*). *African Journal of Biotechnology* 6(21).
- Oskaybaş-Emlek B., Özbey A. and Kahraman K. 2021. Effects of germination on the physicochemical and nutritional characteristics of lentil and its utilization potential in cookie-making. *Journal of Food Measurement and Characterization* 15(5): 4245–4255.
- Pastrana-Pastrana Á.J., Flores-Gallegos A.C., Roa-Acosta D.F., et al. 2025. Rheological behavior of quinoa, lentil, and rice flour mixtures under different pH conditions. *Food Hydrocolloids* 158. <https://doi.org/10.1016/j.foodhyd.2024.110457>
- Patrascu L., Vasilean I., Banu I., et al. 2017. Functional properties of pulse flours and their opportunities in spreadable food products. *Quality Assurance and Safety of Crops and Foods* 9(1): 67–78. <https://doi.org/10.3920/QAS2015.0770>
- Pattanaik A.K. and Kore K.B. 2022. Partial replacement of soybean meal with red gram and lentil as vegetable proteins in limited ingredients homemade diets for pet dogs. *Legume Science* 4(2): e119.
- Patterson C.A., Curran J. and Der T. 2017. Effect of processing on antinutrient compounds in pulses. *Cereal Chemistry* 94(1): 2–10. <https://doi.org/10.1094/CCHEM-05-16-0144-FI>
- Portman D., Blanchard C., Maharjan P., et al. 2018. Blending studies using wheat and lentil cotyledon flour—Effects on rheology and bread quality. *Cereal Chemistry* 95(6): 849–860.
- Portman D., Dolgow C., Maharjan P., et al. 2020a. Frost-affected lentil (*Lens culinaris* M.) compositional changes through extrusion: Potential application for the food industry. *Cereal Chemistry* 97(4): 818–826.
- Portman D., Maharjan P., McDonald L., et al. 2020b. Nutritional and functional properties of cookies made using down-graded lentil—A candidate for novel food production and crop utilization. *Cereal Chemistry* 97(1): 95–103.
- Quintero J., Torres J.D., Corrales-Garcia L.L., et al. 2022. Effect of the concentration, pH, and Ca²⁺ ions on the rheological properties of concentrate proteins from quinoa, lentil, and black bean. *Foods* 11(19): 3116. <https://doi.org/10.3390/FOODS11193116>
- Rachwa-Rosiak D., Nebesny E. and Budryn G. 2015. Chickpeas—composition, nutritional value, health benefits, application to bread and snacks: A review. *Critical Reviews in Food Science and Nutrition* 55(8): 1137–1145. <https://doi.org/10.1080/10408398.2012.687418>
- Raman M., Saiprasad G.V.S. and Madhavakrishna K. 2019. From seed to feed: assessment and alleviation of raffinose family oligosaccharides (RFOs) of seed-and sprout-flours of soybean [*Glycine max* (L.) Merr.]—a commercial aspect. *International Food Research Journal* 26(1): 105–116.
- Ramírez-Ojeda A.M., Moreno-Rojas R. and Cámara-Martos F. 2018. Mineral and trace element content in legumes (lentils, chickpeas and beans): Bioaccessibility and probabilistic assessment of the dietary intake. *Journal of Food Composition and Analysis* 73: 17–28. <https://doi.org/10.1016/j.jfca.2018.07.007>
- Romano A., Gallo V., Ferranti P., et al. 2021. Lentil flour: Nutritional and technological properties, in vitro digestibility and perspectives for use in the food industry. *Current Opinion in Food Science* 40: 157–167.

- Romero H.M. and Zhang Y. 2019. Physicochemical properties and rheological behavior of flours and starches from four bean varieties for gluten-free pasta formulation. *Journal of Agriculture and Food Research* 1: 100001. <https://doi.org/10.1016/J.JAFR.2019.100001>
- Ryland D., Vaisey-Genser M., Arntfield S.D., et al. 2010. Development of a nutritious acceptable snack bar using micronized flaked lentils. *Food Research International* 43(2): 642–649. <https://doi.org/10.1016/j.foodres.2009.07.032>
- Saleem G., Soomro A.H., Rashid N., et al. 2019. Nutritional and functional evaluation of wheat flour biscuits supplemented with lentil flour. *Pakistan Journal of Agricultural Research* 32(2): 381–389. <https://doi.org/10.17582/JOURNAL.PJAR/2019/32.2.381.389>
- Sengupta S., Mukherjee S., Basak P., et al. 2015. Significance of galactinol and raffinose family oligosaccharide synthesis in plants. *Frontiers in Plant Science* 6: 150383.
- Serdaroğlu M., Yildiz-Turp G. and Abrodímov K. 2005. Quality of low-fat meatballs containing Legume flours as extenders. *Meat Science* 70(1): 99–105. <https://doi.org/10.1016/j.meatsci.2004.12.015>
- Shen P., Peng J., Sagis L.M.C., et al. 2024. Air-water interface properties and foam stabilization by mildly extracted lentil protein. *Food Hydrocolloids*, 147. <https://doi.org/10.1016/j.foodhyd.2023.109342>
- Shevkani K., Singh N., Chen Y., et al. 2019. Pulse proteins: Secondary structure, functionality and applications. *Journal of Food Science and Technology* 56(6): 2787–2798. <https://doi.org/10.1007/S13197-019-03723-8/METRICS>
- Shongwe T.N., Kidane S.W., Shelembe J.S., et al. 2024. Physicochemical and sensory attributes of scones made from wheat–taro (*Colocasia esculenta*)–lentils (*Lens culinaris*) composite flour. *Legume Science* 6(1): e216.
- Sinaki N.Y., Masatcioglu M.T., Paliwal J., et al. 2021. Development of cellular high-protein foods: Third-generation yellow pea and red lentil puffed snacks. *Foods* 11(1): 38.
- Siva N. and Thavarajah P. 2018. The impact of processing and cooking on prebiotic carbohydrates in lentil. *Journal of Food Composition and Analysis* 70: 72–77.
- Tang Q., Roos Y.H. and Miao S. 2024. Comparative studies of structural and thermal gelation behaviours of soy, lentil and whey protein: A pH-dependency evaluation. *Food Hydrocolloids* 146. <https://doi.org/10.1016/j.foodhyd.2023.109240>
- Teterycz D., Sobota A., Zarzycki P., et al. 2020. Legume flour as a natural colouring component in pasta production. *Journal of Food Science and Technology* 57(1): 301–309. <https://doi.org/10.1007/S13197-019-04061-5/TABLES/6>
- Tinus T., Damour M., Van Riel V., et al. 2012. Particle size-starch-protein digestibility relationships in cowpea (*Vigna unguiculata*). *Journal of Food Engineering* 113(2): 254–264. <https://doi.org/10.1016/j.jfoodeng.2012.05.041>
- Tufan B., Sahin S. and Sumnu G. 2020. Utilization of legume flours in wafer sheets. *Legume Science* 2(1): e12. <https://doi.org/10.1002/LEG3.12>
- Turfani V., Narducci V., Durazzo A., et al. 2017. Technological, nutritional and functional properties of wheat bread enriched with lentil or carob flours. *Lebensmittel-Wissenschaft & Technologie* 78: 361–366. <https://doi.org/10.1016/J.LWT.2016.12.030>
- Waleed A.L., Mahdi A.A. and Wang L. 2017. Rheological and physicochemical properties of lentil, millet and whole wheat flour as a composite flour. *International Journal of Research in Agricultural Sciences* 4(4): 2348–3997.
- Yadav N., Kaur D., Malaviya R., et al. 2018. Effect of thermal and non-thermal processing on antioxidant potential of cowpea seeds. *International Journal of Food Properties* 21(1): 437–451. <https://doi.org/10.1080/10942912.2018.1431659>
- Yekta R., Assadpour E., Hosseini H., et al. 2023. The influence of ionic polysaccharides on the physicochemical and techno-functional properties of soy proteins; A comprehensive review. *Carbohydrate Polymers* 319: 121191. <https://doi.org/10.1016/J.CARBPOL.2023.121191>
- Yesenia C.V., Mauricio C.L., and Francisco F.A.R. 2023. Evaluation of the physicochemical, microbiological and sensory properties of a pasta based on lentil flour and turmeric. *Biology and Life Sciences Forum* 26(1): 107. <https://doi.org/10.3390/FOODS2023-15043>
- Yuan T.Z., Liu S., Reimer M., et al. 2021. Evaluation of pasting and gelling properties of commercial flours under high heating temperatures using Rapid Visco Analyzer 4800. *Food Chemistry* 344. <https://doi.org/10.1016/j.foodchem.2020.128616>
- Zhang B., Deng Z., Tang Y., et al. 2014. Fatty acid, carotenoid and tocopherol compositions of 20 Canadian lentil cultivars and synergistic contribution to antioxidant activities. *Food Chemistry* 161: 296–304.