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COMPREHENSIVE REVIEW

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# A review of lentil (*Lens culinaris* Medik) value chain: Postharvest handling, processing, and processed products

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## Abstract

Lentils (*Lens culinaris* Medik.) are grown worldwide in diverse agroecological regions with significant global production and trade. Since early 2000s, lentils production and consumption have been growing beyond its traditional areas of production and utilization, notably in USA, Canada, Australia, UK, and many European Union countries. Lentils are a rich source of protein, minerals, and many bioactive compounds. Therefore, lentil-based products can offer a healthy food choice for all consumers, including those who are vegetarian or vegans, and/or looking for meat protein alternatives due to health and/or environmental concerns. In order to avail all the benefits that lentils offer, a quality maintenance approach is essential across value-chain operations of postharvest handling, storage, and value-added processing. In recent years, lentils have been used increasingly in a variety of value-added products and cuisines in the developed countries. Different processing methods, for example, cooking, autoclaving, extrusion, baking, roasting, fermentation, and sprouting, significantly improve protein bioavailability, total digestibility, and overall nutritional and organoleptic quality. A number of traditional and innovative processing techniques also have been used to produce lentil-based end-products or ingredients for various food applications. Overall, lentils are well positioned as a food legume crop to cater to emerging trends among consumers, especially those looking for healthy food choices, an alternative plant-based protein for global food security, and foods that are produced in environmentally friendly and agriculturally sustainable manner. Significant production and consumption trends for lentils clearly demonstrate enhanced value for consumers and further impact in contributions to a nutritious global food supply.

KEYWORDS
lentil, postharvest storage, processed products, quality defects, value-addition

## 1 | INTRODUCTION

Food legumes are a nutrient-dense staple consumed widely throughout the world. Among legumes, lentils are grown worldwide in diverse agroecological regions with significant global trade. Lentils originated in Mesopotamia (Turkey), with their consumption dating back to the early civilization (Chelladurai & Erkinbaev, 2020). Lentil is the most rapidly expanding crop among legumes, with an average annual growth of 10.3% since mid-1960s. Canada ranks first in lentil production, with 2.87 million metric tons (MMT), thus contributing about 44% of 6.54 MMT global production in 2020, followed by India, Australia, Turkey, and USA with 1.18, 0.53, 0.37, and 0.34 MMT, respectively. These five countries accounted for 82% of the total global output (FAO, Food and Agriculture Organization, 2021). Region-wise, production is led by Americas (with about 50% share of global tonnage), followed by Asia (38%), and Oceania (8%). Traditionally, India has been the foremost lentil producer but, in the last two decades, Australia, Canada, and U.S.A. have shown exceptional growth in lentil production as exhibited by about 220%, 210%, and 145% increases, respectively.

Nutritionally, lentils are an excellent source of protein (about 25%) and selected micronutrients, that is, minerals (calcium, iron, potassium, and zinc) and vitamins (vitamin A, vitamin C, and niacin). Lentil proteins have superior profile as compared to some other legumes, for example, peas and chickpeas. Moreover, lentils are an excellent source of dietary fiber (11% in green and 31% in red/pink lentils), slowly digestible starch, and several bioactive phytochemicals with reported health benefits. Although lentils contain around 60% carbohydrates, it is worthwhile to note that those carbohydrates are somewhat slowly digested in gut resulting in a low glycemic index of about 30, compared to reference 100 for white wheat bread (Dhull et al., 2022; Sidhu et al., 2022). Gowder (2015) reported that the consumption of lentil proteins or use of lentil proteins as a substitute to animal protein results in numerous positive health effects, i.e., mitigation and protection against diabetes, cardiovascular, and metabolic diseases. Lentil proteins are gaining increasing attention with respect to value-added utilization in diverse food applications, especially as plant-based meat alternatives/extenders.

A *Farm to Fork* quality maintenance approach must be employed across the value-chain operations of lentil production, postharvest handling and value-added processing (Joshi et al., 2017). The quality management of lentils starts in the field with the application of preharvest treatment of crop by desiccants, which makes lentils achieve uniform maturity, improve harvest efficiency, maximize crop yield, and enhance postharvest quality. Maintenance of lentil quality during postharvest handling and storage is critical for the economic value and consumers' acceptance of end-products. Red and green types of lentils are the most widely consumed varieties of this food legume. Lentils or lentil-based ingredients are used in diverse products, such as snack foods, flour mixes/doughs, ready-to-eat soups, baked goods, gluten-free products, and ethnic cuisines (Figure 1). Dhull et al. (2022) reported that various processing methods, such as cooking, autoclaving, extrusion, baking, roasting, germination, and fermentation, generally improve protein digestibility. Processing of legumes, like lentils, is also necessary to inactivate or significantly reduce antinutritional factors, for example, phytic acid, protease and amylase inhibitors, lectins, raffinose family oligosaccharides, and saponins (Patterson et al., 2017). This article provides an overview of lentil's postharvest quality management, postharvest handling, storage and losses, quality standards, value-added processing, lentil-based products, and innovative and emerging technologies for lentil processing.

## 2 | POSTHARVEST HANDLING OPERATIONS

Careful handling and appropriate postharvest storage are required for most legume crops, before marketing and consumption. Jones et al. (2012) noted that the major goals of legume grain handling, drying to a safe moisture level, and storage protocols are to maximize preservation and ensure end-quality. These goals are achieved by removing impurities, foreign matter, identifying and separating lots based on quality characteristics, drying (where needed), storing in appropriate facilities, monitoring storage conditions, and ensuring cleanliness and hygiene protocols for products, personnel, and facilities. Postharvest quality and quantity losses can occur due to improper handling, poor drying, and/or lack of proper storage facilities. The critical quality defect of damaged seed coat is impacted at all stages of harvest, handling, and storage. It is very important to minimize impact damage and seed coat abrasion at every phase of handling/transfer because the quality deterioration is cumulative and cannot be corrected or reversed. Damaged seed coats directly affect seed appearance and are generally indicative of overall quality due to associated adverse impact on cooking characteristics. This quality indicator commands much value and has economic consequences throughout the supply chain.

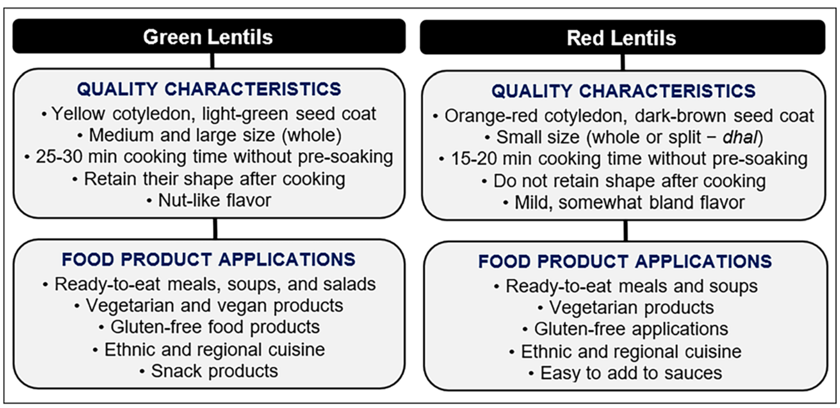


**FIGURE 1** Quality attributes and food product uses of major lentil types *Source*: Based on Pulse Canada (2012)

Figure 2 shows common postharvest operations for food legumes, such as lentils, with respect to receiving and cleaning before storage,nd packaging and warehousing of clean, graded grains, either for direct marketing or value-added processing. Uebersax, Siddiq, Cramer, and Bales (2022) reported that the overall final quality of pulses was mainly related to a control of critical chemical, physical, and biological processes during postharvest handling/storage and for ensuring safe and best-quality end-products. Quality of lentils, which is vulnerable to several problems during storage (insects, molds, rodents, and fluctuations in the storage conditions), requires implementation of appropriate safety protocols during postharvest storage of lentils.

## 2.1 | Drying—optimum storage moisture and quality

Typically, lentils require some form of drying to achieve optimum moisture level (13–14%) for effective storage and quality maintenance. The drying method employed should be according to the requirements and considerations related to the lentils' end-use quality attributes (Ghosh et al., 2007). It is recommended that threshed lentils have around 16–18% moisture. Lantin et al. (1996) reported that since the moisture level of harvested lentils is generally higher than that suitable for long-term storage, some degree of drying (usually with heated air) is employed. In developing countries, some postharvest losses also occur during traditional threshing of lentils, whereas such losses are minimal with mechanized harvesting and threshing in developed countries.

Lentil moisture content of closer to 20% presents some challenges as the crop is difficult to thresh without some degree of damage to lentil seeds. Furthermore, seed with ≥18% moisture requires higher energy input due to longer drying times, which can also be potentially detrimental to the quality (McVicar, 2006; SPG, 2012). It is worthwhile to note that, to maintain safe storage and optimum quality, some type of aeration may be needed to reduce grain temperature in the bins even when the crop is harvested at dry stage (Barker, 2016).

When mechanical drying is needed to lower moisture content of lentils to ~14%, the hot-air temperature in the dryer should not exceed 45°C to avoid seed shrinkage and preserve its germination capability. For red lentil, buyers and processors prefer 13% seed moisture content, which improves the efficiency of dehulling/splitting processes which ensures better quality (SPG, 2012). For automated drying, the use of batch dryers is time consuming and drying efficiency is also relatively low. Typically, continuous air-flow dryers are used for grain (legumes) drying, which could be *cross-flow*, *counter-flow*, or *concurrent-flow* with respect to the direction of air-flow (Jones et al., 2012).

## 2.2 | Storage conditions and shelf life

The most important determinants of grain quality during postharvest storage are moisture level of lentils, relative humidity (RH), storage temperature, and aeration. Bradford et al. (2018) reported that storage life at a given moisture content increases exponentially as both the storage temperature and equilibrium RH decrease. Bello and Bradford (2016) indicated that below 95% RH, the seed respiration stops, and bacteria are unable to grow below ~90% RH. Fungi are unable to grow and generally lose metabolic active below 65% RH, which closely corresponds with the recommended maximum moisture content of 12–14%, 13–15%, and 6–9% for safe storage of cereals, pulses, and oilseed crops, respectively (Bradford et al., 2018; FAO, 2014). Besides quality deterioration induced by microbes and insects, other specific quality changes that occur during storage are related to flavor deterioration, seed coat discoloration and hard-to-cook defect (i.e., slow water uptake and longer cooking time). All these defects have been reported to result in a substantial quality loss in legumes (Bello & Bradford, 2016; Uebersax, Siddiq, & Borbi, 2022).

Storage of lentils at 14% moisture is recommended for safe, long-term storage for the control of damage to the seed coat during handling. At 14% moisture and 15°C storage temperature, lentils can be stored safely for up to 40 weeks, as shown in Table 1 (Barker, 2016; McVicar, 2006). Regardless of the storage temperature, the storage

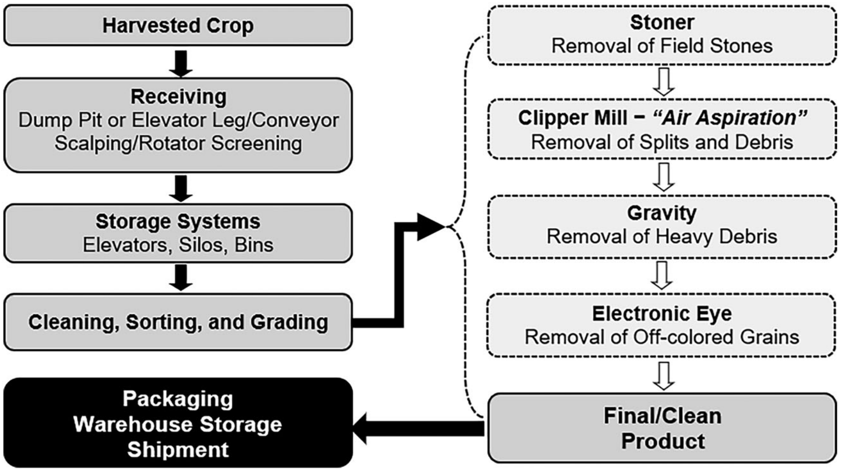


**FIGURE 2** Postharvest value-chain operations for raw legumes *Source*: Adapted from Uebersax, Siddiq, Cramer, and Bales (2022)

**TABLE 1** Weeks of lentil storage at the specific moisture levels and temperature range

| | Moisture content | | | | | |
|---|---|---|---|---|---|---|
| Temperature (°C) | 12% | 13% | 14% | 16% | 18% | 21% |
| 5 | 370[a] | 175[a] | 150[a] | 70[d] | 39[d] | 20[d] |
| 10 | 200[a] | 95[a] | 80[a] | 38[d] | 20[d] | 21[d] |
| 15 | 100[b] | 50[b] | 40[b] | 20[d] | 12[d] | 6[d] |
| 20 | 55[c] | 28[c] | 23[c] | 13[4] | 7[d] | 4[d] |
| 25 | 31[c] | 16[c] | 13[c] | 7[d] | 4[d] | 2[d] |

*Source*: Adapted from McVicar (2006); Barker (2016).
[a]Safe long term.
[b]Safe medium term.
[c]Safe short term.
[d]High risk (unsafe or quality at risk).

life decreases significantly at moisture contents above 16%. Peace et al. (1988) noted that appropriate storage conditions for lentils are 20°C temperature and 12% RH, which do not incur any significant negative impact on protein quality for up to 3 years. Lentils are susceptible to increased chipping and peeling if handled or kept at or below ~20°C (SPG, 2012). Ghosh et al. (2007) reported that long-term storage, especially above 25°C, can results in darker color lentils, possibly from seed coat tannins' oxidation. Such darkening or discoloration of lentils severely reduces their quality and market value. Overall, storage-related damage and contamination of lentils can be controlled or reduced following good handling and monitoring protocols (Uebersax, Siddiq, Cramer, & Bales, 2022).

It is recommended that farmers should not mix lentils from successive years, to avoid having the entire batch downgraded. Since lentils with green seed coat are prone to discoloration during extended storage, green lentils should not be stored for more than 1 year to minimize or avoid excessive discoloration and downgrading their marketability (SPG, 2012).

### 2.3 | Postharvest quality defects

Lentils require careful postharvest handling and maintaining optimum storage conditions (storage temperature and RH) to assure the high quality required for subsequent processing and utilization. Adverse storage conditions and their fluctuations are reported to induce a number of quality defects in legumes, for example, lower water uptake and prolonged cooking time as well as lower digestibility and bioavailability of nutrients (Paredes-Lopez et al., 1989; Uebersax, Siddiq, & Borbi, 2022). Furthermore, storage for a long-term can induce seed discoloration to darker color, stemming from oxidation of seed coat phenolics/tannins, thereby reducing the quality and market value of lentils (Ghosh et al., 2007). Numerous studies have shown that adverse storage conditions result in storage-induced *hard-to-cook* (HTC) condition in legumes, including lentils, producing in a substantial quality loss (Bhatty, 1990; Cenkowski & Sosulski, 1997). Optimum storage conditions can control legume seed quality loss, with seed moisture, storage temperature, RH, and storage duration considered the main parameters of interest (Uebersax, Siddiq, & Borbi, 2022). A summary of storage induced defects in legumes and their effect on quality is presented in Table 2.

**TABLE 2** Storage induced defects and their impact on legume quality

| Storage/cooking defect | Effect on quality |
|---|---|
| *Dry seed*: | |
| Seed coat/cotyledon discoloration | Mold, "bin burn" |
| Seed coat cracking | Checks, splits |
| Hard-to-cook defect | Reduced hydration (yield), longer cooking time |
| Off flavor/odor | Mold, chemical taints (from warehouse or containers) |
| Microbial growth | Mold, bacteria |
| Insect proliferation | Field damage, storage-related insects |
| *Thermally cooked/processed*: | |
| Color change | Discoloration and pigment leaching |
| Hard texture | Firm, hard versus soft and mushy |

*Source*: Adapted from Uebersax, Siddiq, and Borbi (2022).

## 3 | VALUE-ADDED PROCESSING

Lentil is a very versatile crop among legumes, and it is well-suited for processing and diverse food applications. Most of the lentil consumption continues to be in the form of traditional cooking and processed products. Lentils are relatively quick and simple to prepare in comparison to most other food legumes. However, there are wide variations in consumption trends across different countries. Some of these variations are based on the type of lentil consumed rather than the culinary method or products prepared. *Red* and *Green* lentils are the widely used lentil types in most countries with regular lentil intake, whereas *Yellow* and *Spanish Brown* lentils are consumed in relatively few countries (Siva et al., 2017; Thavarajah et al., 2008). Typically, red/yellow lentils are commonly used in Asian and Middle Eastern foods. Green lentils are eaten as whole seeds or as dehulled-split form while red lentils are generally dehulled before cooking and consumption (Siva et al., 2017). Black lentils, somewhat lesser known commercially, are smaller, look like caviar, and are nicknamed Beluga. Lentils can be processed by a variety of methods to produce various ingredients and end-products. The flowchart presented in Figure 3 outlines ingredients and products obtained from value-added processing of lentils.

Lentils, like other legumes, contain a number of antinutrients, for example, enzyme inhibitors, phytates, lectins (haemagglutinin, a glycoprotein) saponins, polyphenols, and oligosaccharides (Campos-Vega et al., 2010; Dhull et al., 2022). These antinutrients are known to negatively impact the nutritional quality, especially, reduced bioavailability

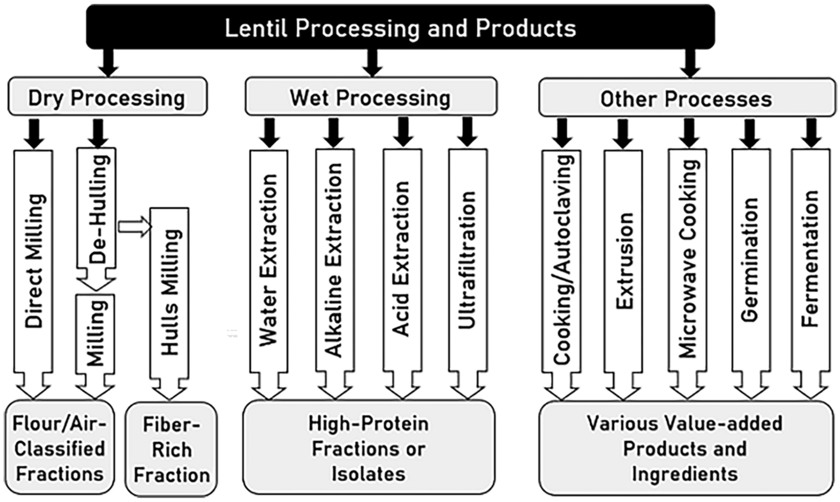


**FIGURE 3** Typical lentil processing techniques for producing value-added ingredients *Source*: Dhull et al. (2022)

of proteins and lower absorption of important minerals (Joshi et al., 2017; Patterson et al., 2017; Vidal-Valverde et al., 1994). Therefore, appropriate traditional or innovative processing techniques must be used to reduce or completely eliminate antinutrients in lentils. Different pre-processing treatments (soaking, dehulling and milling) and processing methods (cooking, boiling, extrusion, fermentation, and germination) are reported to minimize or inactivate the antinutritional factors in lentils (Dhull et al., 2022; Hefnawy, 2011; Wang et al., 2009). It removes the oligosaccharides, which are known to cause abdominal discomfort due to flatulence (Elango et al., 2022). This role is particularly helpful to improve the acceptance of lentil products by consumers.

## 3.1 | Dehusking/dehulling and splitting

The seed coat removal, referred to as "dehulling" or "dehusking" are reported to improve the palatability and flavor of legumes. The seed coat (testa) of food legumes, which is rich in tannins, has a somewhat bitter taste and is indigestible (Dhull et al., 2022). Besides improving sensory quality (flavor), dehulling also improves water absorption during soaking/cooking and thereby reducing cooking time significantly. Dehulling, followed by splitting (i.e., separation of cotyledons) is a common practice to satisfy consumer preference for most market classes of lentils (Joshi et al., 2017; Singh & Singh, 1992). Wang et al. (2009) reported that significantly higher starch, protein, resistant starch, potassium and phosphorus contents were observed after dehulling. By contrast, total dietary fiber, which includes both soluble and insoluble fractions, and tannins decreased significantly after dehulling. Most of red lentil consumption is in the form of dehulled seed, either split or whole seed. Thavarajah et al. (2008) reported that in India, Bangladesh and Nepal, dehulled whole red lentils are a major market class, whereas dehulled and split red lentils are widely popular in several South-Asia and Middle-East (e.g., Pakistan, Sri Landa, Turkey, Iraq, Jordan, and Lebanon).

## 3.2 | Cooking (thermal processing)

Cooking, similar to other pulses, is the most common method to prepare lentils for consumption. Generally, lentils do not require soaking but a short-time soak of about 10–15 min is helpful in cleaning any surface dust and aids in partial water uptake. Lentils, especially, dehulled and split red type, are cooked fully in about 15–20 min in boiling water. Whole lentils (both red and green types) require 25–30 min of cooking in boiling water (Sidhu et al., 2022). The amount of water added for cooking can be adjusted for desired consistency of cooked lentils, thereby eliminating any need to drain excess water upon cooking. If water is drained off, it results in the partial loss of water-soluble nutrients. For example, for a thin or soup-like consistency, more water is added than for a thick or pudding-like product.

Thermally processed lentils, in canned form, are marketed in some developed countries; however, traditional cooking methods and cuisines continue to be the main lentil utilization in most of the other countries in Asia and Africa (Sidhu et al., 2022). Since lentils in containers are a low-acid food, that is, pH > 4.6, processing of cans or pouches is typically done in steam or water at temperatures of 116–125°C (under pressure, in retorts). Thermal processing of lentils either in containers or in boiling water provides advantages of meeting desired sensory characteristics and reducing antinutritional factors. Canned foods, including canned legumes, are erroneously perceived by consumers to have a lower quality. This erroneous consumer perception that canned legume products is often associated with concerns of decreased nutritive value due to over-cooking. This may be further expressed as over-packaging in rigid steel containers. These perceptions must be overcome through education that demonstrate the value of recycled steel can packaging and full awareness of the value of safe (food and water) and convenient prepared canned foods. A comprehensive review of the value of processed foods provides increased understanding this consumer misconception (Weaver et al., 2014). However, to overcome this "rigid can" marketing perception, lentils could be thermally processed in multi-layer flexible pouches, since in-pouch foods have grown in popularity and acceptance among consumers due to their convenience and ease of use.

Nosworthy et al. (2018) observed that the protein quality, assessed as in vitro digestibility level, was improved after cooking of both red and green lentils. A substantial increase in resistant starch (RS) was also noted after cooking (Wang et al., 2009) but fat, ash content (selected minerals), and total carbohydrates were reduced in cooked lentils (Dueñas et al., 2016). Cooking also has a positive effect in reducing or eliminating a number of antinutrient, for example, protease inhibitors (trypsin inhibitors), flatulence-causing oligosaccharides, and phytic acid contents. Pal et al. (2017) observed that trypsin inhibitors were inactivated significantly (up to ∼85%) after cooking in boiling water. An earlier investigation by Vidal-Valverde et al. (1994), reported a complete inactivation of trypsin inhibitors and ∼40% reduction in phytic acid content after 30-min cooking (boiling) of pre-soaked lentils. The oligosaccharides were reported to be reduced by cooking of pre-soaked lentils, due primarily to leaching into soak/cook water (Wang et al., 2009). Hefnawy (2011) observed that microwave cooking and autoclaving also reduced the trypsin inhibitors activity, and phytic acid and tannins content significantly.

## 3.3 | Milling (flour, fractions, and isolates)

Milling is one of the common processes for the production of lentil flour, both from whole and dehulled seeds. Dhull et al. (2022) reported that dry or wet milled lentil can be used to obtain flour and fractions (protein- and starch-rich) with excellent quality parameters. The milling method employed significantly affects most of the functional properties of lentil flours, isolates, and fractions. Therefore, milling process parameters must be assessed carefully to produce flours and fractions before their usage in diverse food applications. For effective utilization of lentil flour in different foods, it can be further fractionated into protein- and starch-rich components using water or solvent extraction (Dhull et al., 2022). Funke et al. (2022) noted that production of protein and starch ingredients using dry fractionation has gained increasing attention in recent years, mainly as an alternative to solvent extraction for producing sustainable ingredients from legumes; thus, dry fractionation can also be used for lentils.

Milling processing has a significant effect on nutritional composition and antinutrients' content/activity of legume flour or fractions. Pal et al. (2017) reported that dehulling of lentils before milling reduces tannins by over 90% and phytic acid by nearly 60%, thereby significantly increasing the digestibility proteins and absorption of mineral. Joshi et al. (2017) reported that the milling process further increased nutritional bioaccessibility through an extended cell rupture during milling operation. Xu et al. (2020) reported that lentil flour possesses high lipoxygenase (LOX) activity which can cause off-flavors during processing and storage and hence reduces its shelf life. Various thermal treatments, for example, oven heating, microwave heating, steaming, and autoclaving can inactivate LOX (Jiang et al., 2016).

Ahmed et al. (2022) noted that milling produces ingredients from the food legume with definite sizes. Therefore, a thorough knowledge of micro-structural attributes of legume-based flour and ingredients is essential for designing processing equipment and operational planning. Furthermore, the evaluation and understanding of the functional properties (oil and water absorption, water solubility, gelation, emulsification, and foaming properties) of lentil flour and protein and starch fractions are critical for their successful incorporation in different foods, for example, bakery, extruded, soups, meat, and dairy applications (Dhull et al., 2022). Table 3 presents a summary of selected functional characteristics of lentil flour with respect to their relationship to the lentil-based products' quality.

**TABLE 3** A summary of functional properties and applications of lentil flour (LF)

| Functional property | Food products and % LF level | Quality attributes |
|---|---|---|
| Water absorption capacity (WAC) | • Baked products (<30%) | - Improvement of viscosity |
| | • Meat products (4–15%) | - Resistance to dough expansion |
| | • Dairy products—Yogurt (1–4%) | - Improved cooking quality |
| Oil absorption capacity (OAC) | • Baked products (<30%) | - Improvement of texture |
| | • Meat products (4–15%) | - Improved cooking quality |
| | | - Improved sensory quality |
| Solubility | • Baked products (<30%) | - Improved emulsification |
| | • Pasta (up to 100%) | - Improved foaming properties |
| | | - Improved gelling properties |
| Emulsification | • Baked products (<30%) | - Control of coalescence |
| | • Meat products (4–15%) | - Lower flocculation |
| | • Salad dressing (3–11%) | - Lower sedimentation |
| Gelation | • Cereal-based products (up to 100%) | - Improved texture |
| | • Meat products (4–15%) | - Improved sensory quality |
| | • Dairy products—Yogurt (1–4%) | |
| Foaming properties | • Baked products (<30%) | - Better crumb structure |
| | | - Better loaf volume |

*Source*: Adapted from Romano et al. (2021).

## 3.4 | Extrusion processing

Berrios et al. (2022) reported that extrusion technology can be used to produce lentil flours possessing variable functional properties, by manipulating extrusion parameters of feed rate, moisture level, and barrel internal temperature. Extrusion is a useful processing method that converts raw flours and granules into fully-cooked end-products or ready-to-use extrudates or ingredients. Extruded products are of low-moisture and shelf-stable, requiring no additional preservatives (Berrios et al., 2022). However, to retard deterioration, extruded lentil products must be stored and marketed in moisture- and oxygen-barrier packaging. Extrusion processing has been used to prepare a variety of lentil-based products or ingredients, for example, snacks (Lazou & Krokida, 2010; Morales et al., 2015), noodles (Rathod & Annapure, 2017), lentil flour (Berrios et al., 2010; Ek et al., 2021), modified lentil starch (Gonzalez & Perez, 2002), flour blends (Dogan et al., 2013), and lentil-based meat analogs (Chandler & McSweeney, 2022.).

Extrusion has a significant positive impact on the nutrients and antinutrients profile of extruded products from lentils (Gonzalez & Perez, 2002; Lazou & Krokida, 2010). Rathod and Annapure (2017) observed that extrusion enhanced the *in vitro* protein and starch bioavailability and digestibility in lentil noodles, without any changes in total protein content. Furthermore, extrusion significantly reduced different antinutrients, for example, protease inhibitors, phytic acid, and tannins—all by over 98%. Besides inactivation of lectins, extrusion was shown to result in improved amino acid score and true digestibility percentage of protein in green lentil flour (Nosworthy et al., 2018).

## 3.5 | Baking, roasting and frying

Commercially, baking and roasting of lentils are not very common, although fried lentils are available in some ready-to-eat snack mixes in South-Asia, especially, India and Pakistan. Nonetheless, lentil-based baked and roasted products have a great potential to be commercialized owing to their high-protein and very low-fat concentration. The feasibility of lentil and bean flours in baked bread dough product (rolls) was studied by Kohajdová et al. (2013). Farinographic characteristics and baking behavior of wheat flour, replaced with 10, 20, or 30% of lentil and some common bean flours, were assessed. Adding legume flours resulted in improved water absorption capacity to 74.90% (from 58.50% in control sample) and the time of dough development to 5.5 min (from 3.5 min); however, dough stability declined to 2.3 min from 6.7 min. The addition of both lentil and bean flours showed a negative effect on the physical quality of baked rolls, including reduced specific volume and cambering. Based on sensory assessment, the best quality baked rolls were produced with 90:10 wheat-legume flour blend. Substitutions with higher than 10% lentil or bean flour had an adverse effect on the crust color, shape, crumb elasticity, and texture of baked rolls.

The addition of lentil flour in two types of cakes (layer and sponge), and the resulting changes in the batter characteristics and of the final product were studied by de la Hera et al. (2012). Lentil flour addition improved batter viscosity in both types of cake formulations. The batter density for both types of cakes was lower with 100% lentil flour or higher with 1:1 lentil-wheat flours, than that of the control cakes made with 100% wheat flour. Increased firmness was observed in layer cake with lentil flour, and this effect was more pronounced in 100% lentil flour cake.

Roasting effect, along with that of cooking and fermentation, on the physical and compositional quality of selected legumes' flours and their application was investigated by Baik and Han (2012). Roasting reduced the oligosaccharide content by 44.0–64.0%. The protein solubility was shown to decrease as a result of roasting while in vitro digestibility of protein was improved. Bread dough prepared from roasted flours was less sticky than those prepared with raw as well as fermented flours. It was further observed that the roasted legume flour showed a more desirable aroma and increased loaf volume compared to the other two processing treatments. Ma et al. (2011) studied the roasting and boiling process effect on trypsin inhibitor, physico-chemical quality attributes, and microstructure characteristics of flours from selected legumes, including lentil flour. The trypsin inhibitor activity was reduced significantly by both of the thermal treatments. Roasted flours had similar compared microstructure to that of the untreated flours. Both treatments exhibited no or minimal effect on the emulsifying properties of legume flours. It was concluded that heat-treated legume flours could be potentially used as nutrient-rich ingredients in the formulation of diverse food products.

Fried whole red lentils (non-dehulled) are a major ingredient in a popular snack mix, *Chevda*, in India and Pakistan. The uses of lentil flour are rather limited in fried products, but research has been carried out on its feasibility in different products. Khorsand et al. (2018) prepared fried doughnut by adding soy or lentil flour (at 15% and 30%) to the formulation and studied the effect on doughnut's physicochemical properties. The hardness of doughnut decreased with the addition of legume flour. Moreover, a reduction in moisture loss, fat content, volume, and porosity were also observed in doughnut made with added soy or lentil flour. Saguy et al. (1996) reported that the fried products containing 1–10% lentil and chickpea flour exhibited reduced oil uptake compared with those made without legume flour. Shokrolahi et al. (2019) determined the effect of adding 10%, 25%, or 50% lentil flour on batter's quality for deep-fried product (crust). Batter formulation and frying time were shown to significantly affect the color and both moisture and oil content of crusts. Lentil flour addition lowered the oil content of the crusts, with the 50% flour addition showing the maximum effect. The crust color of samples prepared with lentil flour addition was significantly darker in comparison to control samples.

## 3.6 | Germination and fermentation

Germination and fermentation are useful for improving the nutritional and sensory properties of legumes. Dhull et al. (2022) noted that germination of lentils is a traditional and economical process for improving health benefits by enhancing the nutritional profile, antioxidative potential, and reducing the antinutrients. Ghumman et al. (2016) revealed that germination of lentil seeds resulted in notable changes in nutritional quality, particularly, by reducing carbohydrates and lipid content and by increasing in crude protein content. Reduction in carbohydrate content is attributed to the activation of endogenous enzymes, such as glucosidase, and α- and β-amylases. The hydrolytic enzymes during germination convert starch into mono- or oligo-saccharides, which decreases the overall starch content. Dueñas et al. (2016) showed that germination of lentils reduced non-starch carbohydrates, namely, insoluble, soluble, and total dietary fibers. Flour produced from germinated lentil exhibited improved breakdown viscosity, foaming, and water absorption capacities; however, emulsification activity decreased in comparison to the control sample (Ghumman et al., 2016).

Fermentation is another process by which the nutritional and functional quality of lentils can be potentially enhanced, primarily through improved concentration and bioavailability of bioactive compounds. Fermented lentil ingredients have a potential to be used for developing innovative lentil-based foods, including plant-based meat alternatives. The digestibility of legume protein is reported to be improved by fermentation, which is due partially to a reduction in antinutritional factors. Dhull et al. (2020) studied the results of solid-state fermentation of lentil and observed an increase in minerals (iron, zinc, calcium, copper, sodium, and potassium) contents and *in vitro* bioavailability of both iron and zinc upon fermentation. Bautista-Exposito et al. (2018) observed that 30-h fermentation at alkaline pH, using *Lactobacillus plantarum*, was shown to have a positive effect on proteins, peptides, and phenolic contents, besides increase in antioxidant, hypo-glycemic, hypo-lypidemic, anti-inflammatory, and anti-hypertensive activities.

## 4 | EMERGING RESEARCH TRENDS

Lentil is a least researched crop among common beans and pulses; therefore, emphasis should be on lentil value chain (LVC) research, especially in breeding strategy to develop varieties with high yield. The research should focus on LVC using a holistic approach that allows sustainability mechanisms. Modern tools and techniques of biotechnology should be used for developing varieties with novel traits that will make them "climate smart" (Kaale et al., 2022). A number of innovative technologies have been introduced in recent years for food processing/preservation and enhancement of physico-chemical, and sensory quality of food products. These technologies include high pressure processing, ultrafiltration, ionizing radiation, ultraviolet radiation, pulsed electric field, pulsed light treatment, ohmic heating, and ultrasound treatment (Ahmed, 2018; Gharibzahedi & Smith, 2020; Guillermic et al., 2021; Najib et al., 2022; Tokuşoğlu & Swanson, 2014). These innovative processing technologies can be applied for processing of food legumes, including lentils. However, it is noteworthy that the exploration of most of the innovative processing technologies is mostly at research and development stages. Therefore, it is suggested that further research on optimization of processing conditions and quality assessment of produced lentil ingredients and products can help towards commercial application of such technologies.

The effect of high pressure (HP) treatment (at 300, 450, and 600 MPa levels for 15 min) was investigated by Ahmed et al. (2019), on the alcalase-catalyzed hydrolysis of lentil protein (using 0.5% and 1% enzyme). Improvements in the functional properties and antioxidant potential of lentil hydrolysates by HP treatment were assessed. It was shown that HP treatment preceding alcalase-catalyzed hydrolysis aided in significant changes in proteins' secondary structure. The foaming properties and antioxidant activities were improved by 50% and 100%, respectively. Authors concluded that the HP treatment of lentil starch can be utilized to improve its functional properties and develop new food products with better quality and enhanced consumer acceptance. It was suggested that the HP treatment, especially at variable temperatures, offers a potential means to effect additional modification of lentil starch's structure or adding other ingredients to develop functional foods.

Ultrafiltration (UF) along with isoelectric precipitation or IEP application was investigated by Boye et al. (2010) to assess their effects on the physicochemical attributes of protein concentrates (PCs) isolated from selected legumes, including lentils. The protein content of the control or untreated pulses, which ranged from 16.7% to 24.8%, was concentrated nearly fourfold. The UF treatment yielded higher protein content in the PCs (69.1 to 88.6%) than the IEP method, which yielded 63.9 to 81.7% protein. It was further observed that red and green lentils' PCs had higher protein solubility of 70–77% using UF isolation. The functional properties (water holding capacity, water solubility, emulsifying property and foam expansion) varied as a function of pulse type and the process used.

Lv et al. (2018) investigated supercritical fluid ($CO_2$) extrusion (SCFX) to process a powdered blend of lentil flour and pregelatinized potato starch, which was extruded at of 95–99.5°C and 40–120 rpm screw speeds. The density, expansion ratio, degree of porosity, water solubility, and rehydration capacity were improved with increasing screw speed (40 to 120 rpm). SCFX resulted in an increase of the transition temperature of starch and protein in lentil flour, and increased screw speed significantly increased starch gelatinization. No retrogradation of starch, which is common in traditionally cooked lentils, was noticed in the extruded red lentil products stored at 4°C for 60 days. Trypsin inhibitor activity was shown to decrease significantly with the higher screw speed. The DPPH antioxidant activity in SCFX sample enhanced, respectively, by 30% and 18%.

Gharibzahedi and Smith (2020) showed that the sonication or high-intensity ultrasound (HIU) treatment was an efficient technique to break disulfide bonds without requiring reducing agents. The HIU processing treatment was shown to reduce particle size and viscosity of proteins dispersions. Microwave-assisted infrared (MW-IR) heating is an innovative drying technique that significantly reduces the drying time, thereby maintaining a better quality of the dried food products (Najib et al., 2022). A combination of germination and MW-IR drying to process lentil flour with improved quality attributes for use in diverse food applications was studied by Najib et al. (2022). Results of this study showed that microwave power had the greatest effect on the drying rate, followed by IR power, whereas the effect of germination time had no significant effect. Based on the kinetic results, the drying rate constant (k) of the diffusion approach was shown to be highly correlated with the MW-IR power whereas no correlation was observed with germination time. Authors concluded that the results of their study can provide potential impetus for processing of flour (rich in proteins) by commercialization of MW-IR drying of germinated lentils.

Guillermic et al. (2021) used a novel technique, X-Ray microtomography imaging, to elucidate and quantify the microstructure of extruded red lentils. Extrusion parameters can be varied to achieve optimum microstructure and texture in puffed extruded products. The weak spots in the extrudate microstructure resulted in reduced texture, measured as hardness and crunchiness. The cell wall rupture at higher screw speed was also observed, however, this negative effect could be offset by an increased moisture level during extrusion cooking.

## 5 | LENTIL-BASED PRODUCT DEVELOPMENT

The traditional utilization of lentils is primarily in home-prepared cuisines. In many least-developed countries in Asia and Africa, lentils and other food legumes are recognized as a major source of protein and part of traditional cuisines that are consumed regularly. However, research and development efforts have been made in recent years to formulate lentil-based products, which were prepared using whole or dehulled lentil flours. Selected examples of such products included pan/flat bread (Asadi et al., 2021), crackers (Yaver, 2022), extruded snacks (Li et al., 2022), puffed snacks (Guillermic et al., 2021), lentil-potato extruded snacks (Lv et al., 2018), Besides flour, lentil protein isolates or concentrates can be incorporated in developing new lentil-based products. In particular, lentil protein isolates have a great potential for use in energy drinks and dairy-based beverages, and gluten-free snacks.

Current and some potential applications for using lentil protein, starch, and fiber ingredients include (1) flour mixes, doughs, and baked products; (2) dairy foods applications; (3) gluten-free products; (4) snack products; and (5) meat alternatives and meat extenders. Lentils possess excellent functional properties for use in these value-added products. Red lentils are particularly suitable for developing lentil-based new products, especially for applications as a source of meat alternative protein for use in meat analogs and related products. Since protein isolates from red lentil possess natural red color, it makes them suitable for mimicking meat color and avoiding the use of added synthetic colors, which have been reported to have potential food safety issues and negative consumer response (Arshad et al., 2022; Jarpa-Parra, 2018; Lee et al., 2021). Lentil-based gluten-free products (e.g., pasta and snacks) are commercially produced and marketed in in some countries, including Canada and U.S.A. (Amin & Borchgrevink, 2022). Apostolidis and McLeay (2016) indicated that social, health and environmental benefits could have a significant impact on choosing plant-based protein alternatives and reducing meat intake by the consumers.

Keskin et al. (2022) noted that despite a number of nutritional benefits, the consumption of legumes on per capita basis, including lentils, continues to be relatively low in the developed countries where a major portions of proteins consumption is derived from animal-based food products. The superior techno-functional properties of pulse-based fractions and ingredients could aid in expanding consumption of lentils and other legumes beyond traditional products, uses, and consumers. Sidhu et al. (2022) reported that the success of newly developed lentil-based products depends on fully understanding the functionality of lentil flours and isolates, and their effects on physico-chemical and consumer acceptance.

## 6 | CONCLUSION

Among legumes, lentils occupy an important place owing to their production, international commerce, and consumption. Lentils have shown a consistent growth in production and area under cultivation since 1970s. Appropriate postharvest handling and storage are necessary for preserving the quality of lentils and reduce losses during storage. Several processing techniques such as milling, extrusion, roasting, frying, fermentation, and germination can be used to improve the quality of lentils and other food legumes. In addition to improving taste, and flavor, other important objectives of cooking and value-added processing reduce or eliminate antinutrients and increase the bioavailability of essential nutrients. Lentils are utilized in many traditional cuisines and as ingredient in various food applications. Lentils, owing to their rich protein profile and presence of many bioactive phytochemicals are well-suited for preparing a range of processed products and functional foods. Lentil whole flours and isolated fractions (rich in protein and starch) have an excellent potential for developing gluten-free products and alternative plant-based protein. Development and commercial production of lentil ingredients, particularly, novel starches, protein isolates/concentrates and dietary fibers can not only offer healthy food options to consumers but economic return to all stakeholders across lentil value chain, i.e., growers, processors, foodservice establishments, supply chain, marketers, and consumers.

### CONFLICT OF INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

### AUTHOR CONTRIBUTIONS

**Charlotte Oduro-Yeboah** contributed to the writing – original draft and editing – final draft; **Rabiha Sulaiman** contributed to the writing – original draft and editing – final draft; **Mark A. Uebersax** contributed to the conceptualization and writing and editing – original draft; **Kirk D. Dolan** contributed to the reviewing and editing – final draft.

## DATA AVAILABILITY STATEMENT

Data are not applicable since this is a Review Article and no data are reported.

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