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Versatile Functions of Raw and Modified Lentils/Lentil Components in Food Applications: A Review

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ABSTRACT

Lentil (*Lens culinaris* Medik.) and lentil components are cost-effective, sustainable, eco-friendly, nutritious, and vegan functional ingredients in food formulations. These versatile properties have recently increased the popularity of them among consumers and food manufacturers. Various emerging processing technologies, such as microwave (MW), infrared (IR), high pressure (HP), ultrasound (US), cold plasma (CP), ozone, ionizing irradiation, ultraviolet (UV)-light, ultrafiltration (UF), and isoelectric precipitation (IEP), have been effectively applied to improve the functional properties of lentils and lentil components, thereby increasing their consumption and utility. This review article focuses on the nutritional, health-promoting, and technological functions of raw and modified lentils/lentil components in food applications and the effects of emerging technologies on their functionality. Selecting appropriate, sustainable technology and determining optimized process conditions are crucial for producing functional, healthy food from modified lentils that display enhanced consumer acceptability. Recent research indicates that MW, IR, HP, US, MW-IR, HP-enzymolysis, UV-US, and US-γ-irradiation technologies have substantial potential for modifying and enhancing the functionality of lentil and lentil components.

1 | Introduction

Food insecurity, climate change, significant livestock production (a major source of greenhouse gas emissions and a cause of climate change), and the increase in chronic diseases represent key global challenges (Malterre et al. 2024). The growing world population leads to higher demand for food and greater livestock production which can inversely affect the limited resources and the environment (Yanni et al. 2024). On the other hand, due to the rise in consumer health and wellness awareness, daily dietary habits have shifted towards more healthy (low-sodium, low-fat, high-protein, cholesterol-free, bioactive, and meat-free) and nutritionally adequate foods. These include plant-based, vegan, and gluten-free (GF) functional food products (Malterre et al. 2024; Yanni et al. 2024).

Lentils (*Lens culinaris* Medik.) are safe, cheap, widely available, sustainable, nutritious, healthy, and technologically functional GF materials with low environmental footprint (Keskin and Sumnu 2023). Lentils contain considerable amounts of functional components that have the potential to promote human health by decreasing blood pressure, cholesterol, and cancer risk, or increasing bifidogenic and prebiotic activity (Faris, Takruri, and Issa 2013; Faris and Attlee 2017). Furthermore, these valuable constituents render lentils as healthy options suitable for developing value-added food products, such as plant-based meat and dairy alternatives (e.g., meat analogs and meat extenders; milk, cheese, or yogurt analogs), and functional GF products with high protein and dietary fiber contents or low glycemic index (Dhull, Kinabo, and Uebersax 2023). In addition to these nutritional and health benefits, lentil-based ingredients provide technological functions, such as gelation, emulsifying, foaming, binding, and texturing ability, in food applications (Keskin et al. 2022). The use of these versatile components in food formulations enables the production of functional foods with modified sensory, nutritional, and textural properties (Keskin and Sumnu 2023).

In addition to these considerable functions, lentils have positive environmental and economic impacts. Both governments and consumers address environmental issues (such as carbon, blue water, and land use) and economic concerns (like cost reduction) (Chaudhary and Tremorin 2020). It has been reported in a recent study by Chaudhary and Tremorin (2020) that when cooked lentil puree was used in the lean beef burger formulation, ~33% and 26% reductions in environmental food print and cost were observed, respectively.

However, the existence of unwanted flavor compounds, raffinose family oligosaccharides, antinutritional factors (ANFs) (e.g., saponins, phytic acid, tannins, lectins, and protease inhibitors), and the allergenic proteins, respectively, results in a "beany flavor," gastrointestinal discomfort and flatulence, adverse nutritional effects (e.g., reduced protein digestibility and nutrient absorption), and allergenic reactions. These factors affect the nutritional, technological, and sensory quality of lentil-based products (Siddiq, Oduro-Yeboah, and Abong 2023). Additionally, the high lipoxygenase activity of lentil and the low solubility of lentil proteins are the other challenges that limit their use in food applications (Alrosan et al. 2022). In recent years, various technologies, including IR, MW, HP, US, ozone, UV-C, CP, and ionizing radiations, have been explored. These are often termed as "emerging high-potential novel treatments for tomorrow" (Rao et al. 2023) and have been utilized to alter and improve the nutritional and technological functionality of lentils and lentil components, thus mitigating some of the mentioned challenges in food systems (Hefnawy 2011; De Vries et al. 2018; Ahmed et al. 2019; Bou et al. 2022; Quintero-Quiroz et al. 2022; Laing et al. 2023a, 2023b; Miranda et al. 2023). These technologies have facilitated the creation of functional, healthier food with enhanced quality and consumer acceptability. They achieve this by removing unwanted compounds, reducing allergenicity, boosting digestibility, improving sensory features, and providing health benefits (Ahmed, Dhull, and Dwivedi 2023). This aligns with the current nutritional trends, culinary practices, and food market demands, meeting food security standards (EU Horizon 2021–2026) and promoting health and environmental sustainability (UN Sustainable Development Goals 2030) in the long run (Ahmed and Nahar 2023; Yanni et al. 2024).

This review focuses on the nutritional and technological functions of lentils and lentil components in food applications and the role of emerging processing methods to modify/improve their functionality.

2 | Nutritional and Health-Promoting Functions

The valuable components of lentils, such as proteins, essential minerals and amino acids, bioactive peptides, dietary fibers, resistant starches, oligosaccharides, and phytochemicals (e.g., polyphenols, saponins, and phytosterols), are responsible for the nutritional and health-promoting functions of lentils (Faris, Takruri, and Issa 2013).

The proximate compositions of freeze-dried cooked lentil powders obtained from five different lentil varieties with different colors (red and green) and seed sizes (extra small, small, medium, and large) are given in Table 1. Lentils are known as rich sources of carbohydrates and proteins, which can change according to the lentil variety (Ramdath et al. 2020). Adequate dietary intake of these essential compounds is important for human metabolism and a healthy life. Furthermore, the low total fat, low sodium, and high potassium contents make lentil a healthy choice for people suffering from obesity and cardiovascular diseases (Ganesan and Xu 2017).

Although sulfur-containing amino acids and tryptophan are the limiting amino acids, lentil contains considerable amounts of all other essential amino acids (EAAs). In a recent study by Alrosan et al. (2022), the average EAA contents of lentil, quinoa and casein proteins, and whey protein isolates were compared. The EAA contents of lentil proteins were found to be comparable to those of dairy proteins, and it has been stated that the EAA contents of lentil proteins exceed the recommended daily intake of FAO/WHO (FAO/WHO 1991) for healthy adults (except cysteine and methionine amino acids) (Alrosan et al. 2022).

TABLE 1 | Proximate compositions of freeze-dried cooked lentil powders from different lentil varieties with different colors and seed sizes (dry weight basis).

		Average amount				
		Red lentil		Green lentil		
Composition	Unit	Impala (extra small)	Imvincible (small)	Viceroy (small)	Imigreen (medium)	Impower (large)
Energy value	kJ	1846	1881	1880	1861	1856
Protein	g	31.2	29.6	28.9	28.8	27.4
Total lipid (fat)	g	0.85	0.93	0.50	0.62	1.10
Ash	g	3.43	3.01	3.00	2.74	2.70
Carbohydrate	g	64.5	66.4	67.6	67.8	68.8

Note: Adapted from Ramdath et al. (2020). The values of five of 20 different lentil varieties with different colors (red and green) and seed sizes (extra small, small, medium, and large) are used in the table.

Bioactive peptides, another functional component in lentils, have health-promoting abilities such as reducing inflammation and blood pressure and supporting the immune system (Faris, Takruri, and Issa 2013).

In addition, the dietary fiber, resistant starch, and oligosaccharides of lentils have proven health benefits (e.g., hypocholesterolemic, anticancerogenic, antitumor, hypoglycemic, and antimicrobial effects in human body) associated with their significant contribution to gastrointestinal health (Ganesan and Xu 2017). They can regulate bowel function and modulate the structure and activities of the gut microbiota, which stimulates the growth of probiotic bacteria (Ganesan and Xu 2017).

Saponins, the bioactive compounds of lentils, have hypocholesterolemic, hypoglycemic, anti-inflammatory, and antimicrobial effects that positively affect human health (Ganesan and Xu 2017; Del Hierro et al. 2020; Mustafa et al. 2022). The hypocholesterolemic effect of saponins can be explained by two mechanisms. One of them is the prevention of cholesterol absorption from the small intestine by forming an insoluble saponin-cholesterol complex, and the second mechanism is the solubilization of cholesterol in the small intestine (Mustafa et al. 2022). Saponins inhibit the production of proinflammatory cytokines and inflammatory enzymes and the degradation of IκB-α, which results in anti-inflammatory effect (Conti et al. 2021). Del Hierro et al. (2020) stated that fermentation of saponin-rich fractions from red lentils by human gut microbiota modulated the growth of specific intestinal bacteria, mainly lactic acid bacteria and *Lactobacillus* spp., via the transformation of saponins into sapogenins (soyasapogenol B), resulting in antimicrobial activity.

Polyphenols (e.g., phenolic acids, flavan-3-ol, flavonols, and condensed tannins) are the functional components of lentils that are responsible for their antioxidant activity (Mustafa et al. 2022). Zhang et al. (2015) determined the antioxidant activity, total phenolic content (TPC), total flavonoid content (TFC), total condensed tannin content (CTC), and enzyme activity (α-glucosidase and pancreatic lipase) inhibition ability of hydrophilic extracts of 20 lentil (10 green and 10 red) cultivars grown in Canada. The antioxidant activity, as measured by the 2,2diphenyl-1-picrylhydrazyl (DPPH) assay, showed the ability of antioxidants to scavenge a DPPH radical, ranged from 23.83 to 35.03 μmol Trolox equivalent per gram dry weight (DW) (μmol TE/g DW) lentil. The ferric reducing antioxidant power (FRAP) value ranged from 18.75 to 34.52 μmol ascorbic acid equivalent (AAE)/g DW. The oxygen radical absorption capacity (ORAC) values of the lentil extracts were reported to range from 105.06 to 168.03 μmol TE/g DW. Furthermore, the TPC, TFC, and CTC values of the samples were found to be in the range of 4.56–8.34 mg gallic acid equivalent (GAE)/g DW, 0.60–1.98 mg catechin equivalents (CE)/g DW, and 3.00–7.80 mg CE/g DW, respectively (Zhang et al. 2015). The authors have stated that lentils are rich in phenolic compounds, which have strong antioxidant activities (especially flavonols and flavanols) and inhibitory effects (especially flavonols) on α-glucosidase and pancreatic lipase activity (Zhang et al. 2015). Inhibition of these enzyme activities by phenolic compounds provides antiobesity and antidiabetic activity by reducing glucose and fat digestion and absorption in the intestine (Zhang et al. 2015; Ganesan and Xu 2017). Additionally, the phenolic compounds in lentils have antioxidant activity which can potentially reduce the incidence of various cancers, such as colon, thyroid, liver, breast, and prostate cancer through the inhibition of oxidation reactions and reduction of free radicals in the body (Ganesan and Xu 2017).

3 | Technological Functions

Recent studies have shown that lentil protein, starch, and dietary fiber have versatile technological functions in various food applications. These lentil components can serve as binder (water/oil), foamer, emulsifier, or antifungal agent, or foam or emulsion stabilizer, thereby enhancing the features of food products. The properties (e.g., molecular structure, granular structure, size, shape, and composition) of lentil components, the possible interactions between the lentil components and the food medium, and the reaction conditions determine their degree of functionality in food applications (Keskin and Sumnu 2023). The molecular structure, size, shape, amino acid number, and composition of proteins affect their functionality (Byanju and Lamsal 2023). Lentil starches differ from maize and tapioca starches because of their specific properties, such as amylose content, chain length, and type of polymorphic arrangement, which affect their gelation and pasting behaviors and digestibility levels (Joshi et al. 2013; Ren et al. 2021). The properties and roles of raw lentil-based ingredients in recent food applications are discussed in Sections 3.1–3.5.

3.1 | Lentil Flour (LF)

The nutritional and technological properties of LF and its mechanism of action in food applications have been reviewed in a recent study by Romano et al. (2021). Since LF includes all necessary elements, such as protein, starch, and dietary fiber, every component in the flour interacts with food ingredients based on their unique properties, including chemical structure and functional group. The action mechanism related to water absorption capacity (WAC) has been described with the hydrophilic interactions and hydrogen bonds created between lentil components (starch, fiber, and proteins containing polar amino acids) and water molecules. This functionality improves product quality, shelf stability, and sensory properties such as mouthfeel (e.g., juiciness) and texture. In a recent study by Rajpurohit and Li (2023), plant protein isolates and concentrates have been used as texturized vegetable proteins due to their good WAC. The WAC of proteins changes according to protein conformation, amino acid sequence, surface hydrophobicity, and environmental conditions, such as temperature, pH, and ionic strength of the medium (Badjona et al. 2023). The oil absorption capacity (OAC) and solubility of LF have been associated with the interaction between hydrophobic groups of lentil protein and oil and the interaction of hydrophilic compounds (e.g., sugar, some vitamins, phytochemicals, and hydrophilic groups of lentil protein) with water, respectively (Romano et al. 2021). Proteins with good WAC and OAC are considered functional components of plant-based meat analog or extender formulations (Rajpurohit and Li 2023). The foaming, emulsification, and gelation properties of proteins largely depend on their solubility. Solubility is a desired functional feature in milk substitutes and other dairy-type products and beverages (Rajpurohit and Li 2023). Furthermore, lentil proteins can act as natural emulsifiers because of their amphiphilic character. During emulsion formation, hydrophobic groups of proteins interact with the oil phase, hydrophilic groups interact with the water phase, and interfacial tension are lowered (Khazaei et al. 2019). The emulsification ability of proteins makes them useful formulation ingredients for plant-based meat analogs, dressings, sauces, milk analogs, and cream analogs (Rajpurohit and Li 2023). Moreover, lentil proteins or starch granules can form gels. Food gel is a three-dimensional (3D) polymeric network capable of absorbing and retaining water and maintaining its structural integrity. Gelation affects the rheological, nutritional, and sensory properties of food products by regulating their microstructure, texture, viscoelasticity, and stability (Shrestha et al. 2023). Furthermore, lentil proteins can act as foaming agents and migrate to the air–water interface, reduce surface tension, and cover the air bubbles with a cohesive layer. The physical properties (such as molecular weight and solubility) and surface properties (like surface hydrophobicity) of pulse proteins, in addition to their susceptibility to denaturation, influence the foaming properties, specifically foaming capacity (FC) and foaming stability (FS) (Byanju and Lamsal 2023).

In a recent study by Badia-Olmos et al. (2023), the technofunctional properties of seven vegetable flours, including LF, were determined. The swelling, WAC, OAC, emulsifying capacity (EC), and FC, and FS of whole-grain LFs were reported as 3.23 mL/g, 1.31 g/g, 0.69 g/g, 46.2%, 57.1%, and 43.2%, respectively. The swelling and WAC of dehulled red LF were lower, whereas its EC was higher than that of whole-grain LF. The OAC, FC, and FS of whole-grain lentils and LFs were found to be statistically the same. The higher swelling and WAC for whole-grain LF compared with those for dehulled red LF were related to the higher fiber content of whole-grain LF (Badia-Olmos et al. 2023).

Table 2 presents examples of recent studies (2020-to present) that investigated the impact of raw LF on the quality of various food items, including bakery (wheat bread, GF cookie), meat (beef and pork meat burgers), and dairy (yoghurt) products. The addition of LF to wheat bread and GF cookie formulations improved the nutritional value (e.g., protein content,

TABLE 2 | Functions of raw lentil flour (LF) in some bakery, meat, and dairy products.

Food products	Amount of LF	Main functions	Reference
Wheat bread	0%, 5%, and 10% germinated LF	– Increase in protein content – Increase in hardness and chewiness – Increase in sensory acceptance in terms of general attributes – Decrease in fat content – Decrease in breakdown and final viscosities – Decrease in dough extensibility and swelling index	Hernandez-Aguilar et al. (2020)
Gluten-free cookie	0% and 100% black, brown, green, red, or yellow LF	– Decrease in L* and increase in b* values – Increase in sensory quality, crude protein content, phenolic and flavonoid content, and antioxidant capacity as compared to rice cookies (control)	Hajas et al. (2022)
Beef burger	5% and 10% red LF	- Increase in LF concentration resulted in an/a – Increase in moisture and protein contents – Increase in cooking yield – Increase in sensory quality (improved textural attributes [juiciness and tenderness]) – Decrease in lightness – Decrease in cooking loss – Decrease in diameter reduction	Boisteanu, Manoliu, and Ciobanu (2023)
Pork meat burger	80 and 150 g/kg LF	– Highest WAC among pulse flours (pea, chickpea, and bean) – Increase in hardness – Increase in cooking yield – Decrease in product size reduction	Argel et al. (2020)
Yoghurt	4% roasted and unroasted LF	– Increase in pH – Increase in dry extract – Decrease in syneresis – Decrease in titratable acidity	Benmeziane et al. (2021)

Abbreviations: LF: lentil flour; WAC: water absorption capacity.

phenolic and flavonoid content, and antioxidant capacity) and sensory quality of them (Hernandez-Aguilar et al. 2020; Hajas et al. 2022). Additionally, research indicates that LF flour can be utilized to make low-fat burgers that are nutritionally, technologically and sensorially superior (Argel et al. 2020; Boisteanu, Manoliu, and Ciobanu 2023) (Table 2). The inclusion of LF in burger formulas demonstrated a reduction in cooking loss and an increase in cooking yield, attributed to LF' s WAC (Argel et al. 2020). Benmeziane et al. (2021) added LF (at 4% level and obtained from either roasted or unroasted seeds) to the formulation and produced a new functional yoghurt (containing both probiotics and prebiotics) with lower syneresis and acceptable sensory quality. The lower syneresis values compared to control yoghurt have been associated with the water absorbing ability of lentil components (Benmeziane et al. 2021).

3.2 | Lentil Protein Isolate (LPI)

Lee et al. (2021) investigated the effects of pH level (in the range of 2–10) on the technofunctional properties of LPIs from red lentils (from the United States, Nepal, and Turkey). The pH level changed the solubility, foaming, and emulsifying properties of the LPIs, especially at pH 5.2, which is the isoelectric point of LPIs. At that pH level, the least favorable functional properties were observed. Under high alkaline and acidic conditions, more desirable solubility, FC, and emulsifying stability index (ESI) values for LPIs have been observed (Lee et al. 2021). The technofunctional properties of LPIs were determined in a recent study by Tang et al. (2021). WAC, OAC, and the least gelling concentration of yellow LPIs were determined as 1.2 g water/g protein, 1.78 g oil/g protein, and 140 g/L, respectively, whereas those of white LPIs were reported as 4.9 g water/g protein, 1.80 g oil/g protein, and 110 g/L, respectively. The functional properties of yellow and white LPIs were found to be more desirable than those of soy and yellow pea PIs (Tang et al. 2021).

3.3 | Lentil Starch

Joshi et al. (2013) studied the physicochemical and functional properties of three types of starch: lentil, corn, and potato. Among the three starches, the amylose content (32.52%) of lentil starch was the highest, whereas its crystallinity (9.12%) and gelatinization enthalpy (11.80 J/g) were the lowest. The gelatinization and peak temperatures of lentil starch were 71.9°C and 69.3°C, respectively, which were between the gelatinization and peak temperatures of corn and potato starches. The gel strength and final viscosity of lentil starch were higher than those of the other starches. Associated with its desired gelation and pasting properties, lentil starch could be recommended as a functional ingredient when high gel strength and final viscosity are required (Joshi et al. 2013). In another study, the solubility index, swelling, and functional properties of native lentil starch were investigated by Majeed, Wani, and Hussain (2017). The authors assessed the swelling and solubility indices of native lentil starch in relation to temperature (50°C–90°C), discovering an increase in these indices with rising temperature. The swelling and solubility indices of lentil starch were 2.32 g/g and 0.02 at 50°C and 16.77 g/g and 0.24 at 90°C, respectively. Increases in these parameters with temperature were associated with an increase in the hydration ability of lentil starch (Majeed, Wani, and Hussain 2017). Moreover, the EC, WAC, and OAC of native lentil starch were found to be 5.01%, 5.49 g water/g sample, and 4.83 g oil/g sample, respectively (Majeed, Wani, and Hussain 2017).

3.4 | Lentil Fiber

Wang and Toews (2011) determined the functional properties of dehulled lentil fibers obtained from the varieties of CDC Plato, CDC Viceroy, and CDC Blaze. The fat absorption, water hydration, swelling, and water retention capacities (WRCs) of lentil fibers were found as 1.10–1.12 g oil/g, 5.0–5.7 g water/g, 22.7–27.1 mL/g, and 8.9–11.4 g water/g, respectively (on dw basis). In a separate study conducted by Dalgetty and Baik (2003), it was identified that the swelling, WAC, and OAC of the lentil seed coat (hull) were 2.38 mL/g, 3.60 mL water/g, and 1.63 mL oil/g (dw basis), respectively. Conversely, the same properties of insoluble cotyledon fibers measured 8.04 mL/g, 11.10 mL water/g, and 4.01 mL oil/g (dw basis). Insoluble cotyledon fibers of lentil have higher swelling, WAC, and OAC, which make them preferred ingredients for food formulations (Dalgetty and Baik 2003).

3.5 | Aquafaba

Aquafaba from lentils not only offers nutritional benefits such as being a rich source of prebiotic oligosaccharides, water-soluble macro- and micronutrients, and bioactive compounds but also serves technological functions like structure-shaping (Serventi 2020; Martins et al. 2023; Stasiak, Stasiak, and Libera 2023). So far, aquafaba has been used in various food formulations, such as meringues, biscuits, cakes, cookies, bread, crackers, vegan mayonnaise, and ice cream (Stasiak, Stasiak, and Libera 2023). Aquafaba is the cooking water of legumes. The composition of cooking water depends on the type, variety, and genotype of the legume and the process conditions (Stasiak, Stasiak, and Libera 2023). Damian, Huo, and Serventi (2018) determined the phytochemical content (TPC and saponin content) and technofunctional properties (WAC, OAC, EAI, and emulsifying ability) of the cooking water of whole green lentils (WGLs). The WGL was soaked in water for 16 h at room temperature, followed by boiling for 60 min at a pulse to water ratio of 1:1.75. The yield was approximately 0.6 parts of lentil cooking water (LCW) per part of lentil. The total phenolic and total saponin contents of LCW were reported as 0.7 and 14 mg/g, respectively. Moreover, the WAC, OAC, EAI, and emulsifying ability of LCW were found to be 0.13 g/g, 2.71 g/g, 47.1 m^2/g, and 52.7%, respectively.

4 | Emerging Processing Technologies That Improve the Functionality of Lentils/Lentil Components in Food Applications

Various emerging processing technologies like microwave (MW), infrared (IR), high pressure (HP), ultrasound (US), cold plasma (CP), ozone, ionizing irradiation, ultraviolet (UV)-light, ultrafiltration (UF), and isoelectric precipitation (IEP) are used to modify lentil components and enhance their functionalities in food systems. A schematic representation of the impact of different emerging technologies on lentil properties has been given in Figure 1. These novel treatments can modify the germination and growth rates of lentils, break down starch and/or protein components, lessen antinutritional factors, boost starch and/or protein digestibility, or improve their technological properties through their action mechanisms. Table 3 summarizes the prominent features, action mechanisms, and process parameters of emerging processing technologies, as well as their roles in the various functions of lentil components as per recent studies.

4.1 | MW Technology

MW treatment is an emerging technology that has the potential to alter the WAC, OAC, in vitro digestibility, and emulsion characteristics of lentil components, predominantly starch and protein, as well as diminishing antinutritional elements (Mahalaxmi et al. 2022; Mazı, Yıldız, and Barutçu-Mazı 2023).

In a recent study, Mazı, Yıldız, and Barutçu-Mazı (2023) determined the ANFs and functional properties (WAC, OAC) of red and green LFs. They obtained flours through various treatments, which included soaking (with or without the use of sonication) and drying (either via an oven or MW), under different process conditions. The MW-dried red and green LFs had higher WAC values, ranging from 286.3 to 330.3g and 317.4 to 358.9g water per 100g, respectively, compared to the WAC of oven-dried red and green LFs, ranging from 108.5 to 153.1g and 124.4 to 132.7g water per 100g, respectively. This is attributed to differences in starch damage and protein denaturation during the MW and oven-drying processes. The authors stated that LF with good color, high WAC, and low ANFs (phytic acid and trypsin inhibitor contents) could be obtained quickly and effectively by soaking followed by MW drying at 900W (Mazı, Yıldız, and Barutçu-Mazı 2023).

In another study, Mahalaxmi et al. (2022) used MW treatment to modify the functional properties of lentils (18% moisture content). The MW treatment enhanced WAC, OAC, and emulsion properties of lentils, as a result of the protein denaturation that occurred during processing. In addition, the crystalline and amorphous natures of the LF were also changed by the MW treatment, which greatly affects the structure and thermal properties of LF. It was determined that LF processed at 720W had the desired binding, foaming, and emulsifying properties compared with other treatments (Mahalaxmi et al. 2022).

In recent years, MW technology has been combined with different technologies, such as IR, vacuum treatments, or soaking/germination pretreatments, to change/enhance the functionality of lentil components (Heydari, Najib, and Meda 2022; Najib et al. 2023). Heydari, Najib, and Meda (2022) modified LFs (tempered to different moisture contents, 20%, 35%, and 50% [dry basis]) by MW-assisted IR treatment. The combined treatment caused starch gelatinization and protein denaturation, which led to a decrease in the ordered structure of starch and protein and modified the LF structure to a certain extent. When the lentil seeds with a high moisture content (50%) were subjected to high thermal intensities (combined high MW and IR powers of 0.7 and 0.75kW, respectively), more significant modifications were observed in the starch and protein structure. This led to improved WAC, increased in vitro starch and protein digestibility, and decreased protein solubility (Heydari, Najib, and Meda 2022).

Najib et al. (2023) investigated the performance of MW-based technologies (MW, MW-IR, and vacuum-MW drying) to modify the starch component of LFs and compared them with conventional technologies. MW-IR and vacuum-MW treatments appeared to be effective substitutes for roasting at 240°C and convective air-drying, respectively, as they resulted in similar modified starch properties but required significantly less time (up to 7.9-fold reduction in drying time). Most thermal treatments have been observed to enhance total starch digestibility. MW-IR drying and roasting increased rapidly digestible starch due to significant starch gelatinization under high temperatures. On the other hand, vacuum-MW and convective air-drying increased slowly digestible starch due to partial starch gelatinization at lower temperatures. The WAC of flours obtained from MW-IR dried and roasted seeds was found to be significantly higher than that of flours obtained from raw and conventionally treated seeds. The high temperatures provided

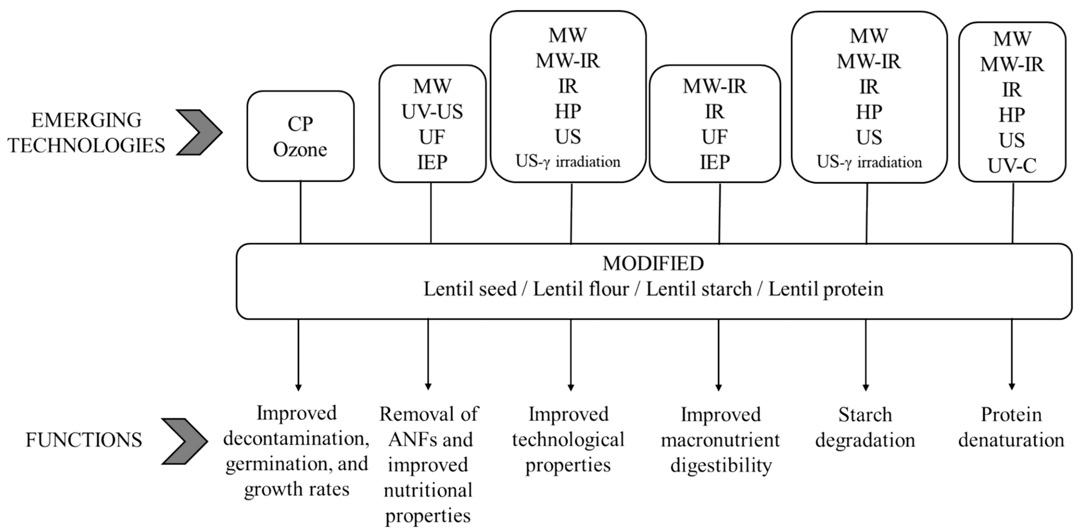

FIGURE 1 | Schematic representation of the impact of different emerging technologies on lentil properties.

TABLE 3 | Featured properties, action mechanisms, and process parameters of different emerging processing technologies and their role in the versatile functions of lentil components.

Emerging technology	Featured properties	Action mechanism	Process parameters	Main properties of starch and protein components changed by processes		Main observations	References
				Starch	Protein		
MW	– Rapid heating – Short processing time – Nonionizing electromagnetic radiation – Volumetric heating – Selective heating	– Creates interaction between alternating electromagnetic field and the dielectric material through ionic interaction and dipolar rotation – Creates water vapor pressure rise inside the heated material	Frequency: 2450 MHz Power: 600 and 900 W Process time: dried until 10% moisture content	– Denaturation degree	– Denaturation degree	– Increase in WAC – Decrease in antinutritional components (PAC, TIC)	Mazı, Yıldız, and Barutçu-Mazı (2023)
			Frequency: 2450 MHz Power: 540, 720, and 900 W Process time: 2, 4, and 6 min	– Denaturation degree	– Denaturation degree	–increase in WAC, OAC, EAI, and ES values – Decrease in FS	Mahalaxmi et al. (2022)
MW-IR	– Rapid heating – Short processing time – Nonionizing electromagnetic radiation – Volumetric heating – Selective heating	– Combination of MW and IR mechanisms	Frequency: 2450 MHz MW power: 0.37–0.7 kW IR Power: 0.0375–0.75 kW Process time: dried until 10% MC (d.b)	– Denaturation degree – Gelatinization degree – Crystallinity degree – Damaged starch content – Digestibility	– Denaturation degree – Solubility – Digestibility	– Increase in in vitro starch digestibility – Increase in in vitro protein digestibility – Decrease in protein solubility	Heydari, Najib, and Meda (2022)
			Frequency: 2450 MHz MW power: 0.42 kW IR power: 0.0375–0.75 kW Process time: dried until 8%–10% MC (d.b)	– Denaturation degree – Gelatinization degree – Damaged starch content – Digestibility	—	– Increase in total starch digestibility – Increase in rapidly digestible starch – Increase in WAC	Najib et al. (2023)
IR	– Rapid heating – Short processing time – Nonionizing electromagnetic radiation – Selective heating	– Creates water vapor pressure rise inside the heated material – Raises surface temperature and evaporation	Process temperature: 120°C and 140°C	– Denaturation degree – Gelatinization degree – Damaged starch content – Digestibility	– Denaturation degree – Digestibility	– Increase in in vitro starch digestibility – Increase in in vitro protein digestibility – Increase in damaged starch – Decrease in resistant starch – Increase in WAC – Decrease in FC	Laing et al. (2023a, 2023b)

(Continues)

TABLE 3 | (Continued)

Emerging technology	Featured properties	Action mechanism	Process parameters	Main properties of starch and protein components changed by processes: Starch	Main properties of starch and protein components changed by processes: Protein	Main observations	References
HP	– Nonthermal – Short processing time	– Immersion of a product under water and exposition of it to a hydrostatic pressure of several hundred megapascal in a HP vessel	Pressure: 400, 500, and 600 MPa Process time: 10 min	– Denaturation degree – Retrogradation degree – Damaged starch content – Resistant starch content	—	– Decrease in peak, hot paste, cold paste, setback, breakdown, and final viscosities (at 600 MPa) – Decrease in paste temperature (at 600 MPa) – Increase in peak temperature and time (at 600 MPa) – Increase in WAC, damaged starch, and resistant starch (at 600 MPa)	Ahmed et al. (2016)
			Pressure: 50–550 MPa Process time: 10 min	—	– Denaturation degree	– Increase in surface hydrophobicity – Insignificant changes in emulsifying and foaming properties	Navare, Karwe, and Salvi (2023)
			Pressure: 600 MPa Process time: 4 min Process temperature: 5°C	—	– Denaturation degree	– Increase in WAC, ESI, FE, and FLS – Increase in surface hydrophobicity – Decrease in protein solubility – Decrease in EAI	Hall and Moraru (2021)
US	– Simple, reliable, eco-friendly – Nonthermal – Chemical-free – Low energy consumption – Short processing time	– Creates cavitation that produces stable and unstable bubbles inside a food material and disrupts food components	Frequency: 37 kHz Power: 320 W Process time: 20 min	—	– Denaturation degree	– Increase in WAC, FAC, EAI, and ESI values – Decrease in gelation temperature – Insignificant changes in molecular weight, isoelectric point, particle size, and SH group	Quintero-Quiroz et al. (2022)

Abbreviations: EAI: emulsifying activity index, ES: emulsifying stability, ESI: emulsifying stability index, FAC: fat absorption capability, FC: foaming capacity, FE: foam expansion, FLS: foam liquid stability, FS: foaming stability, HP: high pressure, IR: infrared, MC: moisture content, MW: microwave, MW-IR: microwave-infrared, OAC: oil absorbing capacity, PAC: phytic acid content, TIC: trypsin inhibitor content, US: ultrasound, WAC: water absorbing capacity.

during the MW-IR drying and roasting processes can result in greater starch gelatinization and the release of hydroxyl groups that can bind water molecules through hydrogen bonds (Najib et al. 2023).

4.2 | IR Technology

IR or micronization technology is a rapid heating process, elevating the water vapor pressure inside the heated substance via electromagnetic radiation in the IR range. This results in considerable alterations to lentil components, primarily starch and protein fractions (Fasina et al. 2001).

In a recent study by Laing et al. (2023a), green lentil grains with 20% and 30% moisture content were exposed to IR treatment at 120°C and 140°C. Depending on the process conditions, IR treatment increased in vitro protein digestibility (IVPD) from 73.47% to 77.88%–81.74%, rapidly digestible starch from 8.52% to 14.00%–22.74% (dry basis), slowly digestible starch from 8.89% to 10.50%–14.80% (dry basis), and decreased resistant starch from 22.74% to 8.78%–17.49% (dry basis). The optimum moisture-temperature combination determined for the highest IVPD was 30%–140°C (Laing et al. 2023a).

Another study by Laing et al. (2023b) investigated the physicochemical and functional properties of green lentils treated under the same conditions mentioned in their previous study (Laing et al. 2023a). The WAC values of LFs increased with the IR treatment applied to lentil seeds before milling, but other functional properties were insignificantly or detrimentally affected. As the moisture content and process temperature increased, the EA, ES, and FC values of LF decreased, whereas the FS values remained stable. The inferior functional properties were associated with protein and starch denaturation. Denaturation of protein and starch fractions resulted in the presence of buried amino acids and short-chain carbohydrates in solution, changing the binding affinities or physically blocking important reactions. The optimum moisture-temperature combination for the highest EA was 20%–120°C (Laing et al. 2023b).

4.3 | HP Technology

HP is a nonthermal food processing and preservation technology that can be used alone or in combination with other technologies (Ahmed et al. 2019; Landim et al. 2023). The functional properties of lentils can be modified by changing the structure of their main components, starch and protein (Ahmed et al. 2016, 2019; Hall and Moraru 2021; Navare, Karwe, and Salvi 2023). Structural changes in lentil components have been associated with denaturation, followed by the formation of new bonds and conformational changes, resulting in altered functional properties (Ahmed et al. 2016; Hall and Moraru 2021).

In a study by Ahmed et al. (2016), the rheological, functional, thermal, and structural properties of HP-treated (at 400, 500, and 600 MPa for 10 min), lentil starch dispersions were determined. HP treatment at 600 MPa resulted in significant changes in WAC, damaged starch and resistant starch contents, and rheological properties of lentil starch as a result of complete starch gelatinization and structural destruction of starch granules. Because of HP treatment at 600 MPa, the WAC, damaged starch, and resistant starch values of starch samples increased from 2.23 to 5.22 g/g, 0.73% to 21.52%, and 5.07% to 6.80%, respectively. Considering the pasting parameters of the same starch samples, the paste temperature reduced from 64.1°C to 56.2°C. Simultaneously, the peak temperature and peak time escalated from 77.7°C to 95.0°C and from 9 to 44.43 min, correspondingly. Furthermore, all viscosity parameters of the starch samples, HP-treated at 600 MPa, significantly decreased. The percentage reductions in peak, final, breakdown, and setback viscosities were 45.72, 58.70, 99.19, and 84.16, respectively (Ahmed et al. 2016).

In a recent study (Navare, Karwe, and Salvi 2023), the effect of HP process parameters (pressure and time) and pH (3–7) of protein dispersion (process pH) on the physicochemical and functional properties of yellow lentil protein concentrate (YLPC) dispersions (10% w/v) was investigated. They also determined the effect of pressure (50–550 MPa) on the properties of YLPC at fixed treatment time (10 min.) and fixed pH (pH 7) during the HP process. At fixed time and pH, it was observed that an increase in applied pressure increased the surface hydrophobicity, which was associated with protein unfolding under HP and caused a slight but significant increase in protein solubility up to 150 MPa (at mild processing conditions). However, the authors stated that the effect of HP treatment on the emulsifying and foaming properties of LPCs was insignificant (Navare, Karwe, and Salvi 2023).

Hall and Moraru (2021) investigated the structure and functionality of HP-treated (at 600 MPa, 5°C for 4 min) and thermally treated (at 95°C for 15 min) LPCs. Both treatments affected the particle size, surface hydrophobicity, foaming, emulsifying, and gelation properties of lentil proteins. Pressurization increased the particle size of lentil proteins, indicating particle aggregation. The surface hydrophobicity of HP-treated LPCs was found to be higher than that of untreated samples, which was associated with the exposure of hydrophobic residues due to protein denaturation. HP treatment increased WAC, ESI, foam expansion (FE), and foam liquid stability (FLS) from 32% to 96%, 2303 to 2894 min, 345% to 7080%, and 54% to 95%, respectively, and significantly decreased protein solubility from 65% to 25% (Hall and Moraru 2021). The decrease in protein solubility has been associated with the exposure of hydrophobic residues, which can lead to the formation of insoluble aggregates. The significant increase in emulsifying and foaming properties was linked with changes in protein properties as a result of protein denaturation after HP treatment (Hall and Moraru 2021).

HP treatment has been combined with enzymolysis to enhance protein digestibility and antioxidant activity (Garcia-Mora et al. 2015; Ahmed et al. 2019). In a recent study by Ahmed et al. (2019), HP (at 300, 450, and 600 MPa for 15 min) followed by enzymolysis treatment (with alcalase at 0.5% and 1.0% w/w) was used to modify the technofunctional properties of LPIs. HP pretreatment (at 300 MPa for 15 min) was found to increase the WAC and EAI of LPIs. On the other hand, enzymatic hydrolysis significantly decreased WAC, EAI, ESI, and FS, while increasing the FC values of LPHs. The authors attributed the reduction in WAC values of LPHs to the decrease in hydrophilic groups after the combined HP-enzymolysis treatment. Moreover, it has been reported that the weak viscoelastic film formed by small peptides at the interface decreases both the EAI and ESI values of hydrolysates (Ahmed et al. 2019).

4.4 | US Technology

US waves have been used to extract functional components from lentils (Kaya, Tuncel, and Yılmaz 2017; Quintero-Quiroz et al. 2022) or to modify the functional properties of lentils (Majeed, Wani, and Hussain 2017). US is a physical process in which US waves are used to create cavitation bubbles in a solution due to temperature and pressure changes (Majeed, Wani, and Hussain 2017). As a result, the extraction of functional components from lentils or structural changes in starch and protein components leading to modified functional characteristics can be achieved (Majeed, Wani, and Hussain 2017; Quintero-Quiroz et al. 2022).

In a study by Kaya, Tuncel, and Yılmaz (2017), lentil (green and red)-water suspensions were sonicated to extract lentil hull and to investigate the effects of US treatment on the technofunctional properties of lentil hull. Sonication treatment did not significantly alter the soluble dietary fiber content, PAC, WAC, and OAC values of lentil hulls. Majeed, Wani, and Hussain (2017) determined the physicochemical and functional properties of sonicated lentil starch. Compared with native starch, sonicated starch was observed to have similar physicochemical and functional properties but lower amylose content (Majeed, Wani, and Hussain 2017). Quintero-Quiroz et al. (2022) compared the physicochemical, emulsifying, binding, and gelling properties of LPIs extracted by US-assisted or leaching treatments. The sonication treatment (37 kHz, 320 W, and 20 min) enhanced protein extraction yield, WAC, fat absorption capability (FAC), EAI, and ESI, increasing them from 23.19% to 57.57%, from 154.42% to 182.09%, from 176.65% to 229.79%, from 46.26 (m^2/g) to 51.05 (m^2/g), and from 11.10 min to 29.22 min, respectively. Additionally, it decreased the gelation temperature. It can be concluded that US-assisted extraction provided partial protein denaturation and modified the functional properties of LPIs (Quintero-Quiroz et al. 2022).

4.5 | Other Emerging Technologies

In the literature, CP, ozone, ionizing irradiation, UV light, UF, and IEP technologies have been also used to change the properties of lentils and lentil components (Majeed, Wani, and Hussain 2017; De Souza et al. 2021; Joehnke et al. 2021; Gutiérrez-León et al. 2022; Medvecka et al. 2022; Hernandez-Aguilar et al. 2023; Abeysingha et al. 2024; Levent and Aktaş 2024).

CP is a safe, efficient, solvent-free, and environmentally friendly technology that can be used in the decontamination of lentil seeds and activation of biochemical and molecular processes within seeds, which can affect nodulation, growth, and germination rates of plants (Gutiérrez-León et al. 2022; Medvecka et al. 2022; Abeysingha et al. 2024). In their 2022 study, Medvecka and colleagues used plasma activated water (PAW), generated by pulsed corona discharge (CD), and high-power air plasma jet (APJ), to successfully inhibit the growth of *Escherichia coli* and aerobic bacteria in lentil sprouts. The APJ-activated PAW provided strong decontamination effect on lentil sprouts (Medvecka et al. 2022). In another study, Abeysingha et al. (2024) investigated the role of CP treatment (plasma sources: dielectric barrier discharge and pin electrode reactor) on red lentil seed nodulation and plant growth. After 4 weeks, the authors observed notable enhancements in nodule number and DW, root DW, length, volume, surface area, and shoot DW. Gutiérrez-León et al. 2022 activated three water sources (potable, wastewater from poultry farming, and rain) with the help of cold (nonthermal) plasma (plasma source: corona discharge) and used them during lentil development. Improved germination and growth rates, along with a reduction in bacterial load (*E. coli* and *Salmonella typhimurium*) were observed in lentils exposed to PAW (Gutiérrez-León et al. (2022).

Ozone treatment is also an environmentally friendly approach to improve the water uptake, growth, and germination rates of lentils (De Souza et al. 2021). In the study by De Souza et al. (2021), lentil seeds were exposed to ozone (1 g/m^3) for 2, 3, 5, 10, and 15 min. The water absorption in lentil seeds treated for 3 and 5 min was observed to be significantly higher than that in untreated control samples. The best germination rates (90%), stem and root growth, and mass gain were determined for the lentil seeds treated with ozone for 3 and 10 min (De Souza et al. 2021).

Majeed, Wani, and Hussain (2017) modified lentil starch with a dual treatment of US and gamma (γ) irradiation (5 kGy). The dual treatment significantly increased the solubility, transmittance, WAC, and OAC, while significantly decreasing the swelling index, syneresis, and pasting properties of lentil starch, because of starch degradation (Majeed, Wani, and Hussain 2017).

UV alone or in combination with other technologies, such as UV-US, is one of the innovative technologies used to modify lentil properties (Hernandez-Aguilar et al. 2023; Levent and Aktaş 2024). Hernandez-Aguilar et al. (2023) reported that 10 min of UV-C (200–280 nm) treatment damaged protein structure, but no starch damage was observed. In another study by Levent and Aktaş (2024), UV, US, and their combination (UV-US) treatments were applied before germination process to improve functionality of black lentils. All treatments increased the TPC and antioxidant activity of lentil samples, while decreasing the phytic acid content. The highest phenolic content and antioxidant activity and the lowest phytic acid content were reported for UV-US pretreated germinated black LFs (Levent and Aktaş 2024).

Joehnke et al. (2021) employed UF and IEP treatments to produce LPIs on a pilot scale and evaluated their nutritional and antinutritional values. IEP and UF treatments reduced the trypsin inhibitor activity (TIA) by 81% and 87% and total galacto-oligosaccharides (GOSs) by 58% and 91%, respectively. They also increased protein content and IVPD by 35%–53% in LPIs compared to whole seed LF. UF-treated LPIs were found to have the highest purity and low total GOS and TIA contents along with high nutritional quality and protein digestibility (Joehnke et al. 2021).

4.6 | Role of Modified Lentils/Lentil Components in Specific Food Applications

Although various studies investigate the effects of emerging technologies on the nutritional and technological properties of lentils, there is limited research on the comparative advantages of using these modified lentils over raw ones in different food applications. This section details some specific food applications, such as beef burgers, noodles, snack food, and cookies, that incorporate IR, US, MW, and UV-US-modified lentils or lentil components.

The use of unprocessed lentils or lentil components as meat binders in the formulation of processed meat products presents challenges, including the acceleration of meat pigment and lipid oxidation due to the high lipoxygenase activity of raw lentils (Li 2017). Given the significance of maintaining fresh meat color and stability and inhibiting lipid oxidation during storage, it is essential to limit the activity of endogenous lipoxygenase when raw LF is utilized as a meat binder. In the literature, IR pretreatment has been applied to raw LFs to improve color stability and to slow down lipid oxidation in raw beef burgers (Der 2010; Pathiratne 2014; Li 2017). Der (2010) investigated the potential use of IR-treated dehulled red and green LFs (15% moisture content and heated to a surface temperature of 135°C) at 6% and 12% levels as a binder in low-fat (< 10%) beef burgers stored at 4°C. The inclusion of IR-treated LF resulted in higher a* values, indicating greater preservation of redness during 7 days of storage. Furthermore, significantly lower thiobarbituric acid reacting substance (TBARS) values of beef burgers containing IR-treated LF compared with those containing untreated LF demonstrated that IR treatment suppressed oxidation reactions in LFs by decreasing lipoxygenase activity and enhanced oxidative stability in raw burgers during 7 days of storage at 4°C. According to the sensory analysis, the authors recommended the use of IR-treated LF at 6% in the beef burger formulation as a meat binder, which received higher overall acceptability scores from consumers (Der 2010). Other authors have also presented that raw low-fat beef burgers containing IR-treated LF (6%) had significantly higher a* and lower TBARS values compared to the burgers containing the same amount of untreated LF (Pathiratne 2014; Li 2017). In another study by Shariati-levari et al. (2016), the volatile organic compounds (VOCs) formed due to the lipoxygenase activity have been determined for IR-treated and untreated LFs. IR treatment significantly reduced lipoxygenase activity and formation of VOCs for LF, which can cause off-flavors. The addition of 6% IR-treated LF significantly reduced off-flavor and increased sensory scores (overall flavor acceptability) of beef burgers indicating increased consumer acceptance (Shariati-levari et al. 2016).

Lin et al. (2022) investigated the effects of US, enzyme, and US-assisted enzyme-treated red LPI addition on the quality and in vitro digestibility of brown rice noodles. US treatment significantly changed the secondary structure of red LPIs and increased their random coil and α-helix contents while decreasing the β-sheet content. Compared with untreated red LPI, the incorporation of US-treated red LPI significantly reduced the cooking loss from 5.63% to 3.58%, while increasing the protein digestibility of rice noodles from 62.1% to 73.3%. The decreased cooking loss values were associated with increased interaction of small particle size proteins (obtained by US treatment) with starch molecules, which provided structural integrity during cooking and reduced solid loss. The increase in protein digestibility has also been associated with the decrease in the particle size of LPIs and the change in their secondary structure caused by US application, which in turn increases the sensitivity of LPIs to digestive enzymes.

Sinaki et al. (2022) recently produced third-generation, lentil-based, high-protein snack foods using mild extrusion (low temperature, high moisture) followed by MW treatment in their study. Extensive starch damage and complete protein denaturation were observed in MW-treated samples. MW heating has been reported to improve the thermal and physical properties of lentil-based snacks, for example, increasing their overall expandability and reducing their density (Sinaki et al. 2022).

Levent and Aktaş (2024) used UV, US, and UV-US pretreated germinated black LF (GBLF) at a level of 20% in cookie formulation. Cookies formulated with pretreated (UV, US, and UV-US) GBLF had lower phytic acid and higher TPC, antioxidant activity, Ca, K, and Mg contents compared to cookies containing raw BLF. This indicates that UV and US pretreatments increased the nutritional value and bioactivity of BLFs as well as cookies formulated with them (Levent and Aktaş 2024).

5 | Limitations of the Review

This review examines neither the effects of traditional processing techniques on the properties of lentil components nor the role of traditionally modified lentils in food applications. Due to the broad nature of the subject, this study focuses only on recent research and excludes nonfood applications. Keskin and Sumnu (2023) provide comprehensive information about these topics, which can complement this review.

6 | Future Research Directions

Emerging technologies are beneficial alternatives to traditional methods, which may be utilized alone or in combination, for modifying lentils. PEF, a burgeoning technology, modifies bean, pea, and chickpea seeds by creating pores in the cell membrane, thereby increasing the seeds' water absorption and promoting the production of health-boosting secondary metabolites during germination (Devkota et al. 2022; Bagarinao et al. 2024). There is no published data on the effect of PEF treatment on lentil functionality. Therefore, as future research, PEF can be used to modify lentils and improve their functionality. Furthermore, more research is needed on the effects of emerging technologies, especially CP, UV, ionizing radiation, ozone, and their combination, on nutritional and technological functions of lentils. Additionally, standardizing process equipment, optimizing the process, scaling up and conducting commercialization studies, and lowering equipment costs may promote the extensive use of these emerging technologies in modification applications.

On the other hand, further research is needed on the nutritional, technological, and sensory quality and shelf life of more food types formulated with modified lentils and lentil components to improve the understanding of the functional properties of lentils in food systems.

Additionally, innovative tools like X-ray tomography, near-IR hyperspectral imaging, and computer vision can be used to enhance our understanding of lentils' structural properties and their impact on functionality. The use of 3-D printing and artificial intelligence (AI) technologies to develop new food products formulated with lentil components, such as meat analogs, is another innovative approach for future research.

7 | Conclusion

Lentils offer versatile nutritional, health-promoting, and technological functions that make them popular ingredients of food formulations and novel diets (e.g., GF and vegan). The degree of functionality of lentils in food applications is affected by (i) molecular and granular structure, size, shape, and composition of lentil components, (ii) possible interactions between the lentil components and the food environment, and (iii) processing conditions. In addition to their desirable functions, raw lentils possess high lipoxygenase activity and contain unwanted flavor compounds, raffinose family oligosaccharides, ANFs, and the allergenic proteins. Recent studies have shown that emerging technologies with their unique mechanism of action, alone or in combination, can overcome some of these disadvantages. At appropriate processing conditions, MW, MW-IR, IR, HP, US, and US-γ irradiation are successfully used to modify starch and protein components and improve the technological properties of lentils. Moreover, MW, UV-US, UF, and IEP can remove ANFs and improve nutritional properties, while MW-IR, IR, UF, and IEP can increase the digestibility of macronutrients. These promising results may help increase the use of modified lentils in value-added food formulations as foaming, emulsifying, binding, or antioxidant agents, thus improving consumer acceptance and consumption levels.

Author Contributions

Semin Ozge Keskin: conceptualization, investigation, writing – original draft. **Gulum Sumnu:** conceptualization, writing – review and editing.

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

Data sharing is not applicable to this article as no new data were created or analyzed in this study.

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