Discover Food

Review

Innovations in industrial and functional food applications of lentil in the era of biofortification

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Abstract
Lentil can serve as a prebiotic and therapeutic healthy food due to the presence of essential micronutrients, functional proteins, minerals, and carbohydrates, as well as phytochemicals that have shown to be promising in the prevention of several chronic diseases. Nutraceutical properties derived from the phytochemicals present in lentil has expanded its scope of usage to a broader perspective. In this regard, a lot of innovations have been carried out to use lentil in the form of crisps, chips, bakery products, yogurt, pasta, including in the brewing industries. Efforts are being carried out to develop meat analogs out of lentil flour. However, niche area specific consumer preferences have limited its explorations in other innovative areas. This will also necessitate developing genetic resources and varieties aligning to the needs of producers and consumers with acceptable sensory properties. Hence, demand driven development of breeding materials for biofortification and crop improvement programs needs considerable amount of investment in research and development of the crop. This review is a campedium of innovations in development of industrial, functional food products from lentil along with their nutritional properties and sensory acceptability serve a foundation for the researchers to invent more to popularize lentil among the consumers to ensure nutritional security.

Keywords Lentil · Functional food · Industrial value addition · Sensory acceptability · Omics

Abbreviations

kg	Kilogram
ha	Hectare
Mha	Million hectare
Mt	Million ton
Leu	Leucine
Ile	Isoleucine
Lys	Lysine
mg	Milligram
g	Gram
µg	Microgram
CE	Catechin equivalent
GAE	Gallic acid equivalent

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NaFe EDTA	Sodium iron ethylenediaminetetraacetic acid
MPa	Mega pascal
RILs	Recombinant inbred lines
SNPs	Single nucleotide polymorphism
SSRs	Simple sequence repeats
LC-MS	Liquid chromatography mass spectrometry

1 Introduction

Lentil (*Lens culinaris*) is a diploid ($2n=14$) self-pollinating annual crop that is mainly cultivated in semi-arid regions. It is one of the world's healthiest food, due to its outstanding nutritional profile [1]. Globally, the average production of lentil is about 1004.3 kg/ha with an acreage of 5.59 Mha (FAO, 2021). In 2020, lentil recorded maximum production of around 6.54 Mt. In the past two decades (2001–2020), the area under lentil cultivation has marked a huge leap with an increment of 26.83% while total production has marked an increase of 49.96% in 2020 compared to 2011 [2]. Canada is the leading producer of lentil contributing about 28.5% (1.6 Mt) to the global market followed by India (1.49 Mt), Australia (0.85 Mt), Turkey (0.26 Mt) and Nepal (0.24 Mt) (FAO, 2021). India shares the maximum production area (1.73 Mha) during cultivation of lentil followed by Canada (1.71 Mha), Australia (0.5 Mha), and Turkey (0.29 Mha). The major exporting countries of lentil are Canada, Australia, Turkey, the United States of America, and the United Arab Emirates while importing countries are India followed by Turkey, Bangladesh, United Arab Emirates, and Pakistan [2].

Lentil is a vital meal usually consumed as dry seeds (whole decorticated, seed decorticated, and split). In India, it is commonly prepared as 'Dal' by removing the outer peel and separating the cotyledons, as well as snacks and soups. It is widely advised that patients with diabetes, especially type II diabetes need to consume a variety of carbohydrate and protein rich diets from pulses and other nutrient rich sources [3] in which lentils fit pretty well with its digestive properties, nutritional value and easy preparation, and therefore considered as 'patient food' [4]. Moreover, lentil is also utilized in cattle feed; mostly dry leaves, stalks, and empty and broken pods [5]. Lentil protein also has good Leu/Ile (1.24–1.98) and Leu/Lys ratios (1.08–2.03) [5]. Due to the presence of high lysine content in lentil, it can be used in cereal-based products that contain sulfur-containing amino acids to meet nutritional needs [6].

Lentil has been explored as an industrial and functional food delivering a range of products to the market. Industrial processing of involves three steps such as primary, secondary and tertiary. Primary processing involves cleaning, categorizing, and packaging as whole lentil whereas secondary processing involves dehulling and splitting [7]. Industrial value addition as a part of tertiary processing involving milling, fractionation (starch and protein isolates) and thermal processing (bursting, baking) etc. has increased the popularity lentil consumption. Snack items such as, biscuits, cookies, cakes, crisps and puffs etc. [5, 8–10] produced from thermal processing have gained increased consumer acceptance. Lentil protein isolates alone or in conjunction with other pulse proteins, are being used in tofu-like products, imitation milk, meatballs, and bread [6]. Moreover, milk produced from lentil isolates was of intermediate quality which is similar to milk from soy isolates [11]. Among other products, lentil malts are being explored in the brewing industry to produce colorful low-alcohol gluten-free beers [12, 13]. Moreover, lentil micro-greens having rich nutritional sources are becoming popular among the health-conscious masses [14]. Lentil consumption in a regular diet provides several health advantages, including protection against coronary heart disease, type 2 diabetes, cardiovascular disease, and cancer [15].

This manuscript briefly describes the nutritional properties of lentils followed by phytochemical preference, market presence and culinary preference. The novelty of the article lie in the section of industrial and functional food products developed from lentil that are described keeping in view of consumer preference and sensory acceptability of lentil based products. Moreover, the nutritional value of lentil microgreens compared to other legumes as well as the biofortified lentil varieties developed for industrial and functional food purposes are tabulated. Lastly, omic resources available in lentil to unleash its potential nutraceutical role are reported with future directions for product development in lentil. This review would serve as a foundation and reference for future innovations to develop industrial and functional food products from lentil.

2 Nutritional breakdown of lentil: a comprehensive overview

2.1 Nutritional properties of lentil

Lentil is a good source of protein (22–31%), carbohydrate (54.08–55.81%), fat (1.93–2.15%), crude fiber (6.99–8.14%), minerals (2.4%), and vitamins [16]. Lentil protein is composed of 70% globulins, 16% albumins, 11% glutelin, and 3% prolamins [17, 18]. It is rich in several amino acids such as isoleucine (1.06 g), leucine (1.79 g), lysine (1.72 g), phenylalanine (1.22 g), valine (1.22 g), arginine (1.9 g), alanine (1.03 g), aspartic acid (2.72 g), glutamic acid (3.82 g) and proline (1.03 g) [19]. In lentil, fats are found to be slightly lower than in chickpeas. Lentil seed contains a total 1.4 g/100 g of fat that is distributed unevenly (saturated, monounsaturated, and polyunsaturated fatty acids by 16.7, 23.7 and 58.8% respectively) [19]. Due to high nutritive properties, consumption of lentil-based products in regular diet has been proven to offer enormous health benefits against several chronic illness conditions, including cancer, high blood pressure, high cholesterol, and cardiovascular disorders [20]. Lentil has also been studied for improving hunger, lowering food intake, and thus managing body weight because of their high fiber content and low glycemic response [21]. Further, lentil is rich in prebiotic carbohydrates such as raffinose-family oligosaccharides, sugar alcohols, fructo-oligosaccharides (FOS), and starch carbohydrates in lentil is about 4071 mg, 1423 mg, 62 mg, and 7.5 g per 100 g dry weight, respectively [22] that can help in avoiding digestive disorders [20]. Furthermore, folate was found to be higher in lentil (50–202 μg/100 g) than the other pulse crops such as chickpeas, and field peas (42–125 and 41–55 μg/100 g) [23]. Lentil, being a good source of folates has potential to lower the risk of stroke and ischemic heart disease as increased the amount of folate in the diet (0.8 mg of folic acid) lowers the risk of stroke and ischemic heart disease by 16% and 24%, respectively [24]. In addition, Ryan et al. [25] also measured the range of vitamin E (a, b, and c tocopherols) was measured in lentil by 15, 1.6, and 4.5 mg/day. The human body requires more than 22 minerals and lentil contain almost all the elements such as P (281 mg), K (677 mg), Ca (35 mg), Mg (47 mg), and Na (6 mg), Fe (6.51 mg), Zn (3.27 mg), Cu (0.754 mg), and Mn (1.39 mg); (all the values are out of 100 g of lentil) (Table 1) [19]. The studies reported that 100 g of lentil seed can provide the recommended daily allowance (RDA) of Fe (41–113%), Zn (40–68%), and Se (77–122%) followed by β-carotene (2–12 μg/g) [26]. Additionally, lentil have very low Na^+ with high K^+ along with a high K^+/Na^+ ratio [27]. Therefore, lentil is a promising potential for a healthy livelihood.

2.2 Antinutritional properties of lentil

Although, lentil is an important grain legume for the vegetarian diets and low-income societies, presence of certain antinutrients limits its widespread use in various countries [18]. The anti-nutritional factors in lentil seeds can be majorly divided into two groups; proteinaceous (lectins, proteases, amylase inhibitors, and seed hydrolase inhibitors) and non-proteinaceous fractions (phytic acid, tannins, cyanogenic glycosides, and some oligosaccharides) [29]. Increased consumption of lectins from the pulses like chickpeas, lentils etc. causes nutritional deficiencies and immune (allergic) reactions, by disrupting hormone balance and deplete nutrient reserves, resulting in severe growth retardation and a high death rate. Saponins are triterpene glycosides that are present in lentils and are poorly absorbed by humans and form huge, mixed micelles with bile acids and cholesterol, and to form insoluble complexes with 3-hydroxysteroids [30]. Amylase inhibitors cause reduced hydrolysis of polysaccharides such as starch and glycogen hence result in a reduction in growth [31]. Trypsin and chymotrypsin inhibitors found in lentils were also found to reduce growth in diets containing free amino acids [17, 32].

Phytic acid has been labelled an antinutrient because of its binding to the minerals such as phosphorous, calcium, magnesium, zinc, and iron, rendering them indigestible resulting in poor mineral bioavailability [33]. Phytic acid can also form complexes with proteins such as lipase, a-amylase, pepsin, trypsin, and chymotrypsin, lowering their solubility and enzyme function [32]. Tannins can irritate the stomach lining and induce mucus secretion, increasing endogenous protein release and, as a result, protein demand. They also generate divalent metal complexes, which limit mineral absorption [33]. Weight loss is a common aspect of tannin-rich diets [34]. Lentils have a high concentration of cyanogenic glycosides and have potential for causing human food poisoning if present in excess concentrations [33]. Grain legumes including lentils also contain Mimosine & 3-*N*-oxalyl-L-2, 3-diaminopropanoic acid (ODPA), two poisonous non-protein amino acids that have a significant deleterious impact on animals and humans who consume them [34] i.e. The most well-known effect is lathyrism, a non-progressive motor neuron disease linked to a

Table 1 Comparison of nutritional status of red lentil vs. green/yellow lentil

Components	Green/yellow	Pink/red	References
Water	8.26 g	7.82 g	[19]
Energy	352 kcal	358 kcal	
Energy	1470 kJ	1500 kJ	
Dietary fiber	10.7 g	10.8 g	
Ash	2.71 g	3 g	
Protein			
Protein	24.6 g	23.9 g	
Tryptophan	0.221 g	0.223 g	
Threonine	0.882 g	0.895 g	
Isoleucine	1.06 g	1.08 g	
Leucine	1.79 g	1.81 g	
Lysine	1.72 g	1.74 g	
Methionine	0.21 g	0.212 g	
Cystine	0.322 g	0.327 g	
Phenylalanine	1.22 g	1.23 g	
Tyrosine	0.658 g	0.667 g	
Valine	1.22 g	1.24 g	
Arginine	1.9 g	1.93 g	
Histidine	0.693 g	0.702 g	
Alanine	1.03 g	1.04 g	
Aspartic acid	2.72 g	2.76 g	
Glutamic acid	3.82 g	3.87 g	
Glycine	1 g	1.01 g	
Proline	1.03 g	1.04 g	
Serine	1.14 g	1.15 g	
Minerals			
Calcium, Ca	35 mg	48 mg	
Iron, Fe	6.51 mg	7.39 mg	
Magnesium, Mg	47 mg	59 mg	
Phosphorus, P	281 mg	294 mg	
Potassium, K	677 mg	668 mg	
Sodium, Na	6 mg	7 mg	
Zinc, Zn	3.27 mg	3.6 mg	
Copper, Cu	0.754 mg	1.3 mg	
Manganese, Mn	1.39 mg	1.72 mg	
Selenium, Se	0.1 µg	–	
Carbohydrates			
Carbohydrate	63.4 g	63.1 g	
Total sugars	2.03 g	–	
Sucrose	1.47 g	–	
Fructose	0.27 g	–	
Maltose	0.3 g	–	
Starch	49.9 g	47.6 g	
Vitamins			
Vitamin C	4.5 mg	1.7 mg	
Thiamin	0.873 mg	0.51 mg	
Riboflavin	0.211 mg	0.106 mg	
Niacin	2.6 mg	1.5 mg	
Pantothenic acid	2.14 mg	0.348 mg	
Vitamin B-6	0.54 mg	0.403 mg	
Folate, total	479 µg	204 µg	

Table 1 (continued)

Components	Green/yellow	Pink/red	References
Folate, food	479 µg	204 µg	
Folate, DFE	479 µg	204 µg	
Choline, total	96.4 mg	–	
Vitamin A, RAE	2 µg	3 µg	
Carotene, beta	23 µg	35 µg	
Vitamin A, IU	39 IU	58 IU	
Vitamin E (α-tocopherol)	0.49 mg	–	
γ-Tocopherol	4.23 mg	–	
Vitamin K (phylloquinone)	5 µg	–	
Fats			
Total lipid (fat)	1.06 g	2.17 g	
Saturated fats	0.154 g	0.379 g	
Monounsaturated fats	0.193 g	0.5 g	
Polyunsaturated fats	0.526 g	1.14 g	
Stigmasterol	–	4 mg	
Campesterol	–	6 mg	
Beta-sitosterol	–	47 mg	
Phytochemicals			[4]
Total polyphenolics		26 mg GAE/100 g FW	
Flavonoids		221 mg	
Flavonones		33.1–186.0 µg	
Flavonoles		9.6–241 µg	
Procyanidins, dimer		619–1122 µg	
Procyanidin, trimer		441–498 µg	
Procyanidins, tetramers		18.5–59.5 µg	
Procyanidins, galloylated		69.3–123 µg	
Prodelphinidins		369–725 µg	
Transresveratrol		5.5–9.3 µg	
Hydroxybenzoic acids		4.5–28.4 µg	
Hydroxycinnamic acids		11.7–29.5 µg	
Catechin		919–1633 µg	
Gallocatechin		140 µg	
Total phytosterols		22.9–31.6 mg	
Antinutritional components			
Condensed tannins		870 mg	
Phytic acid	739 mg	643 mg	
Saponins		34 mg	
Stachyose	5102 mg	5651 mg	[28]
Raffinose	1502 mg	2118 mg	

Values are mentioned in units per 100 g of dry weight

high intake ODPA [35]. Oligosaccharides such as raffinose, stachyose, ciceritol, and verbascose, present in legumes like lentils, peas, chickpeas etc. are common causes of flatulence in humans [33]. Significant efforts by the research groups to lower these antinutritional compounds in lentil can enhance their public acceptability.

3 Phytochemical potential of lentil

Lentils contain higher amounts phytochemicals including phenolic acids, flavanols, phytosterols, phytic acid, tannins, saponins, carotenoids, and tocopherols [36]. Bioactive substances present in lentil based diets impart antioxidant, anti-carcinogenic, antimutagenic, and anti-hyperglycemic properties to make it an important crop for human health. Polyphenols, which are abundant bioactive compounds present in lentil, have antihyperlipidemic, hyperhomocysteinemia, anti-cholesterolemic, and cardioprotective properties and help in reducing the incidence of hypertension and coronary artery disease [20]. The phenolic concentration in green lentil (4.46–8.34 mg/g DW) has been observed comparatively higher than in red lentil (5.04–7.02 mg/g DW) [37]. The flavonoid concertation of lentil ranged from 0.27 to 289 µg/g DW which can be further classified into flavan-3-ols, flavanols, flavones, flavanones, anthocyanidins, and isoflavones. In lentil, the TPC of insoluble phenolics ranged from 0.18 to 17.5 mg GAE/g, while TFC ranged from 0.03 to 4.13 mg CE/g [36, 38]. In the category of phytosterols, the concentration of β-sitosterol was 123.4 mg/100 g, followed by 20.0 mg/100 g of stigmasterol and 15.0 mg/100 g of campesterol [25]. The raw lentil contains 6.4–7.3 mg/g of phytic acid while Canadian lentil, contains slightly higher amount of phytic acid i.e. from 6.2 to 8.8 mg/g [28, 39]. The saponin content of lentil was reported in the range of 340–1269 mg/kg DW [28, 40]. Lentil has high amount of lipophilic antioxidants such as carotenoids and tocopherols. Carotenoids like lutein and zeaxanthin contents in lentil ranged from 4.32 to 17.29 µg/g DW and 0.32 to 2.73 µg/g DW, respectively followed by tocopherols (37–64 µg/g DW) [28].

4 Market value of lentil depend on its appearance

The color, appearance, seed size, and weight of lentil are important criteria that determine its quality and consumer preference [41]. Further, according to seed size lentils are categorized into Microsperma (small-seeded) and Macrosperma (large-seeded). Based on their seed weight lentil are divided into extra small (2.9–3.2 g), small (3.3–4.5 g), and large (>5 g) [2]. Lentil varieties have a broad range of forms such as red, green, speckled green, tan and black. From these, red and green lentil are consumed in most countries while yellow and Spanish brown are used in a few countries [42]. The seed of green lentil is thick, and uniform in color with having unstained and unwrinkled seed coat, hence more preferred [2]. Countries including Turkey, Syria, Egypt, India, Pakistan, Sri Lanka, Bangladesh, Nepal, Australia, and Canada, usually prefer to consume red lentil while people from Algeria, Morocco, Greece, Italy, Spain and Mexico, prefer green lentil. Additionally, England, Germany, and the United States of America especially prefer yellow lentil while Spanish people usually consume brown-colored lentil [2]. Among the light tan-brown and dark brown lentil, dark brown lentil are perceived as low-quality ones [43]. Lentil seeds are prone to discolouration on extended storage due to the loss of secondary metabolites which lowers their nutritional value [44]. Further, the damaged seed coats affect the appearance and aesthetics; hence, mishandling at any phase of processing and transportation leads to reduce the market value. Therefore, it is suggested that harvesting at a relatively higher moisture level (16–20%) and drying (13–14%) preserves the seed quality in lentil [43]. Moreover, the lentil categorized into three categories to facilitate their marketing, import, and export depending on the damages caused by the weevil, heat; admixtures, contrasting lentil, skinned and wrinkled lentil percentage, and seed coat [2]. The red lentil are dehulled before preparation and consumption whereas green lentil are consumed as whole seeds [42]. Therefore, consumer preference for lentil varies depending on the size, color of the testa and cotyledon, quality of the seed, purpose of use and geographical area. For sustainable food security and to appease the flexiterians and conscious meat eaters meat analogs were developed. However, successful combination of processing methods and functional ingredients is necessary to generate meat like sensory qualities [45]. By conducting sensory evaluation, companies and researchers will learn valuable information regarding product attributes and overall liking that help to provide more widely accepted and sustainable foods [45].

5 Regional differences and tastes call for culinary creativity for lentil

Lentil is used as snacks, pan/flatbread, and fortified yogurt which provides energy sources in Egypt and Syria. Similarly, soup made with dehulled lentils is integral part of daily diet in many North African and Middle Eastern countries [46]. Aromaticity of lentil can be intensified during processing by making use of different spices and herbs like green chillies

[47]. Dal, the commonly used dish in South Asia is made up of different pulses like lentil, mung bean, urd dal, and chickpea. In South-Asian countries like India, Pakistan, Nepal, Bhutan, Sri Lanka etc., lentil is consumed in the form of Dal, soup, salads and with mixed vegetables [48]. 'Kirmizi Mercimek' is form of dal made from lentils which is exclusively consumed in turkey and is different from that of North African and South Asian countries. Although, sprouts of many legumes are popular among the masses, lentil sprouts are rarely consumed because of their nutty flavor [48]. To enhance food quality, slit seeds is preferred than whole seeds of lentil as they absorb spices easily and [48]. Powdered form and split seeds of lentils are used for making sauce 'Kik watt' and 'Shiro watt' which is consumed with bread in Ethiopia [48]. 'Sambusa' (boiled lentils mixed with onion and green chillies stuffed in wheat flour) and 'Azifa' (cooked & mashed lentils) are very much popular in north-western Ethiopia [48]. Lentil straw is used for animal feed as it contains low cellulose and the vegetative part is used as green manure [49]. In the dish 'Potage Saint Hubert' lentils are used to enhance the taste of meat which is popular in Europe [48]. Similar dishes with different ingradients are also common in Lebanon, Syria and Iran [48]. It can be concluded that lentil is very much popular among the masses across the globe, however the recipe and culinary creativity varies depending on the regions.

6 Sensory acceptability of biofortified and industrial products of lentil

Sensory attributes such as taste, flavor, appearance, aroma, richness of colour etc. greatly influence the choice of purchase by the consumers which in turn can impact consumer satisfaction and affect demand based production of a certain commodity [45]. Unlike other legumes i.e. chickpeas, peas and soybean, lentil are available in various colors such as yellow, red, green and black etc. which affects their preferential purchase by consumers. Therefore in the era of biofortification, understanding the impact of increased levels of phytochemicals, minerals and other nutritional parameters on the sensory acceptability of lentil is crucial for optimizing its consumer appeal. In a germination experiment of lentil strong correlation was found between bitterness and astringency (negative sensory attributes) which is decided by catechin gallate and flavonols [50]. Further, it was found that these phenolic compounds interact with other components of sprouts to produce a number of volatiles such as alcohols, aldehydes and esters ultimately producing a desirable or undesirable taste in the product.

Generally aroma profile of lentil is influenced by phytochemical composition, however elevated levels of these phytochemicals may enhance the aroma intensity and complexity or in contrast may introduce undesirable odours and off flavors [10]. Consumer perception and acceptability of lentil based products can be influenced by enhancing the aroma profile through various treatments such as thermal processing for making hot or cold extrusion products [51] and chemical treatments such as treatment by ethanol, isopropanol or acetone [52]. In another experiment Dougkas et al. [53] found that lentil based products incorporating herbs and spices receive higher sensory scores. These findings emphasize that understanding the relationship between phytochemicals and other nutritional compounds with aroma characteristics, taste and flavour is essential for optimizing the sensory acceptability of lentil [54].

Besides taste, flavour and aroma, texture and colour of lentil are of prime importance in terms of sensory properties which affect the consumer acceptability of lentil and lentil-based products. Products made from 100% lentil or with a high level of substitution of lentil flour affect the textural attributes like tenderness, chewiness and mouth-feel which finally becomes unacceptable to the consumers. However, processing technologies such as extrusion, fermentation, addition of hydrocolloids etc. proved to be beneficial to improve the textural and sensory attributes of final products [55]. Phytochemicals like flavonoids, anthocyanins, phenolics, tannins and carotenoids contribute towards coloration of lentil and their products [56, 57]. Ariyawardana et al. [58] reported that consumer preference for lentil is inclined towards red lentil compared to green/brown/yellow or black lentil owing to their visual appeal and softer texture. It may be noted that increased phytochemical contents may lead to improved coloration producing more vibrant hues which can enhance visual appeal and perceived freshness; however excessive phytochemicals may lead to product instability by lowering the quality. According to Turco et al. [59] pasta made from 100% red lentil with higher bioactive polyphenols and flavonoids fetched lower sensory acceptability among the consumers compared to conventional durum wheat pasta; however, the researches stated that according to overall rating, it is still acceptable to the masses [55, 59]. Contrastingly, wheat sourdoughs added with lentil enhanced the sensory characteristics (salty, elasticity, color and taste) along with nutritional and antioxidant properties [60].

Addition of certain products such as hull, changes the sensory properties of lentil based products. Hull/seed coat is considered as a mineral reservoir. When added in the crisps, they impart diverse effects on colour, rheological and textural properties, glycemic potential and mineral content of final product [61]. Changes in processing methods also call for increased sensory acceptability of lentil and lentil based products. For instance, an iron-fortified lentil variety, Pusa Vaibhav was acceptable among Indians in the form of samber, pulao, kesari and poli [62]. Similarly, cooked meal of iron fortified lentil developed [63] (using NaFeEDTA) fetched higher sensory evaluation than that of the uncooked ones. The researchers also confirmed that the overall sensory perception regarding the colour, odour, taste and texture of cooked iron-fortified was minimally affected and the scores were consistent according to the reliability estimates (Cornbach's alpha value- CA > 0.80). However, the sensory acceptability among the consumers of Saskatoon (Canada) and Bangladesh confirming the regional differences also call for the variation of sensory acceptability of lentil-based products [63]. A similar experiment by Podder et al. [61] using dual fortified lentil varieties also fetched identical results. As sensory acceptability drives the food choice and intake by the individuals, it can also be connected with the overall public health and well-being. A pleasant sensory experience would encourage people to continue and increase the intake of fortified lentil-based diets for improved health outcomes and potential recommendations to others will presumably enhance the demand driven production of lentil and lentil-based industrial and functional food products.

7 Innovations in industrial value addition of lentils

Generally, the industrial processing of lentil involves three-tier procedures as follows, *Primary processing* starts with the cleaning, categorizing, and evaluation or packaging as whole lentil for consumers, *Secondary Processing*; dehulling and cracking the whole lentil into two parts (splitting). *Tertiary processing*—milling for parting the starch and protein for further utilization in food industries [7]. Lentil flours can be acquired by dry or wet milling, producing the fractions of starch and protein. However, the starch and protein fractions need to be validated before using the flour for large-scale applications in diverse foods [64]. Moreover, lentil flour can be produced by optimizing the feed rate, moisture content, and processing temperature in the extrusion method [64]. Lentil-based products are in demand for their nutritional benefits, particularly for high protein contents, however, optimal processing technology is mandatory for wide-application of lentil. For instance, the usage of raw lentil flour resulted in adverse effects such as sour flavor due to lipids peroxidation and anti-nutritional factors [2]. The processing approaches affect palatability, protein digestibility, nutritional content, level of tannins and phenolics, texture, and flavors [65].

Several legume processing methodologies were utilized for the lentil post-harvesting including UV radiations, pulsed electric field, sonication, ionization, and ultrafiltration [2]. These techniques facilitated the higher shelf-life and other features of value-added lentil products such as protein yield [5]. The processing of red and green lentil by using the ultrafiltration approach produced higher protein content (70–77%) in comparison to isoelectric precipitation techniques [5]. Similarly, enzymatic hydrolysis of lentil using alcalde under high-pressure (300–600 MPa) for 15 min significantly influenced the protein secondary structures and enhanced the foaming properties and antioxidant potentials [66]. Moreover, to improve the protein digestibility of lentil, a nano-emulsion strategy has been explored using a high-pressure homogenization system [67]. Najib et al. [68], reported that the processing of lentil flour prepared from germinated seeds using microwave-assisted infra-red drying technique enhanced the flour quality. The research and development technologies associated with post-harvest processing of lentil for large-scale commercial purposes are still emerging. In the future, a combination of thermal and non-thermal processing approaches can facilitate the industrial acceleration of novel value-added production of lentil-based products.

Cookies, crisps, and puffs are among the major industrial products directly consumed by people. Lentil offers a gluten free, high protein and antioxidant-rich alternative to traditional cookies, crisps and puffs. Thakur et al. [10] produced baked lentil crisps with iron and zinc biofortified Indian lentil varieties which had 18% protein, glycemic potential of 34.8, 5.14–9.19% iron, 4.5–7.8% zinc and 6–12% calcium content. [8] made gluten-free cookies from five different varieties of colored lentils (red, tallow and black lentils) and reported them to have higher protein and antioxidant content with good sensory quality and consumer acceptability. Teja et al. [69] optimized a recipe for making nutritionally rich cookies with malted lentil. Bravo-Nunez and Gomez [70] reported various success stories of making lentils cookies and cakes. Similarly, extruded puffs made from lentil or with conventional procedures with added lentil flour have a huge potential market and offer a better alternative to health-conscious consumers. However, optimizing the cooking conditions is necessary for making a better quality cellular high-protein puffs [9].

Table 2 Nutritional status of lentil micro-greens compared with other legumes

	Lentil (*Lens culinaris*)	Mung beans (*Vigna radiata*)	Black medick (*Medicago lupulina*)	Green peas (*Pisum sativum*)	Amaranths (*Amaranthus*)	References
Dry matter (%)	46.4 ± 0.2a	4.7 ± 0.2i	6.2 ± 0.0g	8.1 ± 0.1e	5.4 ± 0.1h	[71]
Protein (g/100 g FW)	1.84–2.67	2.34–3.75	nd	nd	nd	[14]
Soluble solid content (Bx)	33.2 ± 0.2a	3.4 ± 0.2hi	4.2 ± 0.1g	6.3 ± 0.3d	3.8 ± 0.2gh	[71]
pH	6.6 ± 0.0a	5.3 ± 0.3i	5.6 ± 0.1g	6.0 ± 0.4e	6.0 ± 0.3e	[71]
Titratable acidity (g malic acid/100 g fw)	0.5 ± 0.0b	0.3 ± 0.0d	0.4 ± 0.0c	0.4 ± 0.1c	0.2 ± 0.0f	[71]
Pectins (%)	3.1 ± 0.0a	0.0 ± 0.0c	0.0 ± 0.0c	0.0 ± 0.0c	0.0 ± 0.0c	[71]
Σ Ash (%)	1.3 ± 0.0b	0.2 ± 0.3j	0.4 ± 0.1i	0.4 ± 0.0h	1.6 ± 0.2a	[71]
L-Ascorbic acid (mg/100 g fw)	28.3 ± 1.0d	7.1 ± 0.2hi	11.0 ± 0.8g	31.1 ± 1.4c	8.9 ± 0.8gh	[71]
Free aminoacids (mg/100 g FW)						
L-Histidine	92.6 ± 2.4a	22.8 ± 2.1c	20.9 ± 1.3c	7.7 ± 1.1f	1.5 ± 0.2g	[71]
L-Asparagine	438.5 ± 4.2a	211.7 ± 7.3c	317.8 ± 8.6b	106.2 ± 4.1e	6.7 ± 0.3k	[71]
L-Arginine	36.1 ± 1.2d	52.5 ± 4.1c	39.8 ± 2.3d	83.2 ± 2.5a	27.5 ± 1.1e	[71]
L-Serine	25.9 ± 1.2c	16.0 ± 1.2d	8.7 ± 1.1f	12.9 ± 1.0e	7.6 ± 0.4f	[71]
L-Glutamine	73.7 ± 3.2f	11.4 ± 1.7i	32.1 ± 4.2h	53.5 ± 2.6g	48.0 ± 1.1g	[71]
L-Glycine	20.8 ± 1.1b	3.3 ± 0.5f	5.4 ± 0.5e	10.3 ± 1.0c	4.0 ± 0.2f	[71]
L-Aspartic acid	151.4 ± 2.5a	6.6 ± 0.6h	12.3 ± 1.4g	27.0 ± 1.0d	36.1 ± 1.2c	[71]
L-Glutamic acid	77.2 ± 3.2a	2.0 ± 0.2g	18.3 ± 1.3b	16.6 ± 2.10c	14.8 ± 0.5c	[71]
L-Threonine	40.6 ± 2.0a	13.8 ± 0.9d	20.7 ± 1.0c	5.8 ± 1.1e	2.9 ± 0.0f	[71]
L-Alanine	47.5 ± 1.1a	7.5 ± 0.4f	16.8 ± 0.6d	6.9 ± 1.0f	10.0 ± 0.1f	[71]
γ-Amino *n*-butyric acid	46.3 ± 0.8a	nd	5.3 ± 0.2e	3.4 ± 2.1f	5.7 ± 0.5e	[71]
L-Ornithine	nd	nd	nd	nd	nd	[71]
L-Proline	113.2 ± 4.6a	10.6 ± 0.8c	5.4 ± 0.7d	1.8 ± 1.1f	1.5 ± 0.3f	[71]
L-Cystine	nd	nd	1.0 ± 0.1g	8.5 ± 0.3c	5.8 ± 0.1d	[71]
L-Lysine	14.7 ± 1.2c	14.2 ± 1.1c	5.5 ± 0.3e	13.5 ± 0.9c	3.5 ± 0.3e	[71]
L-Tyrosine	10.4 ± 2.1d	16.7 ± 1.6b	3.5 ± 0.2f	3.2 ± 0.1f	3.7 ± 0.1f	[71]
L-Methionine	1.5 ± 1.1b	3.9 ± 0.4a	0.8 ± 0.1e	1.0 ± 0.2d	nd	[71]
L-Valine	45.9 ± 3.2a	34.6 ± 2.7b	21.6 ± 1.1d	11.7 ± 0.2f	4.5 ± 0.4h	[71]
L-Homocysteine	nd	nd	1.5 ± 0.1a	nd	nd	[71]
L-Isoleucine	12.0 ± 1.1d	28.0 ± 3.1a	9.6 ± 0.6e	5.0 ± 0.1g	3.4 ± 0.1h	[71]
L-Leucine	8.1 ± 0.6c	21.0 ± 1.1a	5.3 ± 0.2d	3.2 ± 0.3e	5.3 ± 0.2d	[71]
L-Phenylalanine	31.4 ± 1.5b	51.8 ± 1.4a	17.8 ± 1.4d	11.1 ± 0.4e	3.8 ± 0.4h	[71]
L-Tryptophan	4.3 ± 0.9e	9.3 ± 0.6c	9.3 ± 0.9c	5.5 ± 0.1e	2.9 ± 0.1f	[71]
Polyphenols (mg/100 g FW)						
Flavan-3-ols	34.9 ± 2.7c	22.1 ± 0.9d	29.9 ± 1.8c	27.6 ± 2.4c	8.8 ± 0.5f	[71]

Table 2 (continued)

	Lentil (*Lens culinaris*)	Mung beans (*Vigna radiata*)	Black medick (*Medicago lupulina*)	Green peas (*Pisum sativum*)	Amaranths (*Amaranthus*)	References
Polymeric procyanidins	94.5 ± 3.1a	1.4 ± 0.3i	6.3 ± 0.3f	14.4 ± 1.2d	1.3 ± 0.1i	[71]
Phenolic acid	7.9 ± 0.3g	2.7 ± 0.2h	6.4 ± 0.4g	41.9 ± 3.3e	58.6 ± 1.6d	[71]
Flavonols + flavones	2.0 ± 0.2c	0.5 ± 0.0e	0.0 ± 0.0f	4.6 ± 0.6b	0.3 ± 0.0e	[71]
Isoflavones	40.5 ± 2.4a	0.0 ± 0.0c	0.0 ± 0.0c	20.0 ± 0.8b	0.0 ± 0.0c	[71]
Anthocyanins	0.0 ± 0.0f	0.0 ± 0.0f	0.1 ± 0.0e	0.0 ± 0.0f	63.9 ± 2.3a	[71]
Chlorophylls (μg/g FW)						
Chlorophylls *b*	16.1 ± 0.6f	1.0 ± 0.2h	1.6 ± 0.1g	157.8 ± 2.4b	186.3 ± 2.1a	[71]
Pheophytin *b*	0.0 ± 0.0c	0.0 ± 0.0c	0.0 ± 0.0c	0.0 ± 0.0c	0.0 ± 0.0c	[71]
Chlorophylls *b′*	0.0 ± 0.0h	0.0 ± 0.0h	0.0 ± 0.0h	14.8 ± 1.4b	17.3 ± 0.7a	[71]
Pheophytin *b′*	0.0 ± 0.0d	0.0 ± 0.0d	0.0 ± 0.0d	3.1 ± 0.3a	2.1 ± 0.2b	[71]
Chlorophylls *a*	77.6 ± 1.5e	3.9 ± 0.1j	10.5 ± 0.7h	288.3 ± 3.6b	336.2 ± 3.2a	[71]
Chlorophylls *a′*	7.6 ± 0.3e	0.0 ± 0.0j	1.3 ± 0.3h	20.3 ± 1.5a	16.9 ± 1.1b	[71]
Pheophytin *a*	7.2 ± 0.7d	1.1 ± 0.3h	1.0 ± 0.1h	35.3 ± 01b	75.4 ± 0.3a	[71]
Pheophytin *a′*	0.0 ± 0.0e	0.0 ± 0.0e	0.0 ± 0.0e	3.2 ± 0.1c	4.3 ± 0.2a	[71]
Carotenoids (μg/g FW)						
Neochrome	0.0 ± 0.0l	1.2 ± 0.3k	5.4 ± 0.1j	255.0 ± 2.9b	301.3 ± 4.0a	[71]
Neoxanthin	2.7 ± 0.3h	3.0 ± 0.2h	45.7 ± 1.7e	256.8 ± 4.1b	293.8 ± 1.3a	[71]
Zeoxanthin	0.0 ± 0.0j	1.1 ± 0.1i	6.7 ± 0.2g	57.1 ± 2.8b	132.2 ± 2.6a	[71]
Lutein	31.0 ± 1.4j	13.2 ± 0.7k	113.2 ± 2.1i	1435.7 ± 2.6a	1478.9 ± 1.2a	[71]
Violaxanthin	0.0 ± 0.0g	0.5 ± 0.0f	4.3 ± 0.1e	16.9 ± 1.1c	36.6 ± 1.9a	[71]
(α + β)-Carotene	0.0 ± 0.0j	0.9 ± 0.1k	10.1 ± 0.2i	728.4 ± 4.2d	1769.2 ± 5.2b	[71]
Other carotenoids	2.8 ± 0.3g	2.5 ± 0.2g	12.1 ± 1.3f	44.4 ± 0.5d	61.6 ± 1.1c	[71]
Σ Carotenoids	36.4j	22.5j	197.5i	2794.4c	4073.5a	[71]
Sugars (g/100 g fw)						
Glucose	0.1 ± 0.0c	0.0 ± 0.0d	0.0 ± 0.0d	0.0 ± 0.0d	0.0 ± 0.0d	[71]
Fructose	0.2 ± 0.0c	0.2 ± 0.0c	0.1 ± 0.0d	0.0 ± 0.0e	0.0 ± 0.0e	[71]
Saccharose	1.4 ± 0.1a	0.0 ± 0.0c	0.1 ± 0.0b	0.0 ± 0.0c	0.0 ± 0.0c	[71]
Sorbitol	0.0 ± 0.0c	0.0 ± 0.0c	0.0 ± 0.0c	0.0 ± 0.0c	0.0 ± 0.0c	[71]
Mannose	0.0 ± 0.0b	0.0 ± 0.0b	0.0 ± 0.0b	0.0 ± 0.0b	0.0 ± 0.0b	[71]
Rhamnose	0.1 ± 0.00a	0.0 ± 0.0b	0.0 ± 0.0b	0.0 ± 0.0b	0.0 ± 0.0b	[71]
Σ Sugars	1.8a	0.2f	0.2f	0.0 ± 0.0g	0.0 ± 0.0g	[71]
Organic acids (g/100 g fw)						
Phytic acid	0.0 ± 0.0d	0.0 ± 0.0d	0.1 ± 0.0c	0.0 ± 0.0d	0.0 ± 0.0d	[71]
Oxalic acid	1.5 ± 0.2f	0.7 ± 0.1g	0.5 ± 0.0g	0.3 ± 0.0g	120.8 ± 1.3a	[71]

Table 2 (continued)

	Lentil (*Lens culinaris*)	Mung beans (*Vigna radiata*)	Black medick (*Medicago lupulina*)	Green peas (*Pisum sativum*)	Amaranths (*Amaranthus*)		References
Citric acid	0.5 ± 0.1b	0.1 ± 0.0c	0.2 ± 0.0c	0.5 ± 0.0b	0.0 ± 0.0d		[71]
Malic acid	0.3 ± 0.0b	0.0 ± 0.0e	0.4 ± 0.1a	0.0 ± 0.0e	0.0 ± 0.0e		[71]
Quinic acid	0.0 ± 0.0d	0.1 ± 0.0c	0.3 ± 0.0b	0.0 ± 0.0d	0.0 ± 0.0d		[71]
Succinic	0.8 ± 0.1ab	0.0 ± 0.0e	0.0 ± 0.0e	0.2 ± 0.0d	0.0 ± 0.0e		[71]
Other organic acid	0.2 ± 0.0e	1.7 ± 0.2ab	0.6 ± 0.1c	2.0 ± 0.1a	0.0 ± 0.0f		[71]
Σ Organic acids	3.2e	2.6e	2.2e	3.0e	120.8a		[71]
Enzymatic activity							
ORAC (mM TE/100 g FW)	4.4 ± 0.6c	1.1 ± 0.1fg	2.5 ± 0.3d	1.2 ± 0.3fg	1.4 ± 0.2f	Antioxidant capacity	[71]
FRAP (mM TE/100 g FW)	0.1 ± 0.0g	>0.01i	0.1 ± 0.0h	0.1 ± 0.0g	0.1 ± 0.0f		[71]
ABTS (mM TE/100 g FW)	2.0 ± 0.3a	>0.01h	0.8 ± 0.1e	0.7 ± 0.1e	0.6 ± 0.1f		[71]
α-Amylase (IC50 mg/ml)	88.4 ± 5.3h	5.3 ± 0.3b	4.9 ± 0.8b	8.3 ± 0.5d	12.5 ± 0.9f	Antidiabetic activity	[71]
α-Glucosidase (IC50 mg/ml)	15.9 ± 2.1g	0.9 ± 0.3bc	0.6 ± 0.2a	8.0 ± 0.1f	4.3 ± 0.2d		[71]
Pancreatic lipase (IC50 mg/ml)	1.5 ± 0.2h	0.2 ± 0.0d	0.1 ± 0.0bc	0.1 ± 0.0bc	0.3 ± 0.0e	Antiobesity activity	[71]
Acetyl cholin esterase (% inhibition)	10.1 ± 1.0fg	14.2 ± 1.2e	8.6 ± 0.6g	52.5 ± 0.4c	50.5 ± 1.4c	Anti-cholinergic activity	[71]
Butyl cholin esterase (% inhibition)	1.0 ± 0.3h	3.0 ± a0.5h	3.6 ± 0.2h	19.6 ± 2.4d	54.9 ± 3.5c		[71]
FRAP (µM TE/g FW)	14.7–55	5.7–20.22	nd	nd	nd		[14]
DPPH (µM TE/g FW)	0.84–3.38	0.69–3.79	nd	nd	nd		[14]
Hydrogen peroxide (nM/g FW)	1.63–5.92	2.61–6.14	nd	nd	nd		[14]
Peroxidase activity (U/g FW)	335–502.8	266.17–518.8	nd	nd	nd		[14]
Catalase activity (U/g FW)	159.9–435.53	239.09–470.56					
Minerals (g/100 g FW)							
Calcium	32–70	47–87	nd	nd	nd		[14]
Potassium	217–389	239–475	nd	nd	nd		[14]
Magnesium	25–66	36–56	nd	nd	nd		[14]
Phosphorus	32–88	39–87	nd	nd	nd		[14]
Sodium	27–45	20–60	nd	nd	nd		[14]
Iron	0.45–0.79	0.4–0.7	nd	nd	nd		[14]
Zinc	0.23–0.49	0.2–0.32	nd	nd	nd		[14]
Copper	0.05–0.22	0.03–0.1	nd	nd	nd		[14]
Manganese	0.06–0.18	0.09–0.19	nd	nd	nd		[14]

7.1 Lentil micro greens can be explored for industrial value addition

Microgreens are young seedlings aged between 7 and 21 days, typically derived from the seeds of various vegetables, herbs, and pulses in which the edible portion mainly includes a stem and a pair of first true leaves. Microgreens have become increasingly popular due to they bring diverse textures, colors, and flavors to dishes [71]. The microgreens market has experienced significant growth in recent years, while the trend is gaining traction in India, particularly in metropolitan areas, in the United States, followed by Canada and Mexico [14]. Consumption of lentils as sprouts and microgreens provides overall health benefits compared to other legumes and plays a crucial role in combating lifestyle diseases associated with oxidative stress (Table 2). Lentil microgreens are superior to other legumes in terms of phytochemical composition, antioxidant capacities, and nutrient contents, particularly when grown in high-altitude regions [14]. They also have a high total chlorophyll and carotenoid content, making them a valuable source of these nutrients [72]. In terms of safety, lentil microgreens are generally safe for consumption, with low microbial load [73].

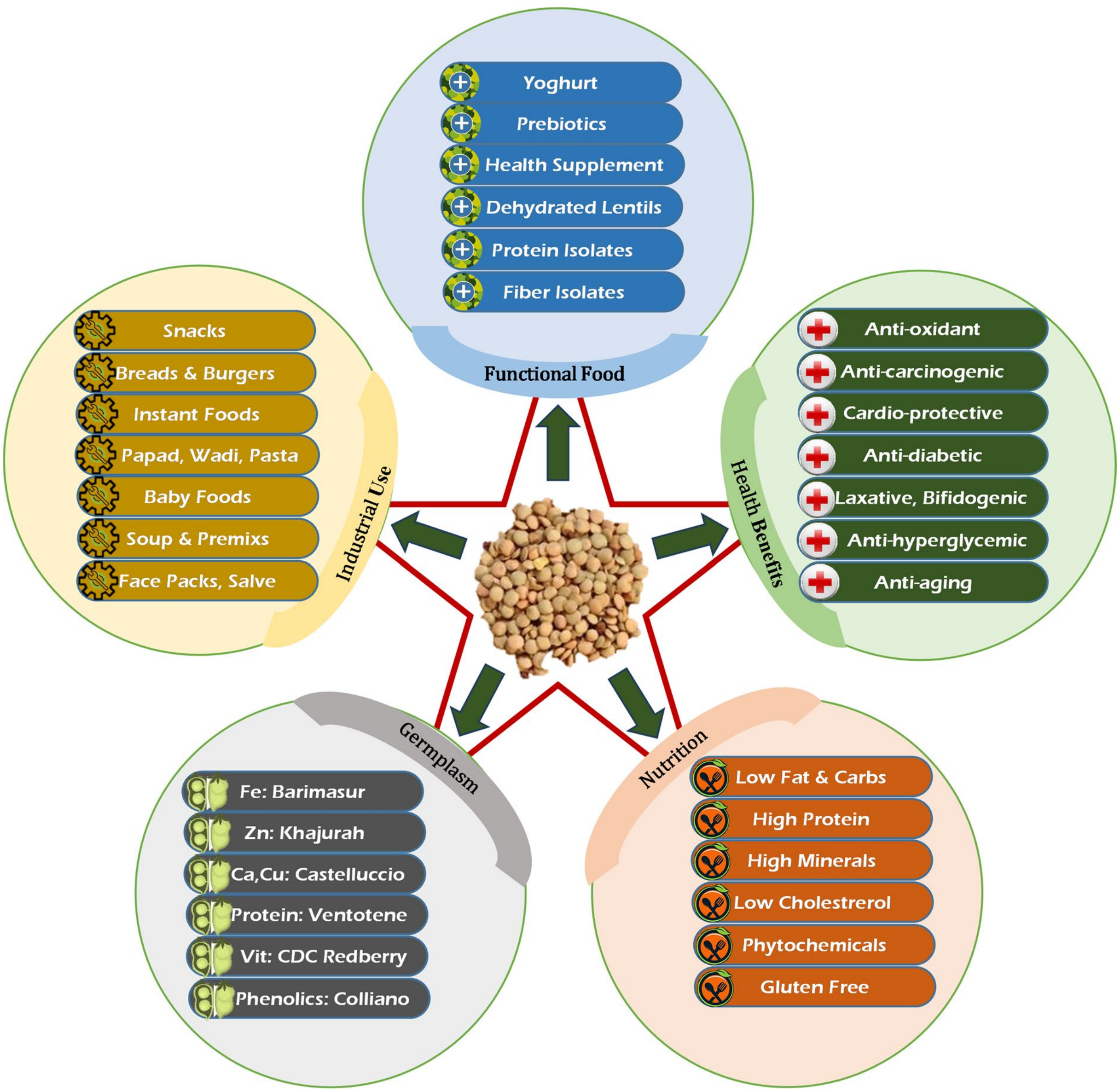

Fig. 1 Lentil: A highly nutricious pulse which goes beyond dal and soup. The figure represents diversified products of lentil from snacks to functional foods and healthcare products along with the health benefits

8 Lentil as a functional food for optimal health

Owing to the occurrence of higher amounts of polyphenols with anti-oxidant potentials, lentil can be considered an excellent choice of functional foods. The recent surge in the food industry for ready-to-eat healthy foods demands ingredients with both nutritive and antioxidant values. Lentil are well-known legume enriched with proteins, vitamins, iron, and fibers. The daily intake of essential amino acids can be supplied by the consumption of lentil. The abovementioned qualities of lentil have extended their utilization in various functional food development as discussed below (Fig. 1).

8.1 Lentil flour pasta

Pasta is a daily basis consuming meal worldwide due to its long shelf life, low cost, tastefulness, and nutritious qualities. Primarily, pasta was prepared using wheat flour, but recently legume-based pasta products have been initiated from lentil and chickpea flours due to the high protein and amino acid contents. This legume-based pasta preparing using red, black, and green lentil with a protein range of 27–29% and fiber contents of 7–15% [74]. Similarly, the gluten-free nature of lentil-based pasta can be considered a preferable alternative to other pasta made from cereals or pseudo-cereals with comparatively less protein and fiber [74]. Further, the addition of lentil flour to pasta can enhance the colour and firmness without compromising other qualities such as cooking efficiency and weight [75]. Similarly, the supplementation of lentil flour with wheat flour decreased the glycemic response by increasing the starch resistance and decelerating the hydrolytic activity of the alpha-amylase enzyme [76]. Additional investigations are necessary to identify the appropriate quantity and type of lentil to be used as the raw material based on the requirements of the food industry.

8.2 Lentil-fortified yogurt

Yogurt is a fermented milk product known for its health benefits particularly, the gut health. It contains strains of *Lactobacillus bulgaricus* and *Streptococcus thermophilus* [77]. Consumers generally preferred fortified yogurts owing to their multiple health properties, sensory qualities, and flavors. The addition of lentil flour to yogurt has increased its nutritional value and antioxidant potential [78]. Further, the augmentation of roasted and unroasted lentil flour influenced the physio-chemical features, sensory qualities, and microbial nature of yogurt [77]. Moreover, lentil-based yogurt as an alternative to milk-based ones is a part of undergoing research that can be utilized in plant-based dairy products [79]. Lentil supplementation also enhances the oligosaccharides such as raffinose and inulin which enables the function of microflora that aids digestion [13]. In addition, the lentil flour added to yogurt consisted of less acidity, higher shelf-life, and promising taste which demonstrates lentil as a potential ingredient in the yogurt industry for the development of novel pro-and prebiotic substances [76].

8.3 Lentil in burgers buns and bread

For large-scale inclusion of lentil in bakery formulation requires a better knowledge of the nutritional and physio-chemical properties for industrial purposes. For example, the augmentation of 10% red lentil flour with wheat flour for bread-making produced better rheological features [80]. Çelik and İlyasoğlu [81] in a study reported that black lentil flour can be augmented up to 10% in white bread to increase its nutritional value without affecting its sensory properties. However, with addition of 0.1 g of baker's gluten per gram of flour, the augmentation of lentil flour can be increased up to 20% [82]. Similarly, the addition of germinated lentil in the bread flour enhanced the nutraceutical value. According to Hemandez-Aguilar et al. [83], bread baked with the inclusion of 10% germinated lentil consisted of higher amounts of phenolic acids and flavonoids with health benefits. Also, the addition of germinated lentil altered the quality of the bread flour and it also increased the sensory acceptance of diabetic people. Lentil-based food formulation can provide both nutritive and higher health benefits to the growing modern population.

8.4 Lentil in weight management snacks

In recent, the demand for protein supplements for weight management has been increasing and a wide array of food markets are continuously striving to meet the demand by providing novel alternatives to carbohydrate-rich snacks. A protein pellet formulation has been recently studied with lentil flours and egg powder using microwave-based extrusion [84]. A 100 g snack consisting of ~31% of the formulated pellet protein that can meet the daily protein intake. Lentils is abundant in complex carbohydrates, proteins, dietary fiber, and micronutrients, and stand out as a promising raw material for the rapidly growing snacks industry. Overall, lentil-based pellets can be a novel state to mitigate malnutrition with less cost of production, and usage of microwave-assisted hybrid extrusion technology which produces high-quality lentil pellets with high sensory acceptable properties.

8.5 Lentil in the brewing industry

Ever-growing demand for new materials in brewing industries and the increased low-gluten lifestyle have given opportunities to introduce several cereals and legumes for malting process [13]. Lentils, which are available in various colors i.e. red, yellow, green, black etc. give a healthier alternative for exploring colorful low-alcohol gluten-free beers both at the producer and consumer level [12]. Lentils are attracting increasing attention for their role in alternative diets. Additionally, along with a rising interest in low-gluten diets, there is a growing demand for new raw materials in the malting and brewing sectors. Lentil malt was incorporated as 10% and 20% adjuncts using the Congress mash method at a laboratory scale, with key parameters of the wort and beer (such as filtration time, pH, color, extract, and fermentability) analyzed, particularly focusing on the concentrations of metal ions (Mg^{2+}, Ca^{2+}, Zn^{2+}, Fe) in the wort. The brewing process using lentil malt was then scaled up to 1 hectoliter, where various beer characteristics, including gluten content and foam stability, were assessed. Results indicated a reduction in gluten content by about 35% and an increase in foam stability by approximately 6% with 20% lentil malt addition. Furthermore, using lentil malt shortened the filtration time by up to 17%. A trained panel evaluated the sensory attributes of the beers produced. Overall, the findings suggest that green lentil malt has promising potential for use in brewing [85]. Even though lentils have poor mashing quality, the malts produced from lentil have higher protein content, increased friability, lower starch and phytic acid content and lower antinutritional raffinose family oligosaccharides [86]. A pilot scale trial by Trummer et al. [13] introducing 20% green lentil malt resulted in the production of beer with 35% less gluten content and 6% more foam stability. It reduced the filtration time by 17%. Moreover, it showed promising results for its sensory quality [13]. Gasinski and Kawa-Rygielska [87] made beer from green lentil malts. However, it yielded a lower alcohol content. This issue can be addressed by the introduction of non-conventional yeasts. In recent years, there has been a growing consumer interest in fermented foods with functional benefits. This study aimed to utilize selected non-conventional yeasts (NCY), specifically Lachancea thermotolerans and Kazachstania unispora, in both pure and mixed fermentation to create craft beer enriched with hydrolyzed red lentils (HRL). Fermentation trials were conducted using pilsner wort (PW) and pilsner wort supplemented with HRL (PWL). The addition of HRL to pilsner wort enhanced fermentation kinetics in both pure and mixed fermentations without negatively impacting the key analytical characteristics. Furthermore, HRL increased the concentration of amino acids in PW. Both L. thermotolerans and K. unispora influenced the amino acid profile of the beers, whether or not HRL was included. Analysis of by-products and volatile compounds in PW trials showed a notable rise in certain higher alcohols with L. thermotolerans and in ethyl butyrate with K. unispora. In PWL, the two NCY exhibited different behaviors, with K. unispora increasing ethyl acetate and L. thermotolerans boosting β-phenyl ethanol levels. Sensory analysis indicated that the presence of HRL distinctly influenced all beers, enhancing the fruity aroma perception in both pure and mixed fermentations [88]. The researchers used hydrolyzed red lentils to produce craft beers using non-conventional yeasts *Lachancea thermotolerans* and *Kazachstania unispora*. This resulted in the production of higher amount of alcohols i.e. β-phenyl ethanol (*L. thermotolerans*) and ethyl acetate (*K. unispora*) with an enhanced fruity aroma and sensory characteristics in the craft beer.

8.6 Lentil as a meat analog

Consumers' alignment towards vegan food alternatives for their nutritional needs is evident in current scenario due to various reasons such as environmental concerns, production constraints, religious beliefs, emotional and ethical issues, in which lentil fit well with their extensive nutritional value and health benefits. Pulses along with lentils can be an ideal alternative to meat products as they can be made into meat-like textured products with high protein content and meat like sensory experience. These are commonly called as high-moisture meat analog (HMMA) [89]. Usman et al. [90] reported that the lentil HMMA resembles livestock meat with a darker color and harder texture. Kim et al. [89] prepared beef-flavored vegetable hamburger patties using lentil protein isolates (55.4%) mixed with pea protein isolates, spices and binders etc. Overall cooked appearance and flavor of lentil HMMA were likable. Many trained tasters liked the sweetness, cohesiveness and beany taste of the patties but the texture was suggested to improve [89]. However, some people do not like the beany flavor, which can be reduced by germination and extrusion of lentils [90]. Similarly, the texture can be enhanced by using germinated lentils for the extrusion process as germination alters the protein profile and functional properties of proteins thereby increasing the bisulfide bonds, filament content and melting temperature. Moreover, mixing multiple legumes along with lentils protein isolates can produce HMMA with less lightness, greater redness, yellowness, moisture content and water solubility index [89]. Therefore, lentil is a viable alternative to produce HMMA and can be explored for industrialization.

9 Biofortification of lentils to meet the needs for industrial innovations and functional food applications: the omics outlook

Omics technologies offer powerful tools for unveiling the underlying molecular mechanism to assess nutrient composition, accumulation, metabolism, gene expression profiling and plant–microbe interactions etc., which are essential for lentil biofortification and improvement [91]. Among all the omics technologies, genomics and metabolomics are currently being utilized for improving the nutritional traits of lentil; however, other innovative technologies such as phenomics, proteomics, ionomics, transcriptomics and metagenomics are still underutilized in lentil.

9.1 Genomics

Over the decades, researchers have started to work on the nutritional traits of lentil after realizing their immense nutritional potential and developed several varieties/registered germplasm with high nutraceutical potential (Table 3). Several studies have been carried out on biparental mapping populations to increase mineral uptake and enhance lentil' milling quality traits. Ates et al. [92] identified 36 putative markers for four QTL (Quantitative Trait Loci) regions explaining 6–16% phenotypic variation (PV) for Selenium uptake using 96 RILs generated from the cross PI32093 x Eston. Similarly, Aldemir et al. [93] 21 QTLs were identified for seed iron content representing 5.9–14% PV after analyzing 118 RILs (ILL8006 x CDC Milestone). A population of 120 RILs (CDC Redberry x ILL7502) was screened for Manganese uptake to find out 6 QTLs [94]. Further, progenies (127 RILs) from the cross CDC Robin x 946a-46 were analyzed by Subedi et al. [95] for milling quality, dehulling efficiency, milling recovery, etc. to identify multiple QTLs.

Genome Wide Association Studies (GWAS) is an efficient strategy to identify the marker-trait associations (MTAs) for desired traits. Singh et al. [112] identified 3 SSRs for seed Fe and 4 SSRs for Zn using GWAS on an association panel of 96 accessions using 73 SSR markers. A panel of 96 diverse genotypes were screened by Kumar et al. [113] using 80 SSRs to identify 2 SSRs for seed Fe (6–17% PV) and 3 SSRs for Zn (13% PV). Khazaei et al. [114] reported 3 MTAs (2 SNPs for Fe and 1 for Zn) out of 1150 SNPs explaining 9–21% PV in an association panel of 138 accessions. Johnson et al. [115] used 22,222 polymorphic SNPs retrieved from GBS of 143 diverse accessions to identify multiple MTAs and neighboring putative candidate genes for prebiotic carbohydrates. The group identified 48 SNPs for mannitol (3), glucose (1), fructose (10), sucrose (1), stachyose and raffinose (22), resistant starch (10) and total starch (1). Singh et al. [116] identified 23 and 14 MTAs for seed Fe and Zn content from GWAS of 95 diverse lentil accessions. Among them, two significant MTAs were obtained in the genic region of ISCA (Iron-sulfur cluster assembly) protein and FMO (Flavin binding mono-oxygenase like) protein which have putative roles in increasing seed iron content.

9.2 Metabolomics

Interspecific metabolome analysis was performed by Llorach et al. [117] among chickpea, lentil and common beans using LC–MS Orbi-trap technology to dissect the composition of bioactive compounds in these pulses. The study revealed 43 compounds from 6 classes of phytochemicals (prenol lipids, fatty acids, organic compounds, α-galactosides and nucleosides) and out of which 40% were lentil specific. Specifically, two flavonoids (Megastimadiene-diol-[apiosyl-glucooside] and Resveratrol glucoside) were found to be discriminately present in lentil [117]. Similarly, Farag et al. [118] reported 66 predominant metabolites by performing LC–MS including sphingolipids, flavonoids, saponins, fatty acids, phenolics, alkaloids etc. in an interspecific study of lentil vs. lupines. The researchers mentioned the saponins and flavone glycosides as specific to lentil. Tiwari et al. [91] analysed the two experiments mentioned above to find out 43 and 94 non-redundant metabolites in lentil from the earlier studies [117, 118]. They also reported 19 common bioactive compounds belonging to the classes Flavonel/Flavone/Flavan derivatives, terpene glycoside, phenolic acids, organic acids, and saccharides.

Table 3 List of registered lentil varieties/germplasm developed with enhanced nutritional value

Country	Accession/varieties	Trait	Quantity	References
India	IC208326	Protein	28.06 (%)	[96]
Tunisia	Krib	Protein	26.8 (%)	[97]
Syria	Assano	Protein	25.6 (%)	[98]
Ethiopia	2009S 96575-1	Protein	26.2 (%)	[99]
Syria	Idlib-3	Protein	25.7%	[100]
	Idlib-4	Protein	26.2%	[100]
Tunisia	Krib	Protein	26.8 (%)	[97]
Pakistan	Markaz-09	Protein	28.45%	[101]
	NL-2	Protein	28.24%	[101]
Italy	Castelluccio	Protein	26.8 (%)	[102]
	Colfiorito	Protein	26.9 (%)	[102]
	Capracotta	Protein	26.4 (%)	[102]
	Onano	Protein	25.8 (%)	[102]
	Ventotene	Protein	28.6 (%)	[102]
	Villalba	Protein	28.2 (%)	[102]
	Castelluccio	Protein	8.05 (mg/100 g)	[102]
	Colfiorito	Fe	7.56 (mg/100 g)	[102]
	Capracotta	Fe	8.82 (mg/100 g)	[102]
	Onano	Fe	8.66 (mg/100 g)	[102]
	Ventotene	Fe	9.50 (mg/100 g)	[102]
	Villalba	Fe	9.74 (mg/100 g)	[102]
	Castelluccio	P	405.4 (mg/100 g)	[102]
	Colfiorito	P	426.1 (mg/100 g)	[102]
	Capracotta	P	542.4 (mg/100 g)	[102]
	Onano	P	486.0 (mg/100 g)	[102]
	Ventotene	P	456.3 (mg/100 g)	[102]
	Villalba	P	440.5 (mg/100 g)	[102]
Italy	Castelluccio	Cu	1.61 (mg/100 g)	[102]
	Colfiorito	Cu	1.14 (mg/100 g)	[102]
	Capracotta	Cu	0.92 (mg/100 g)	[102]
	Onano	Cu	0.96 (mg/100 g)	[102]
	Ventotene	Cu	0.95 (mg/100 g)	[102]
	Villalba	Cu	1.28 (mg/100 g)	[102]
	Castelluccio	Ca	59.79 (mg/100 g)	[102]
	Colfiorito	Ca	52.71 (mg/100 g)	[102]
	Capracotta	Ca	57.80 (mg/100 g)	[102]
	Onano	Ca	55.35 (mg/100 g)	[102]
	Ventotene	Ca	56.97 (mg/100 g)	[102]
	Villalba	Ca	49.57 (mg/100 g)	[102]
Morocco	Chakkouf	Fe, Zn	76.7, 62 (mg kg^{-1})	[103]
India	L-4704 (IC0616579, INGR15056)	Fe	136.91 (µg/gm)	[104]
	L-4704 (IC0616579, INGR15056)	Zn	71.69 (µg/gm)	[104]
	Pusa Ageti Masoor	Fe	65 ppm	[105]
	IPL 220	Fe	73 (µg/gm)	[105]
	IPL 220	Zn	51 (µg/gm)	[105]
Bangladesh	Barimasur 4	Fe	86.2 (ppm)	[106]
	Barimasur 5	Fe, Zn	86, 59 (ppm)	[106]
	Barimasur 6	Fe, Zn	86, 63(ppm)	[106]
	Barimasur 7	Iron	81 (ppm)	[106]

Table 3 (continued)

Country	Accession/varieties	Trait	Quantity	References
Nepal	Sisir	Fe, Zn	98, 64 (ppm)	[106]
	Khajurah-2	Fe, Zn	100.7, 59 (ppm)	[106]
	Khajurah-1	Zn	58 (ppm)	[106]
	Sital	Zn	59 (ppm)	[106]
	Shekhar	Fe	83.4 (ppm)	[106]
	Simal	Fe	81.6 (ppm)	[106]
India	Pusa Vaibhav	Fe	102 (ppm)	[106]
	L 4704	Fe, Zn	125, 74 (ppm)	[106]
Syria/Lebanon	Idlib-2	Fe	73 (ppm)	[106]
	Idlib-3	Fe	72 (ppm)	[106]
Ethiopia	Alemaya	Fe, Zn	82, 66 (ppm)	[106]
Bangladesh	BARI Masur-8 BARI Masur-9	Fe	74 (mg kg^{-1})	[107]
		Zn	61 (mg kg^{-1})	[107]
		Se	325 (µg kg^{-1})	[107]
		Fe	73 (mg kg^{-1})	[107]
		Zn	61 (mg kg^{-1})	[107]
Saskatchewan	IG72831 (*Lens tomentosus)*	Folate	497 (µg/100 gm)	[108]
	IG72611 (*Lens orientalis)*	Folate	416 (µg/100 gm)	[108]
	CDC redberry	Folate	361 (µg/100 gm)	[108]
Russia	VIR-421	Vitamin B1	12.98 (µg/gm)	[109]
Tajikistan	ILL618	Vitamin B2, B9	2.95, 2.77 (µg/gm)	[109]
Canada	CDC milestone	Vitamin B3	23.39 (µg/gm)	[109]
	CDC redberry	Vitamin B5, B6	43.96, 16.35 (µg/gm)	[109]
Southern Italy	Colliano	Total polyphenol content	1594 (µg/g) GAE	[110]
Morocco	6002/ILWL118/1-1	Resistant starch content	2.12 (%)	[111]
		Flavonoids (catechin)	187.9 (µg/g d.m)	[111]
		Kaempferol-7-*O*-neohesperidoside	96.83 (µg/g d.m.)	[111]
		β-Tocopherol	19.86 µg/gr d.m	[111]

Although, significant efforts have been carried out in lentil to improve its nutritional potential, however, it is still far behind than the other crops. The recent release of lentil genome [119] can encourage in-depth analysis for enhancing the nutraceutical potential of lentil.

9.3 Transcriptomics, ionomics and proteomics

Proteomics and transcriptomics can help in identifying the genes and proteins related to nutrient storage and translocation to the seeds. It can also help in unraveling the molecular pathways related to synthesis and transport of antinutritional factors in lentil thereby paving a way to engineer them to reduce these compounds for better public health. Ionomics can assist in a detailed nutrient profiling which would lead to identify better germplasm resource/transgenics with higher desirable mineral nutrients [120].

9.4 Metagenomics

Seed mineral and other nutrient content is directly proportional to the nutrient uptake and assimilation by the plants which are mostly influenced by soil micro-biota. Meta-genomics can offer powerful tools to understand the plant–microbe interactions in modifying the nutrient uptake parameters [121]. It can be helpful in optimizing lentil biofortification strategies and sustainable agriculture practices.

9.5 Phenomics

Current world is focusing on rapid, accurate and cost effective methods to obtain quantity and quality data. High-throughput image-based phenotyping was used to measure anthocyanin, carotenoid and chlorophyll content in lettuce [122] and cassava genotypes [123] to get better results when compared to traditional technologies. Advanced phenomics technologies such as spectral imaging and sensor technology hold potential in studying macro and micronutrient contents, vitamins, pigment concentrations, nutrient distributions and metabolizable energy in seeds as well as in whole plants.

Over two billion global population suffer from hidden hunger caused due to micronutrient deficiency mainly in South Asia and sub-Saharan Africa. Research highlights that consumption of lentil in regular diet can meet a significant amount of recommended daily allowance of micronutrients and vitamins. Since, genetic resources of lentil has shown a substantial variability for nutritional traits, targeted biofortification of lentil can achieve a wholesome solution to global micronutrient malnutrition [106]. Still these need to be optimized in lentil, which can reconnect cost effective and large scale screening for lentil biofortification. By exploring and combining the multi-omics technologies, we can accelerate the development of niche specific biofortified lentil varieties for sustainable food and nutritional security.

10 Conclusion and future directions

Taken together, lentils can be considered as a therapeutic healthy food with many essential micronutrients, proteins, minerals, and phytochemicals. It has unfolded its prospective as potential functional food and in industrial food chain with diverse product options. Moreover, due to increased health consciousness among the consumers, lentil has been accepted as a functional food alternative which is evident from its increased production and consumption trend across the globe. This review compiled the information about nutritional value and innovations in versatile food applications of lentil in a way to cater to the consumer needs to develop a nutritionally secure healthy community. The article highlighted the sensory acceptability of lentil-based products emphasizing culinary creativity and consumer preference alongside innovations in development of industrial, functional food products from lentil. It also examined the efforts to enhance lentil's nutritional value through genetic fortification using multiomics technologies. These innovations in lentil can only make a meaningful impact when the diversified food options aligns with consumer preference and sensory acceptability supported by large scale lentil development programes leveraging advanced omics research. The review would serve as a comprehensive and invaluable resource for guiding the future lenti-based innovations untapping its full nutraceutical potential for product development and delivery.

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Data availability No datasets were generated or analysed during the current study.

Declarations

Ethics approval The authors declare that they research work carried out for the article along with the drafting of the manuscript is in compliance with research ethics.

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