**ABSTRACT**

Chickpea is the dominant rabi pulse crop in India, accounting for 50% (13.5 mt) of the nation’s pulse production. This nutrient-dense and cost-effective legume provides a rich source of energy, protein, minerals, vitamins, and dietary fibre. Beyond its basic nutritional value, chickpea harbor a diverse array of non-nutritive phytochemicals, including oligosaccharides, saponins, tannins, polyphenols, flavonoids, and enzyme inhibitors, holding promising potential for antioxidant, anti-inflammatory, anti-diabetic, anti-obesity, anti-cancer, prebiotic, and cholesterol-lowering effects. Recent advancements in genome sequencing have unlocked the chickpea’s complete genetic blueprint and empowered cutting-edge breeding methods like QTL analysis, GWAS, and genomic selection to effectively pinpoint and target beneficial genomic regions governing key nutritional traits. These findings help germplasm enhancement, nutritional enrichment and optimization of bioactive components to meet the food security of nations. This chapter reviews the current state of knowledge regarding chickpea’s nutritional profile, highlighting past breeding achievements and future prospects for enriching its nutritive value.

**Key words:** Chickpea, Legume, Oligosaccharides, Phytochemicals, Genome sequencing technology, Nutritive value
85% of the global chickpea cultivation area and are commonly dehulled and split to produce dal or flour. In contrast, kabuli chickpeas are distinguished by their white seed coat, ram’s head shape, thin seed coat, and smooth seed surface. Their flowers are white due to the absence of anthocyanin pigmentation. The name “kabuli” derived from “Kabul” in Hindi, and this variety is thought to have originated from Kabul, Afghanistan, when it was introduced to India in the 18th century. Compared to desi chickpeas, kabuli chickpeas have higher sucrose levels and lower fiber content, suiting them for consumption as whole grains. Additionally, kabuli chickpeas require shorter cooking times compared to desi varieties.

NUTRITIONAL VALUE OF CHICKPEA

The nutritional significance of chickpeas in human consumption and the research efforts in improving nutritional value are briefly presented here.

a) Energy

Chickpea is rich in non-starch polysaccharides (complex carbohydrates) that can provide long-lasting energy. The energy provided by chickpeas range from 334 to 437 kcal/100 g for desi types and 357 to 446 kcal/100 g for kabuli types (Kinfe et al., 2015). Under identical growing conditions, kabuli seeds generally have slightly higher energy values than desi type. This difference is ascribed to the smaller seed coat component of kabuli seeds. By incorporating chickpeas into the diet, individuals can reap the benefits of their high energy content and nutritional value.

b) Protein

The protein content in chickpea seeds ranges from 16.7% to 30.6% for desi cultivars and 12.6% to 29.0% for kabuli cultivars which is 2-3 times higher than cereal grains (Badola et al., 2023). Srungarapu et al. (2022) found substantial variation in grain protein content (16.3-26.2%) among 280 diverse chickpea accessions. The amino acid composition of chickpea is exceptional with high lysine content. Over all, its protein configuration is well composed though limited in sulfur amino acids (methionine and cysteine). On account of this, chickpea is rated as a valuable dietary component and a potential therapeutic agent for protein malnutrition. Protein digestibility of raw chickpea seeds varies from 34 to 76% and kabuli types had higher digestibility than that from the desi types (Khalil et al., 2007).

c) Lipids

Chickpea exhibits a higher lipid content compared to other pulses, and displaying wide genotypic variation. Chickpea lipid content varied from 6.35 to 9.35 g/100 g, with linoleic, oleic, and palmitic acids being the major fatty acids (Xiao et al., 2023). The total lipid concentration ranges from 2.9% to 7.4% and 3.4% to 8.8% for desi and kabuli types, respectively, which is high for pulses but lower than certain grain legumes like soybeans and peanuts (Reddy and Lal, 2021). The lipid profile of chickpea is predominantly composed of polyunsaturated (62-67%), monounsaturated (19-26%), and saturated (12-14%) fatty acids (Sahu et al., 2022). This favorable lipid composition indicates that chickpeas mainly contain beneficial monounsaturated and polyunsaturated fats rather than saturated fats, which have been related with cardiovascular diseases. Chickpea seeds are also a valuable source of essential fatty acids, including omega-6 linoleic acid and omega-3 linolenic acid, which play pivotal roles in normal human growth, physiological functions, and cell maintenance.

d) Minerals

Chickpea is recognized as a valuable source of essential minerals, constituting a significant contribution to the overall maintenance of human life. It plays a crucial role in enhancing iron (Fe) and zinc (Zn) intake in the human diet. In chickpea seeds, iron and zinc are available in a range of 44.1-76.7 mg/kg and 36.3-56.2 mg kg⁻¹, respectively (Srungarapu et al., 2022) (Table 1). A single 100 g serving of cooked chickpea offers substantial quantities of essential nutrients, providing up to 40% of the recommended daily allowance (RDA) for certain minerals. Notably, chickpea surpasses the RDA for various micronutrient minerals, emphasizing its nutritional significance. While a single serving can potentially supply approximately 40% of the adult RDA for manganese and copper, as well as around 15% for iron and zinc, it is crucial to acknowledge the variability in seed concentrations across different genotypes. Chickpea seeds boast a commendable content of macronutrients, specifically phosphorus and magnesium. Additionally, these seeds are amusing sources of essential minerals, including manganese, copper, and selenium. Furthermore, the micronutrient profile of chickpea...
seeds encompasses several other metals, such as molybdenum and cobalt.

Table 1. Availability of various minerals in chickpea

<table>
<thead>
<tr>
<th>Nutrient</th>
<th>Kabuli (mg/100g)</th>
<th>Desi (mg/100g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iron (Fe)</td>
<td>4.3-7.6</td>
<td>4.6-7</td>
</tr>
<tr>
<td>Calcium (Ca)</td>
<td>80.5-187.25</td>
<td>115.0-226.5</td>
</tr>
<tr>
<td>Manganese (Mg)</td>
<td>122-212.8</td>
<td>128-188.6</td>
</tr>
<tr>
<td>Zinc (Zn)</td>
<td>3.6-5.6</td>
<td>2.8-5.1</td>
</tr>
<tr>
<td>Copper (Cu)</td>
<td>0.7-1.4</td>
<td>0.5-1.4</td>
</tr>
<tr>
<td>Manganese (Mn)</td>
<td>1.65-4.8</td>
<td>1.72-4.1</td>
</tr>
<tr>
<td>Potassium (K)</td>
<td>816.1-1580.1</td>
<td>878-1479.1</td>
</tr>
<tr>
<td>Phosphorus (P)</td>
<td>294.1-828.8</td>
<td>276.2-518.6</td>
</tr>
<tr>
<td>Sodium (Na)</td>
<td>11.23-21.07</td>
<td>7.35-22.9</td>
</tr>
</tbody>
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Source: Begum et al. (2023); Gaur et al. (2015)

e) Vitamins

Chickpea is a reservoir of various water-soluble and lipid-soluble vitamins essential for human nutrition. Water-soluble vitamins include the B-complex vitamins (folate, thiamin, riboflavin, niacin, pantothenic acid, pyridoxine, biotin, and cobalamin) and vitamin C. Chickpeas contain a significant amount of folate, ranging from 42-537 μg/100g (Begum et al., 2023), and vitamin C, with 12.48 mg/100g (Karaca et al., 2019). Among the lipid-soluble vitamins, chickpeas contain vitamin A, vitamin E, and vitamin K. Vitamin A, primarily found as provitamin A carotenoids (β-carotene), is present in both the cotyledon and seed coat, with concentrations ranges from 0.4–2.6 mg g⁻¹ (Ashokkumar et al., 2015). Chickpea is a reasonable source of vitamin E, as the seed contains ~3-9% lipids and up to 13.7 mg/100g vitamin E (13.7mg/100g). While chickpea’s vitamin K content is lesser than that of leafy vegetables, it surpasses levels found in fruits and most animal products, as reported by the Nutrient Data Laboratory, USDA Agricultural Research Service in 2005. The presence of vitamin K (phylloquinone) in chickpea is noteworthy for its role in modifying proteins crucial for blood coagulation, bone metabolism, and vascular health.

f) Dietary fibre

Dietary fibre is a component of plants that human gastrointestinal enzymes cannot digest. Chickpea dietary fibre consists of polysaccharides such as lignin, cellulose, hemicellulose and pectin (Attia et al., 1994). Dietary fibre acts as a polymer matrix with different physicochemical properties and undergoes several compositional changes due to bacterial activity in the large intestine. The volume of dietary fibre varies, with lignin 18.6-21.7 g, cellulose 29.6-40.4 g, hemicellulose 26.9-77.6 g and pectin 42.1 g per kg of chickpea seeds (Mathew et al., 2022). It has clinical importance in treating disorders of colonic function and lipid metabolism.

NON-NUTRITIVE HEALTH-BENEFICIAL COMPONENTS

Plant-based foods, including pulses, contain a wealth of non-nutritive elements that have been shown to promote good health. These include oligosaccharides (raffinose, stachyose and verbascose), saponins, tannins, polyphenols, flavonoids and enzyme inhibitors. Experimental evidence has demonstrated the beneficial activity of these pulse components modulate different physiological and metabolic processes in the human body, such as antioxidants (Fares and Menga, 2012), anti-inflammatory (Masroor et al., 2018), anti-diabetic, anti-obesity, anti-cancer, prebiotic (Monk et al., 2017) and cholesterol-lowering effects there by prompting a reappraisal of pulses as a cornerstone of a healthy diet. These studies strongly support the notion that regular consumption of pulses, including chickpeas, is an effective strategy for maintaining and enhancing overall health.

a) Carbohydrates

Carbohydrates vary significantly in their glycemic index (GI), influencing their impact on blood glucose levels. Certain carbohydrates in white bread and potatoes, rapidly break down during digestion, causing a rapid spike in blood glucose. In contrast, legumes generally exhibit a lower GI, with chickpea possessing the lowest GI among common foodgrains. The FAO/WHO classifies chickpea as having a GI of 44 for raw chickpeas and 47 for canned chickpeas, compared to a GI of 100 for white bread. Mendosa (2005) reported a GI of 7-11 for raw chickpea, while Nalwade et al. (2003) demonstrated a GI of 21.45 for boiled chickpea, significantly lower than boiled lentils (27.63), boiled rice (61.18), and bread (76.55). This low GI characteristic makes chickpea a suitable dietary component for individuals with diabetes. Additionally, chickpeas contain oligosaccharides (raffinose family oligosaccharides), which act as potential prebiotics, promoting the growth of beneficial microorganisms in the colon. Therefore, incorporating chickpeas into the diet offers multiple health benefits, including improved blood glucose control and enhanced gut health.

The World Health Organization (WHO) has
recognized a high dietary intake of non-starch polysaccharides (NSP) or dietary fiber as a protective factor against obesity (WHO/FAO, 2003). They recommend a minimum daily intake of 20 g NSP. Notably, chickpeas are a rich source of NSP with a low glycemic index (GI). Consuming approximately 40 g of chickpea can meet the daily NSP requirement recommended by the WHO, potentially aiding in blood sugar control and offering protection against diabetes.

b) Polyphenols

Polyphenolic compounds, prevalent in a diverse array of plant foods including vegetables, cereals, legumes, fruits, and nuts, exhibit significant variability in content influenced by genetic and environmental factors, agronomic practices, and storage conditions. Recently, there has been a heightened interest in polyphenolics, particularly flavonoids, attributable to their recognized antioxidant capacity and potential contributions to human health. These potential health benefits encompass the treatment and prevention of various conditions such as cancer, cardiovascular disease, hypertension, hypercholesterolemia, atherosclerosis, bacterial and viral infections, diarrhea, ulcers, inflammation, and allergies (Bravo, 1998; Martens and Mithofer, 2005). This diverse family encompasses 13 distinct subclasses, including chalcones, dihydrochalcones, aurones, flavones, flavonols, dihydroflavonols, flavanones, flavonols, flavandiols (leucoanthocyanidin), anthocyanidins, isoflavonoids, bisflavonoids, and proanthocyanidins (condensed tannins) (Bravo, 1998). Kaur et al. (2019) reported that flavonol content in chickpea varied from 0.80 mg/100 g to 24.20 mg/100 g. Kabuli genotypes possessed lower flavonol content (0.08 mg/100 g to 0.55 mg/100 g) than desi genotypes (5.04 mg/100 g to 13.18 mg/100 g).

d) Tannins

Tannins, once considered antinutritional factors due to their ability to form complexes with minerals and hinder intestinal absorption, have recently gained recognition for their potential health-promoting properties. Studies have demonstrated the chemoprotective, antiviral, and antibacterial activities of certain tannins, suggesting their potential applications in preventive healthcare. In chickpea seeds, the condensed tannin content is modest, measuring less than 0.04% in kabuli types and 0.09% in desi types, as reported by Petterson et al. (1997) and Salgado et al. (2001). Desi and kabuli and wild species had an average tannin content of 11.93, 10.63 and 16.38 mg/g, respectively (Kaur et al., 2019).

e) Plant sterols or phytosterols

Plant sterols exhibit the capacity to impede the absorption of dietary cholesterol in the small intestine, thereby contributing to the reduction of LDL (low-density lipoprotein) blood cholesterol levels in humans and potentially mitigating the risk of coronary heart disease. Beyond their cholesterol-lowering effects, plant sterols have demonstrated anticancer properties, as highlighted by Champ (2002) and Mathers (2002). These compounds are
present in relatively low quantities in legumes, including chickpea. The Nutrient Data Laboratory, USDA Agricultural Research Service (2005) reported that chickpea seeds and flour (besan) contain approximately 35 and 39 mg/100g of sterols, respectively. Additionally, Sanchez-Vioque et al. (1998) determined that defatted chickpea flour contains 0.04% total sterols, with β-sitosterol as the predominant sterol at 83%, followed by campesterol (9%), stigmasterol (6%), and 5-avenasterol (2%).

f) Saponins

Saponins are commonly identified in the seeds of edible legumes and are characterized by molecular structures consisting of sugars linked to triterpenes. Saponins possess several potential health benefits. They play a protective role in plants against infections and microbial invasions. Mounting evidence suggests that saponins may exhibit hypocholesteremic and anticancer properties, stimulate the immune system, protect against microbial and fungal infections, and even act as a spermicide. Chickpea exhibits notably higher saponin content, ranging from 25 to 56 mg/g, when compared to soybeans and other pulses (Fenwick and Oakenfull, 1983; Kerem et al., 2005). From the finding of Choudhary et al. (2015), the saponin content of different kabuli chickpea genotypes ranged from 4.98 to 12.23 mg/g.

g) Enzyme inhibitors

Chickpeas harbor two primary enzyme inhibitors: protease and α-amylase. Both categories of inhibitors have been classified as antinutritional factors due to their ability to impede protein and starch digestion. However, current research advocates that these inhibitors may also possess beneficial properties. Protease inhibitors in chickpea typically range from 1-16 mg/g trypsin inhibitor to 2-13 mg/g chymotrypsin inhibitor. Kaur et al. (2019) reported significant variation in trypsin inhibitor content across chickpea genotypes, ranging from 8.23 to 150.18 IU/g. Desi genotypes specifically showed higher levels (32.91-112.32 IU/g, mean 80.08 IU/g) compared to kabuli genotypes (38.53-64.47 IU/g, mean 47.83 IU/g). These protease inhibitors exhibit anticarcinogenic properties (Champ, 2002; Mathers, 2002). Additionally, α-amylase inhibitors found in chickpea, with a typical content of 5-11 units/g, have the ability to decrease starch digestion, leading to the reduction of blood glucose levels (Sievenpiper et al., 2009). This property suggests potential applications in the management and prevention of obesity and diabetes mellitus.

h) Oligosaccharides

Chickpea seeds harbor a diverse array of oligosaccharides, including raffinose (2.3-14.5 g/kg), stachyose (5.8-25.6 g/kg), and verbascose (1.9-7.2 g/kg) (El-Adawy, 2002; Sreerama et al., 2012; Longvah et al., 2017). Stachyose occupies the dominant position as the primary oligosaccharide (Sreerama et al., 2012). Human intestinal mucosa lacks the α-1,6-galactosidase enzyme necessary for their digestion, leading to fermentation by colonic microbiota and causing flatulence. However, recent research has revealed the benefit of these undigested oligosaccharides. They act as prebiotics, selectively enhancing the growth of beneficial bacteria like Bifidobacteria and Lactobacilli, while simultaneously suppressing the proliferation of harmful bacterial populations within the colon.

BREEDING EFFORTS FOR ENHANCING NUTRITIONAL VALUE OF CHICKPEAS

The rich nutritional and medicinal properties of chickpea have garnered significant attention among emerging plant breeders. Recent advancements in sequencing technologies have facilitated the unveiling of the entire chickpea genome, providing a comprehensive blueprint for understanding and manipulating its genetic makeup. Advanced breeding methodologies, such as quantitative trait locus (QTL) analysis, genome-wide association studies (GWAS), and genomic selection, are effectively harnessing molecular tools to identify genomic regions governing beneficial traits in chickpea. In recent years, substantial research efforts have been directed towards elucidating the genetic basis of nutritional traits in chickpea, paving the way for the development of improved chickpea varieties with enhanced nutritional profiles.

Researchers have employed various approaches to identify genetic factors influencing seed protein content (SPC) in chickpea. Sreerama et al. (2012) found substantial variation in grain protein content (16.3-26.2%) among 280 diverse chickpea accessions. Chakraborty et al. (2023) utilized QTL-Seq and association mapping to uncover two QTLs on chromosomes 5 and 6, each associated with three SNPs. These SNPs were validated and linked to the CaREN1 gene, explaining up to 23% of SPC variation. Wang et al. (2019) identified a major QTL, q-3.2, on chromosome 3, significantly influencing
SPC, accounting for 44.3% of SPC variation, while Upadhyaya et al. (2016a) identified allelic variants in six potential genes regulating SPC. These findings provide valuable insights for marker-assisted breeding and targeted gene manipulation to enhance SPC in chickpea.

Recent studies identified chickpeas as a solution to micronutrient deficiencies, particularly iron and zinc, which can lead to health problems. Genetic variations in nutrient concentrations of chickpea seeds have been investigated using genetic markers. In a study by Srungarapu et al. (2022) identified genetic markers associated with grain protein, Fe, and Zn content, located on chromosomes 1, 4, 6, and 7. These markers hold the potential to be used in breeding for nutrient-rich chickpea cultivars. Additionally, Diapari et al. (2014) identified 9 SNPs significantly associated with Fe and/or Zn concentrations in chickpea seeds. Upadhyaya et al. (2016) identified genetic markers explaining 29% of the variation in seed Fe and Zn concentrations. They further validated eleven trait-associated SNPs using SNP-based high-resolution quantitative trait locus (QTL) maps, revealing robust QTLs for seed Fe and Zn concentrations in eight major genomic regions of the kabuli chickpea genome. Moreover, Tan et al. (2018) proposed a genetic engineering (GE) strategy to enhance the Fe content of chickpea by employing a combination of the chickpea nicotinamine synthase 2 (CaNAS2) and soybean (Glycine max) ferritin (GmFER) genes, which play crucial roles in Fe transport and storage, respectively. Karaca et al. (2019) identified 29, 10, 14, and 4 SNPs associated with protein, lutein, vitamin C, and fructose, respectively, in 180 chickpea varieties, elucidating the genetic basis of nutrient variation in chickpea seeds. Roorkiwal et al. (2022) analyzed 258 chickpea varieties for 12 nutritional traits and discovered genetic markers associated with these traits on chromosomes Ca1, Ca3, Ca4, and Ca6, explaining up to 28.63% of the trait variation.

The presence of protein, carbohydrates, and vitamins, particularly provitamin A carotenoids found in chickpea seeds, renders chickpeas a significant dietary component, especially in numerous developing nations (Abu-Salem and Abou-Arab, 2011). Varieties with green cotyledons exhibit higher concentrations of provitamin A compared to those with yellow cotyledons. In a study by Rezaei et al. (2016) investigated the expression of carotenoid biosynthesis genes in chickpea and found that gene expression was highest at 8 and/or 16 days after flowering, corresponding to the peak accumulation of carotenoids. Furthermore, Rezaei et al. (2019) identified eight quantitative trait loci (QTLs) associated with carotenoid components in chickpea seeds using three F2 populations derived from crosses between green- and yellow-cotyledon chickpea cultivars. These QTLs provide valuable genetic markers for marker-assisted breeding aimed at improving carotenoid content and provitamin-A content in chickpea.

Chickpea harbors bioactive and functional compounds, notably phenolics and flavonoids, which confer significant health benefits. Despite these nutritional merits, chickpeas contain certain antinutritional factors, such as phytic acid, tannins, enzyme inhibitors, and oligosaccharides, which impede the bioavailability of these bioactive nutrients. However, there is limited scientific exploration into these factors. Notably, phytic acid, a phosphorus storage form in plants, exerts a negative influence on mineral bioavailability due to its chelating properties. Studies have revealed the polygenic nature of phytic acid content in chickpea and identified transgressive segregants with extreme phenotypes (Misra et al., 2017). A SSR marker located in the promoter region of the IMP gene has been associated with phytic acid content in chickpea (Dwivedi et al., 2017). Raffinose family oligosaccharides (RFOs) is another major anti nutritional factor found in chickpea seeds. Substantial genetic variation exists in RFO content, as demonstrated by Raja et al. (2015), who reported wide ranges for raffinose (0.16-15.13 mg/g) and stachyose (2.77-59.43 mg/g) across 213 accessions. Among RFOs ciceritol exhibited the most significant variation (4.36-90.65 mg/g). Elango et al. (2022) further explored this diversity within the chickpea mini-core collection, revealing distinct differences between kabuli and desi biotypes. Kabuli chickpeas were characterized by high sucrose content, while desi types possessed elevated levels of raffinose and stachyose. Genome-wide association studies (GWAS) identified 48 SNPs associated with sugar types, coupled with the identification of nine candidate genes potentially involved in sugar metabolism and transport (Elango et al., 2022). These findings provide valuable insights into the genetic architecture of RFO accumulation in chickpea and lay the groundwork for breeding programs aiming to develop cultivars with reduced anti-nutritional factors and enhanced nutritional value.

CONCLUSION

Chickpea stands out as a prominent pulse production legume, but it also holds potential as a source of bioactive and functional compounds, particularly carotenoids and phytic acid. While these factors provide significant health benefits, they also contribute to antinutritional factors that limit the full utilization of chickpea in human diets. Further research is needed to develop cultivars with reduced antinutritional factors through marker-assisted breeding and genetic engineering.
globally, following dry beans in consumption. Its nutritional richness and diverse health-promoting components position it as a valuable dietary resource. Packed with protein, fibre, vitamins, and minerals, chickpeas present a sustainable and versatile source of nutrition, making them an invaluable component of balanced diets across diverse cultures. The disclosure of chickpea’s antioxidant and prebiotic potential, particularly through the presence of oligosaccharides, adds another layer of significance to its nutritional profile. Over the years, scientists have conventionally developed cultivars that not only meet basic nutritional requirements but also go beyond in providing additional health-promoting components and increase the richness of germplasm. The vast genetic variability within chickpea germplasm, coupled with advancements in genome sequencing and editing technologies, offers exciting prospects for further enhancing and optimizing nutritional traits.

REFERENCES


