Breeding Cowpea: A Nutraceutical Option for Future Global Food and Nutritional Security

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Abstract

Nutritional security has become the prime concern for world agriculture through improving the nutritional quality of crop plants and fostering nutri-rich crops. Malnutrition in the developing countries and increased occurrence of several

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health problems are now the major global challenges. Cowpea is a prime pulse legume grown predominantly in the tropical and subtropical regions of Asia, Africa, Latin America, and southern Europe. Compared to other legumes, cowpea is more resilient to climate change and exhibits wider adaptability in different agro-ecologies. Cowpea is a rich source of protein, carbohydrates, minerals, and vitamins with a low lipid content. Besides being nutritious, its health-promoting and health-protective effects are based on resistant starch, dietary fiber, phenolics, and peptides. Major health beneficial features of cowpea include anti-cancer, anti-diabetic, anti-inflammatory activities, and controlling blood lipid content. Germplasm evaluation is paving way for the identification of lines with high protein content and minerals (Cu, Fe, Zn, Mg, Ca, and K) which could be used in breeding for new biofortified cowpea cultivars. Development of databases such as "EDITS-Cowpea" for enabling exploration of cowpea traits, especially those related to grain quality-related traits and "Cowpea Genomics Initiative" for applying modern molecular genetic tools for gene discovery will foster research aimed at cowpea improvement. This chapter examines the nutritive value of cowpea with more emphasis on the remarkable nutraceutical properties of cowpea and suggests taking cowpea forward as a future smart crop for tackling global food and nutritional security.

Keywords

Pulses · Cowpea · Nutritional security · Nutraceuticals · Human health

1 Introduction

Food security for the increasing world population has become a main concern for agricultural scientists and plant breeders, and it is estimated that food production will have to be enhanced by 70% by 2050 (Fróna et al. 2019). The problem is also compounded by the nutritional deficiencies and malnutrition among the world population (FAO 2017). This necessitates that the food will have to be produced in abundance and of good nutritional quality to ensure health of the future generations. Plant breeding over the past several decades has made a significant contribution to the development of high yielding and good quality varieties of cereals, pulses, and oil seeds besides other economically important plants to meet food and nutritional security (Mir et al. 2021).

Cowpea (*Vigna unguiculata*), also known as China bean, black-eyed bean, black-eyed pea, and southern pea, is an annual bean plant and member of the family Fabaceaeor Leguminosae (Oyewale and Bamaiyi 2013). It is widely cultivated in the tropical regions of the world such as Southeast Asia, Africa, Southern United States, and Latin America due to its ability to tolerate climate change. Cowpea is majorly produced and consumed in Sudano–Sahelian zone of sub-Saharan Africa (Boukar

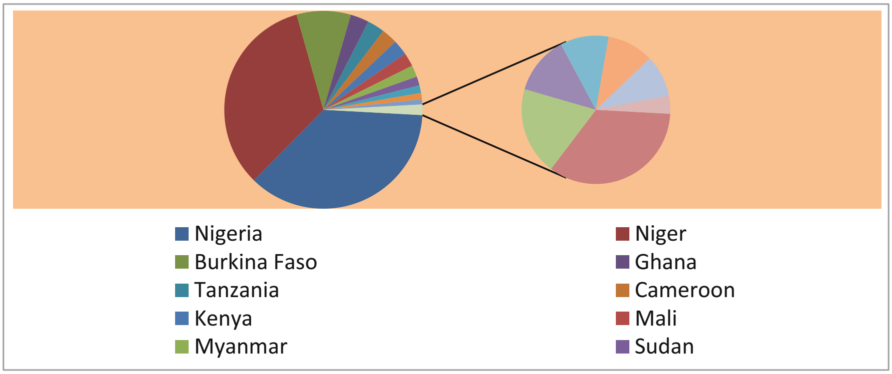

Fig. 1 Global cowpea production (FAOStat 2020)

et al. 2019). According to FAOSTAT report, worldwide production estimates over 8.9 million metric tons of dry cowpeas in 2020, of which 86% is contributed by Western Africa, mainly Nigeria and Niger with 6.3 million tons (FAOSTAT 2020) (Fig. 1). At the global level, cowpea production and yield have been increased by 88% and 35%, respectively (Nedumaran et al. 2015). Most of the cowpea plant parts are edible and consumed such as juvenile leaves, growing points, raw/immature pods, green seeds, and dried/desiccated seeds (Gerrano et al. 2019). It is grown for its high nutritious value, and recently there has been focus on the nutraceutical properties and as fodder for livestock. Moreover, due to its nutritious leaves, cowpea is placed in class of the chief vegetables in Africa and Asia (Mohammed et al. 2021). The American Pulse Association declared "pulses" as the most versatile and multifaceted food source in the world (American Pulse Association 2020). It is often referred to as a multi-potential crop for the future (Fig. 2).

Cowpea is reported to have originated from Africa (Lazaridi et al. 2016). A recent study in 2020 (Herniter et al. 2020) based on genetic, textual, and archeobotanical data proposed a likely spread of cowpea from the two centres of domestication, West Africa and East Africa. From West Africa cowpea was spread by the Bantu migrations south to the equatorial rainforest and then to the areas of modern Sudan, South Sudan, and Ethiopia followed by diversion into three branches. First branch leads to Southern Africa, which joined the East African domestication. Second branch directed toward north up to the Nile and Egypt and remained there up to 2500 BCE. Later on, by 400 BCE, this branch had entrenched itself as a key food crop in the Mediterranean basin and moved to Spain's colonial holdings in the New World, including the modern south-western United States. The third branch makes its way to the west coast of India by 1500 BCE through the "Sabaean lane" in modern Yemen and then spreads to Southeast Asia. *Vigna unguiculata* ssp. *unguiculata* var. *spontanea* is assumed to be the wild ancestor of cultivated cowpea that is grown in sub-Saharan Africa (Pasquet et al. 2021).

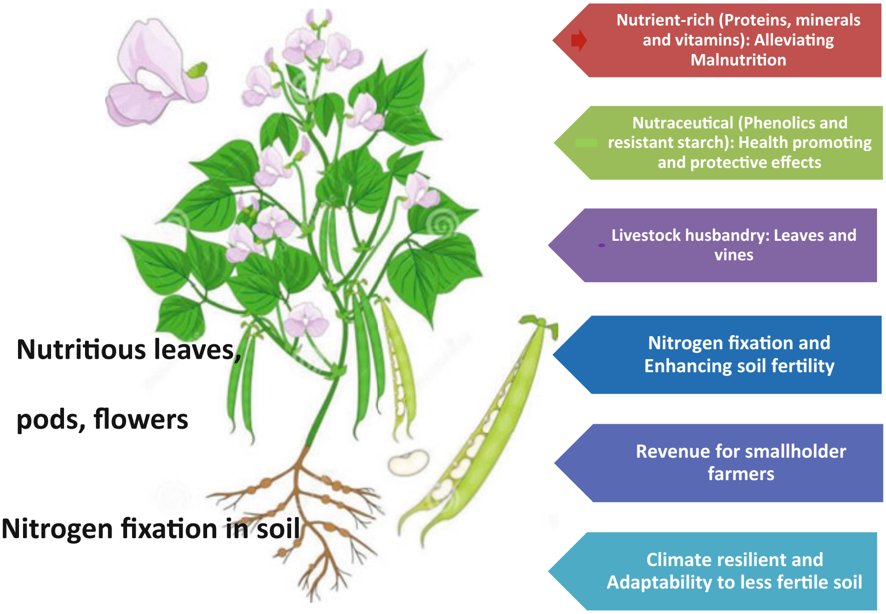

Fig. 2 Multifaceted potentials of cowpea

2 Genetic Resources and Genetic Diversity

Crop genetic resources including germplasm collections are essential for national and global agricultural security. Genetic diversity of crops is important for sustainable development and food security because this gene reservoir will aid in the future in further improvements in the elite cultivars with regard to better performance and well-adaptedness (Pathirana and Carimi 2022). To date several genetic resources have been developed in cowpea to aid in breeding elite varieties. The different forms of these developed genetic resources include physical and genetic linkage maps, genome sequences, databases, microarrays, molecular markers, etc. Few examples of different genetic resources in cowpea are genotyping assays and genetic maps based on single nucleotide polymorphism (SNP), physical maps, mapped quantitative trait loci (QTLs) traits, consensus genetic maps of cowpea (González et al. 2016), reference genome sequence of cowpea (Lonardi et al. 2019), cDNA sequences, unigenes, genic-SSR markers (Mahalakshmi et al. 2007), and linkage maps for cowpea developed using molecular markers and their further refinements through advanced markers (Muchero et al. 2009). Several genetic diversity studies have been conducted to investigate the evolutionary relationships among different genotypes, relationships with wild accessions, origin, taxonomy, domestication, and evolutionary pattern in cowpea. Initially studies were performed using conventional parameters such as allozymes and seed storage proteins that was followed by different marker systems such as chloroplast DNA polymorphism, restriction fragment length polymorphism (RFLP), amplified fragment length polymorphisms (AFLP), DNA amplification fingerprinting (DAF) simple sequence repeats (SSRs), cross species SSRs from *Medicago*, inter-simple sequence repeats, sequence tagged microsatellite sites (STMS), and single-nucleotide polymorphism (SNP) markers.

The largest collection of cowpea consisting of 16,569 cultivated accessions from 100 countries and around 1500 wild accessions of *vigna* is maintained by the International Institute of Tropical Agricultural (IITA). Based on geographical, agronomical, and botanical descriptors, a central group of 2120 accessions and a minor collection of 376 accessions have been established at IITA (Boukar et al. 2019). Other major collections with overlapped data include the US Department of Agriculture–Agricultural Research Service (USDA-ARS) (Griffin, Georgia, USA) with 8379 accessions, the National Bureau of Plant Genetic Resources (NBPGR, New Delhi, India) holding 4003 accessions, and the University of California, Riverside (UCR, California, USA) harboring 5000 accessions and a mini core of 368 accessions. These cowpea accessions exhibited variations among each other with context to several morphological and agronomical traits such as plant pigmentation, plant kind, plant height, leaf type, growth habit, photosensitivity or insensitivity, maturity, nitrogen fixation, fodder grade, tolerance to high temperature and water deficit, root architecture, pod features, seed traits, grain quality and reaction/ response to diseases, root-knot nematodes, insect pests (aphids, bruchid, thrips), and parasitic weeds (Boukar et al. 2020). Large gene bank collections include those of IITA (Nigeria), USDA (Southern Regional Plant Introduction Station, Georgia), World Vegetable Centre (Taiwan), and the N.I. Vavilov Research Institute of Plant Industry (Russia). Padhi et al. (2022) explored 120 diverse cowpea germplasm lines to search for nutri-dense genotypes using biochemical traits and observed broad variability for protein content (19.4 to 27.9%), starch (27.5 to 42.7 g 100 g^{-1}), amylose (9.65 to 21.7 g 100 g^{-1}), TDF (13.7 to 21.1 g 100 g^{-1}), and TSS (1.30 to 8.73 g 100 g^{-1}). The study suggested that the collection showed some nutrient-dense lines having more than a single trait with high nutritional potential.

3 Nutritional and Nutraceutical Profile

The world is facing major critical situations of malnutrition in downtrodden population of developing countries and prevalence of chronic diseases in well-off people in developed countries. Protein energy malnutrition (PEM) is a very serious public health issue in many less developed nations (Bessada et al. 2019). Globally, one-third of all child deaths were estimated to be due to malnutrition, of which 54% occurred in underdeveloped countries (Bain et al. 2013). Thus, there is an urgent need to identify foods that are both nutritious and have nutraceutical properties and to introduce these food types into our regular diet so that their health-protective and health-promoting effects will help in controlling frequent cases of several chronic diseases.

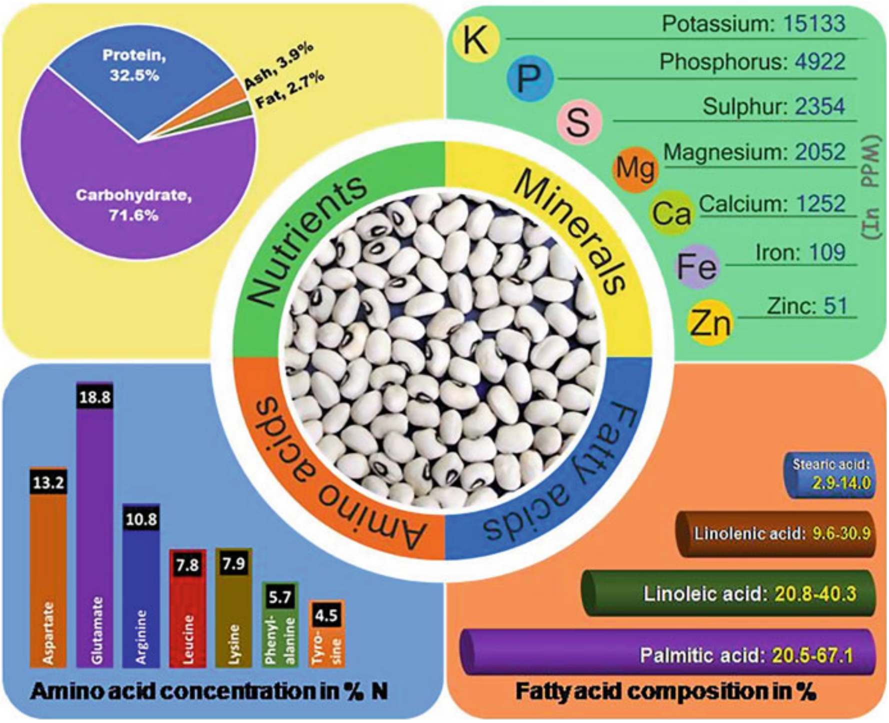

Fig. 3 Major nutritional composition of cowpea seeds (based on the data from Gonçalves et al. 2016)

Legumes are well-known for their protein-richness, of which cowpea has gained more attention due to its remarkable nutritional profile and nutraceutical properties that make it unique among other pulses (Dhanasekar et al. 2021) (Fig. 3). Cowpea is known as "the poor man's meat" because of its protein-rich nature complemented by its less expensive and affordable access to rural poor people (Dugje et al. 2022), and also because the protein content is approximately equal to certain meat types (18–25%). It also has digestible and non-digestible carbohydrates, potassium, and very low lipid and sodium content. The composition of different nutritional components in grains is given in Fig. 4. Cowpea leaves are rich in micronutrients, nutraceuticals, antioxidants (alpha tocopherols, flavonoids, lycopene), and anti-proliferating compounds (Owade et al. 2020). Dakora and Belane (2019) suggested that cowpea leaves could meet the suggested day-to-day dietary intake requirement of the micronutrients Fe and Zn by consuming 4 mg and 76 mg of leaf on a dry matter basis. Cowpea leaves are a nutritious food source, with an abundance of protein and minerals, digestible and non-digestible carbohydrates, and potassium but low lipids and sodium (Kamara et al. 2010). Leaves show higher nutritional content than grains (Fig. 5).

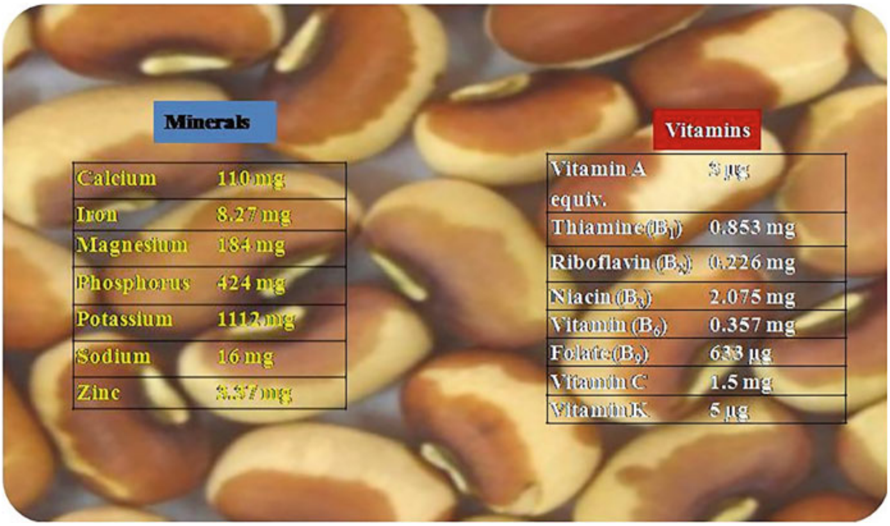

Fig. 4 General nutritional profile per 100 g of raw cowpea seeds. (Source: USDA nutrient database)

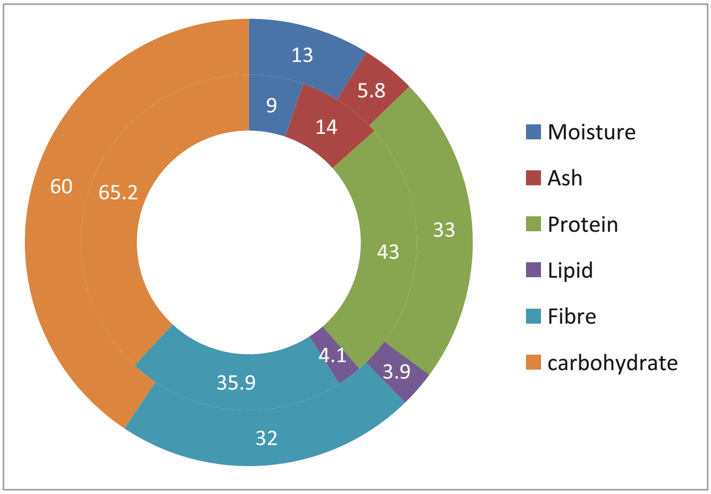

Fig. 5 Proximate and fiber composition (%) of leaves and grain (adopted from Mekonnen et al. 2022)

3.1 Protein Profile

Cowpea is consumed as a high-quality plant-based protein source (Jayathilake et al. 2018) with a protein content of 27 to 43% in leaves and 21 to 33% in dry grains (Gerrano et al. 2019). Cowpea protein fraction includes globulins (legumin and

Table 1 Amino acid composition of cowpea grain and leaves (adopted from Mekonnen et al. 2022)

Amino acid	Leaves (g/100 g protein)	Grain (g/100 g protein)	Amino acid	Leaves (g/100 g protein)	Grain (g/100 g protein)
Arginine	7.4–17.3	5.0–10.8	**Lysine**	3.0–16.3	3.5–8.0
Aspartic acid	10.8–26.7	6.0–13	**Methionine**	1.0–4.5	0.9–3.5
Alanine	4.2–9.8	3.4–5.1	**Phenylalanine**	4.6–14.4	4.4–9.9
Cysteine	0.5–2.9	0.3–2.4	**Proline**	4.0–15.9	3.1–8.9
Glutamic acid	17.2–45.3	8.5–19	**Serine**	3.0–11.6	3.8–5.8
Glycine	3.8–12.6	3.1–4.8	**Threonine**	3.2–10.8	3.0–5.9
Histidine	1.8–8.6	2.0–4.41	**Tryptophan**	1.3–4.1	0.9–1.5
Isoleucine	4.1–11.1	2.8–5.4	**Tyrosine**	3.0–9.3	2.6–4.5
Leucine	7.4–19.6	5.7–11.3	**Valine**	5.0–12.8	3.4–6.2

vicilin/β-vignin), albumins, glutelins, and prolamins (Santos et al. 2012). Because of this, cowpea has been highly promoted in economically backward regions to control protein malnutrition (Iqbal et al. 2006).

Cowpea leaves and grains show a rich profile of different amino acids including essential amino acids like valine, leucine, phenylalanine, lysine, and tryptophan. The amino acid profile of leaves and grains is presented in Table 1.

3.2 Minerals and Vitamins

Cowpea seeds, leaves, and beans are enriched with vital minerals of both macronutrients (Ca, K, Mg, P and S) and micronutrients (Cu, Fe, Mn, Zn, Na, Al, Se, B) that are required for proper functioning of human body (Owade et al. 2020). Cowpea is a source of different vitamins, of which most prevalent are vitamin A, C, and B complex (thiamine, riboflavin, pantothenic acid, pyridoxine, and folic/folate acid) and gamma tocopherol. Cowpea leaves have more vitamin C and minerals compared to grains (Mekonnen et al. 2022). The major and micro-mineral profiles of leaves, immature pods, and grains are presented in Table 2.

3.3 Lipids and Fatty Acids

Cowpea is a low lipid grain crop compared to other legumes (chickpea, lentil, green gram, and lupin) (Belane and Dakora 2011) with 0.5% to 3.9% lipid in grain and 1.3 to 4.3% in leaves. The lipid profile of cowpea is composed of triglycerides (41.2%), phospholipids (25.1%), monoglycerides (10.6%), free fatty acids (7.9%), diglycerides (7.8%), sterols (5.5%), hydrocarbons, and sterol esters (2.6%)

Table 2 Mineral composition of cowpea grains, immature pods, and leaves (adopted from Mekonnen et al. 2022)

Minerals	Grains Mean range	Immature pods Mean range	Leaves Mean range
Macro-minerals (mg/100 g dry matter)			
Phosphorus	2.3–6.10	383.43–537.53	2.1–592.4
Potassium	9.30–35.60	170.74–240.78	9.57–1445.2
Magnesium	4.3–8.4	297.97–426.20	1.3–227.4
Sulfur	153.3–200.0		120.0–147.3
Micro-minerals (mg/100 g dry matter)			
Copper	0.15–2.2	0.48–0.95	0.5–2.2
Iron	26.76–182.33	6.01–9.78	3.4–10.6
Manganese	10.57–204	2.11–4.77	1.38–4.3
Sodium	11.59–43.95	13.70–32.93	8.4–79.81
Zinc	2.78–22.3	1.42–5.63	2.4–5.11
Aluminum		1.84–7.86	
Boron	3.14–5.01	2.13–4.03	1.47–2.14
Selenium		2.5–3.4	

(Kapravelou et al. 2015). Among fatty acids, palmitic and linoleic acids and, within sterols, stigmasterol (42.1 to 43.3%) are predominant (Antova et al. 2014).

3.4 Carbohydrates

Cowpea is also rich in carbohydrates containing 30.39 to 31.11% in leaves and 50 to 60% in grains. Popova and Mihaylova (2019) suggested that the good fraction of carbohydrates consists of sucrose, glucose, fructose, galactose, and maltose, whereas anti-nutrient components of carbohydrates are mostly raffinose, stachyose, and verbascose.

4 Health-Promoting and Health-Protective Properties

Besides above-specified nutritional value, cowpea exerts several health benefits due to presence of soluble and insoluble dietary fibers, phenol-derived compounds, other functional agents, anthocyanins, and carotenoids (de Silva et al. 2021). Epidemiological evidences showed the nutraceutical aspects, i.e., health-promoting and disease-preventing effects of cowpea such as protection against many incurable and immedicable health situations such as cardiovascular diseases, hypercholesterolemia, and obesity (Frota et al. 2015), anti-diabetic (Barnes et al. 2015), anti-cancer (de Silva et al. 2021), anti-inflammatory (Awika and Duodu 2017), antihypertensive and hypocholesterolemia (Tadele 2019), reducing plasma low-density lipoprotein (Talabi et al. 2022), gastrointestinal disorders (Khalid II and Elharadallou 2012), weight loss (Perera et al. 2016), and improving assimilation and strengthening blood flow (Trehan et al. 2015). The nutraceutical aspects of cowpea were reviewed (Jayathilake et al. 2018) and credited with plant-derived compounds, resistant starch, dietary fiber, less fat, and good unsaturated fatty acids. Interestingly, upon germination, the nutritive profile of cowpea seeds is enhanced as observed by increase in antioxidant capacity, vitamin C (Doblado et al. 2007), β-carotene, phenolics (hydroxycinnamic acid, syringic acid, vanillaldehyde, ferulic acid, sinapic acid, *p*-coumaric acid, benzoic acid, ellagic acid, and cinnamic acid), and flavonoid content.

4.1 Protein Hydrolysates and Peptides

The protein lysates of cowpea vegetate shows a low lysine/arginine proportion like soybean, thus making it a potential functional ingredient for reducing cholesterol (Kanetro 2015). Cowpea bioactive compounds such as peptides that are products of enzymatic hydrolysis or fermentation are reported to create favorable physiological conditions for proper functioning of the human body (Marques et al. 2015). These peptides function by acting as antihypertensive (Boonla et al. 2015), anti-dyslipidemic (Udenigwe and Rouvinen-Watt 2015), antioxidative (Marques et al. 2015), anti-carcinogenic and antimicrobial (Felicio et al. 2017), and anti-diabetic (Barnes et al. 2015). Cowpea peptides are known to prevent the occurrence of diabetes mellitus by imitating the activity of insulin and inhibiting dipeptidyl peptidase IV activity (Barnes et al. 2015). The antioxidative properties of cowpea peptides were attributed to the hydrophobic and aromatic amino acids like leucine, isoleucine, tyrosine, phenylalanine, tryptophan, and the sulfur-bearing amino acid cysteine due to their proton giving property to free radicals (Xiong et al. 2013). Similarly cowpea proteins and peptides showed antihypertensive by inhibiting angiotensin-converting enzyme (ACE) (de Leon et al. 2013) and hypo-cholesterolemic effects occur in several ways such as bile acid-binding, disruption of cholesterol micelles, changing hepatic and adipocytic enzyme actions, and gene expression of lipogenic proteins, as well as by inhibiting HMG-CoA reductase activity (Marques et al. 2018).

4.2 Phenolics

Cowpea predominantly contains phenolics (70% free phenolics and 30% bound phenolics), flavonoids (flavonols and flavan-3-ols), coumaric acid and ferulic acid (seed), gallic acid, protocatechuic acid, and *p*-hydroxybenzoic acid (seed coat) and thus is supposed to exert high antioxidant activity (Gutierrez-Uribe et al. 2011). Anthocyanins found in cowpea are delphinidin-3-*O*-glucoside, cyanidin-3-*O*-glucoside, delphinidin-3-*O*-galactoside, cyanidin-3-*O*-galactoside, petunidin-3-*O*-glucoside, peonidin-3-*O*-glucoside, and malvidin-3-*O*-glucoside (Ha et al. 2010). Many studies have reported the phenolic composition and their functioning mechanisms in different cowpea varieties (Liyanage et al. 2014). Phenolic compounds have hypocholesterolemic activity because of inhibition of oxidation of lipids, lowering of blood triglycerides, total cholesterol, LDL, and surge of blood HDL (Hachibamba et al. 2013), anti-inflammatory by downregulating pro-inflammatory gene expression (Ojwang et al. 2015), and having an anticancer effect as antioxidants shields DNA from oxidation and suppress cancerous cell division (Hachibamba et al. 2013).

4.3 Resistant Starch and Fiber

Coming to the other health benefits, cowpea contains high amount of resistant starch up to 12.65 gm per 100 gm (Eshwarage et al. 2017; Chen et al. 2010) which makes it a low glycemic index food. As mentioned earlier, resistant starch and dietary fiber have antidiabetic effect due to slow release of glucose (Onyeka 2007) and hypocholesterolemic effect due to diminution of bile acids from the circulation, abatement of converting cholesterol to supplemental bile acids, and augmenting expulsion of fecal fat (Perera et al. 2016). The two major health benefits of resistant starch are that firstly, it slows the rate of digestion, thus slowing release of glucose into the body followed by less uptake of glucose by the intestinal cells and secondly, due to their incomplete digestion by human digestive enzymes, they act as a substrate for colonic microbes (including probiotics) resulting in production of short-chain fatty acids (butyrate) that aid in proper lipid function and cancer prevention. Cowpea also has low calorific value and thus helps with glucose regulation in diabetic patients and better weight control for the obese (Oboh and Agu 2010).

Cowpea has both soluble and insoluble high fiber content and hence has associated health advantages (Eshwarage et al. 2017). Soluble fiber helps in regulating blood cholesterol and glucose levels, while insoluble fiber due to its water/moisture retention property helps in smooth passage of waste materials through intestine and colon, thereby preventing haemorrhoids, constipation, many other digestive difficulties, colon cancer, diabetes, obesity, cardiovascular diseases, and numerous other long-term health complications (Eshwarage et al. 2017). Some additional health benefits of cowpea include eliminating urination problems such as uneasiness or obstructions, managing leucorrhea, or abnormal vaginal discharge (Alfa et al. 2020).

4.4 Anti-nutritional Factors

Although numerous studies claim cowpea is highly nutritious and a good nutraceutical food, its consumption is still limited due to presence of several anti-nutritional factors, poor digestibility, and lack of sulfur-containing amino acids. These anti-nutrients include some phenolic compounds, such as proanthocyanidins (Ojwang et al. 2013), phytic acid, tanins (Lattanzio et al. 2005), hemagglutinins (Aguilera et al. 2013), cyanogenic glucosides, oxalic acid, dihydroxyphenylalanine and saponins, and enzyme inhibitors (protease inhibitors, phytocystatins) (Monteiro et al. 2017). Phenolic compounds bind proteins and chelate divalent metal ions (Ojwang et al. 2013). Phytic acid (PA), an anti-nutritional factor, is known to conjugate phosphorus and other essential elements like iron and make it unavailable to organisms that feed on seeds rich in PA. Mutations affecting PA content have been identified, and low PA mutants have been isolated in pulses including cowpea (Dhanasekar and Reddy 2017). These mutants are being exploited in varietal development program so as to reduce the PA content to reasonable levels without affecting the physiological balance as they are further involved in responses to biotic and abiotic stresses (Dhole and Reddy 2016; Dhanasekar and Reddy 2017). Another important anti-nutritional factor in cowpea is the raffinose family oligosaccharides (RFOs) known to cause flatulence in organisms ingesting cowpea seeds. The RFOs are highly recalcitrant to various processing methods, and genetic means of reducing the content is the only amenable method. Therefore, it becomes imperative to identify genotypes with low RFOs content. Mutants with low RFOs have been identified in cowpea (Dhanasekar and Reddy 2015) that could be potential donors for developing varieties with low RFOs. Nevertheless, appropriate processing techniques can be used to lower many of the anti-nutritional compounds and enhance their bioavailability levels. Knowledge of nutritional, nutraceutical, and anti-nutritional aspects of cowpea will help in designing appropriate dietary plans/guidelines as per ethnic groups and geographic regions. Besides being in high demand due to its nutritious and nutraceutical values, cowpea cultivation is also supported because of the desirable agronomic attributes such as ease of cultivation, less necessity for fertile soils, their adaptability, and steadiness across all continents, even in drought-afflicted regions (de Silva et al. 2021).

5 Conventional and Molecular Approaches for Enhancing Nutritional Potential

Different processing methods, depending on geographical regions, are widely adopted by respective natives to reduce anti-nutrients present in cowpea and to enhance nutritional profile and also for the ease of intake. These methods include boiling, sprouting, steaming, frying, soaking, de-hulling, and grinding, which result in the alteration of the properties and bioavailability of some nutrients, increase in protein and mineral content (Fabbri and Crosby 2016), increase in phenolics and flavonoids (Laila and Murtaza 2014), and protein quality and digestibility (Deol and Bains 2010). Fermented cowpea flour showed improved antioxidant and hypolipidemic effects on rat (Kapravelou et al. 2015).

Extensive efforts through molecular tools have been made for breeding cowpea varieties resistant to biotic and abiotic stresses, to enhance yield and productivity, but reports on improving nutritional profile through molecular approaches are scarce. However, research on enhancing cowpea nutritional aspects has been conducted for evaluating biochemical properties of cowpea germplasm. Considerable data has been generated on estimation of the protein and minerals content of cowpea germplasm with the objective to identify appropriate parents for breeding nutrient-dense improved varieties (Fig. 3). For example, evaluation of cowpea germplasm lines for protein and minerals (Cu, Fe, Zn, Mg, Ca, and K) content (Gerrano et al. 2019) and analysis of cowpea cultivars for proteins and minerals under rain-fed conditions in

Petrolina, Brazil (Santos and Boiteux 2013), suggested the identification of high protein and mineral content genotypes which could be used in breeding for new biofortified cowpea cultivars.

Reports on cowpea genetics for biofortification with crucial minerals are still lacking, of which one study provided genetic factors for enhancing minerals in cowpea seeds. This study claimed the least number of genes controlling the augmentation of minerals ranging from 2 (K) to 11 (P) with transgressive segregation pattern and either oligogenic or polygenic control for all minerals analyzed (Fernandes et al. 2015). Composite interval mapping detected two QTLs for total soluble solid in pods using the population derived from the cross between yardlong bean (accession JP81610) and a wild cowpea (*V. unguiculata* ssp. *unguiculata* var. *spontanea*) (accession JP89083) (Kongjaimun et al. 2013). Recently in a genotype-by-environment interaction study, the expression of nutritional properties (protein and minerals concentrations) in cowpea leaves was assessed in different agro-ecologies of South Africa and typical agronomical practices of smallholder farmers (Gerrano et al. 2022). This study showed genetic variations among selected genotypes for all four analyzed traits and also influence of climate on expression of these traits. This study suggested that nutritional profile of legume plants is a function of local soil properties and soil health (Gerrano et al. 2022).

Mutation breeding is generally adopted to introduce desired simply inherited trait in elite cultivars. The International Atomic Energy Agency (IAEA) in association with the Food and Agriculture Organization (FAO) encourages the deployment of mutation-inducing technologies in plants for its member states. So far, there have been 22 mutant varieties developed using physical and chemical mutagens in cowpea. Few reports are available in cowpea cultivar development for biotic and abiotic stress tolerance using induced mutations (Horn et al. 2017), of which one study showed increase in the protein content in grains of some mutants by up to 13.3% (mutant from IT84E-124) and 13.64% (mutant from Vita 7) upon treatment with 1.0 mM NaN_3 (Odeigah et al. 1998). Raina et al. (2022) reported that there was a concurrent increase in yield and nutrient density (Protein, Fe, Zn, and Cu) in M_4 mutant lines in cowpea. Seven cowpea cultivars developed through mutation breeding exhibiting high seed productivity, earliness, large grain size, resistance to yellow mosaic virus, or augmented fodder production were released between 1981 and 2007 in India (Punniyamoorthy et al. 2007). One of the mutant varieties, the multifaceted cowpea mutant variety "TC-901," has desirable attributes like high grain yield, fodder yield, high seed protein content (28%), resistance to cowpea mosaic virus, and amenable for summer cultivation. The progress in enhancing nutritional profile of cowpea is underway through evaluation of germplasm lines for identifying appropriate parents for breeding elite, nutri-rich cultivars.

6 Genomics of Nutritional Quality

Information on genomics of the crop nutrition profile has laid a starting point for the implementation of advanced molecular breeding and genetic engineering methods for crop improvement and also helps in switching from time-consuming labor-intensive conventional breeding. Nutritive value of a crop can be enhanced either by upregulating genes/QTLs associated with nutritive traits or by suppressing genes involved in anti-nutrient biosynthesis for which knowledge of target genes is required. Efforts have been made to explore and understand the genomics behind nutritional features in crops like cereals, pulses, oil seeds, legumes, millets, and vegetables in the form of evaluation of crop germplasm, development of genetic resources through introduction of new genotypes/novel genes, mapping and characterization of genes through quantitative trait locus (QTL) interval mapping and sequencing, association mapping such as genome-wide association study (GWAS), and marker-assisted breeding as discussed as follows. For example, development of sorghum with low cyanogenic potential suitable for cattle feed generated by down-regulating an important enzyme of dhurrin biosynthesis pathway through antisense strategy (Pandey et al. 2019) provides opportunities for fine-tuning nutritional quality in grain crops. Interestingly in mung bean which is close to cowpea, 43 noteworthy marker trait associations (MTAs) for seed calcium, iron, potassium, manganese, phosphorous, sulfur, or zinc concentrations were discovered through genotyping by sequencing (GBS) approach (Wu et al. 2020). Coming to the crop improvement through genome engineering, the technique has been successfully applied to few crops including soybean for reducing linolenic acid (silencing of the ω-3 *fad3* gene) (Flores et al. 2008) and increasing oleic acid (suppressing *fad2-1* gene) (Christou et al. 1990). A database for cowpea, "EDITS-Cowpea," has all the required information on the cowpea traits especially related to grain quality-related traits which can be useful to breeders for crop improvement (EDITS-Cowpea 2022). A search conducted for nutritional quality as trait and zinc content as the specific search item showed that the cowpea varieties (240) in the database have a range of zinc content (34.5–46 mg/g).

A remarkable initiative is taken by the Kirkhouse Trust, a UK-based charitable organization through Cowpea Genomics Initiative (CGI) project (http://cowpeagenomics.med.virginia.edu/CGKB/) to help cowpea research community. CGI project is aimed at leveraging advanced molecular tools for gene study and bettering cowpea. This project attempts omics studies including transcriptome, proteome, and metabolome analyses to get comprehensive knowledge on the fundamental biology of host and important agronomic characteristics and also sequencing and annotation of the gene space (gene-rich region of the cowpea genome) (Chen et al. 2007). Muñoz-Amatriaín et al. (2017) developed genome resources for the analysis of an African cultivar IT97K-499-35 which included whole-genome shotgun assembly, a bacterial artificial chromosome physical map, and assembled sequences for use in linkage mapping, synteny analysis, and germplasm characterization. In a further study, Lonardi et al. (2019) developed a genomic assembly with the help of single-molecule real-time sequencing complemented with optical and genetic mapping tolls to categorize repetitive elements, genes, and gene families. Noteworthy advanced genome editing technology, CRISPR-Cas9 system, has been successfully applied first time in cowpea which involved the inactivation of symbiosis receptor-like kinase gene via *Agrobacterium*-mediated hairy root transformation method (Ji et al. 2019). Such project initiatives and implementation of genomics techniques may help in promoting cowpea research for improvement in nutritional quality in related crops through genomics-based trait introgression.

7 Future Perspectives and Conclusions

Increased food production and management of malnutrition always remain major challenges for the underdeveloped and developing countries, whereas in the developed world, increase in the occurrence of several chronic diseases and occupation-related hazards are a priority. The situation is getting worrisome due to the continuously increasing population and climate changes that directly affect agriculture sector. Cultivation of important staple crops in all ecological conditions and climate change scenarios is not possible. In this regard, crops with wider adaptability can help in ensuring food and nutritional safety. Cowpea is a drought-tolerant, climate-adaptable crop amenable to diverse cropping systems. Cowpea is an excellent nutrient-rich food source belonging to orphan crop category that remains to be extensively cultivated since, besides being highly nutritious, it also possesses many health-promoting and health-protective effects. Cowpea nutraceutical properties are attributed to bioactive or functional chemicals like peptides, resistant starch, digestible fiber, plant-derived compounds, antioxidants, vitamins, etc. that get better depending on processing methods. Cowpea has been shown to better the lipid profile, blood glucose content, blood pressure, cancer prevention, anti-inflammatory, anti-diabetic, etc. It is a multipurpose legume crop used for both human consumption and livestock fodder. In the current scenario, though cowpea is a nutrient dense food with several health benefits, it is a neglected crop because of huge losses in its production due to biotic and abiotic stresses, cultural beliefs, and limited research priority. Modern breeding technological interventions will have to be accelerated for cowpea breeding. Also, intensive clinical research on the anti-inflammatory and anti-cancer activity of cowpea is required to realize the nutraceutical aspects of cowpea for better acceptability.

Breeding for biofortification in cowpea is in the budding stage, and hence the adoption of molecular tools and advanced genomic strategies is needed to accelerate the progress of development of nutrient-dense and nutraceutical-rich varieties. This could be achieved through mining available genetic resources for target and novel genes/traits in association with chance breeding (targeted mutation, hybridization, backcrossing, pedigree, and recurrent selection), modern breeding methods (space breeding, speed breeding, genomic selection, and gene/genome editing), innovative techniques (mutagenesis breeding), transgenic development, demand-led breeding, and multi-omics analysis studies. Cowpeas can become a super crop for alleviating nutrient deficiency and health problems. With further research on its nutraceutical aspects, its acceptance will also be on the rise. Being the cheapest protein source and climate change-resilient crop, next-generation cowpea could be promoted for achieving future food and nutritional security at the global level.

References

Aguilera Y, Diaz MF, Jimenez T, Benitez V, Herrera T, Cuadrado C et al (2013) Changes in nonnutritional factors and antioxidant activity during germination of nonconventional legumes. J Agric Food Chem 61:8120–8125

Alfa AA, Tijani KB, Omotoso OD et al (2020) Nutritional Values and Medicinal Health Aspects of Brown, Brown-Blackand White Cowpea (*Vigna unguiculata* L. Walp.) Grown in Okene, Kogi State, Nigeria. Asian J Adv Res Reports 14:114–124

American Pulse Association (2020) Meet Pulses: The World's Most Versatile Superfood. Available online: https://www.usapulses.org/consumers/resources/delicious

Antova GA, Stoilova TD, Ivanova MM (2014) Proximate and lipid composition of cowpea (*Vigna unguiculata* L.) cultivated in Bulgaria. J Food Compos Anal 33:146–152

Awika MJ, Duodu GK (2017) Bioactive polyphenols and peptides in cowpea (*Vigna unguiculata*) and their health promoting properties: a review. J Funct Foods 38:686–697

Bain LE, Awah PK, Awah KP, Geraldine N (2013) Malnutrition in sub-Saharan Africa: burden, causes and prospects. Pan Afr Med J 15:120

Barnes M, Uruakpa F, Udenigwe C (2015) Influence of cowpea (*Vigna unguiculata)* peptides on insulin resistance. J Nutr Health Food Sci 3:1–3

Belane AK, Dakora FD (2011) Levels of nutritionally-important trace elements and macronutrients in edible leaves and grain of 27 nodulated cowpea [*Vigna unguiculata* (L.)Walp.] genotypes grown in the Upper West Region of Ghana. Food Chem 125:99–105

Bessada SM, Barreira JC, Oliveira MBP (2019) Pulses and food security: dietary protein, digestibility, bioactive and functional properties. Trends Food Sci Technol 93:53–68

Boonla O, Kukongviriyapan U, Pakdeechote P, Kukongviriyapan V, Pannangpetch P, Thawornchinsombut S (2015) Peptides-derived from Thai rice bran improves endothelial function in 2K-1C renovascular hypertensive rats. Nutrients 7:5783–5799

Boukar O, Belko N, Chamarthi S, Togola A, Batieno J, Owusu, et al. (2019) Cowpea (*Vigna unguiculata*): genetics, genomics and breeding. Plant Breed 138(4):415–424

Boukar O, Abberton M, Oyatomi O, Togola A, Tripathi L, Fatokun C (2020) Introgression Breeding in Cowpea [*Vigna unguiculata* (L.) Walp.]. Front Plant Sci 11:567425

Chen X, Laudeman TW, Rushton PJ et al (2007) CGKB: an annotation knowledge base for cowpea (*Vigna unguiculata L.*) methylation filtered genomic gene space sequences. BMC Bioinform 8:129

Chen L, Liu MR, Qin C, Meng Y, Zhang J, Wang Y et al (2010) Sources and intake of resistant starch in the Chinese diet. Asia Pac J Clin Nutr 19:274–282

Christou P, McCabe DE, Martinell BJ, Swain WF (1990) Soybean genetic engineering –commercial production of transgenic plants. Trends Biotechnol 8:145–151

Dakora FD, Belane AK (2019) Evaluation of protein and micronutrient levels in edible cowpea (*Vigna Unguiculata* L. Walp.) leaves and seeds. Front Sustain Food Syst 3:70. https://doi.org/10.3389/fsufs.2019.00070

De Leon RC, Torio MAO, Manalo MN, Aguda RM (2013) Isolation, purification and characterization of the major storage protein in cowpea (*Vigna unguiculata*) seed with bioactive peptides exhibiting antiangiotensini-converting enzyme activity. 42nd Annual Convention of the Kimika Ng Pilipinas-Southern Tagalog, University of the Philippines Los Banos, Laguna, pp. 26

de Silva AC, de Freitas Barbosa M, de Silva PB, de Oliveira JP, de Silva TL, Junior DLT, de Moura Rocha M (2021) Health benefits and industrial applications of functional cowpea seed proteins. In: Jimenez-Lopez JC (ed) Grain and seed proteins functionality. IntechOpen. https://www.intechopen.com/chapters/75744,, London. https://doi.org/10.5772/intechopen.96257

Deol JK, Bains K (2010) Effect of household cooking methods on nutritional and anti nutritional factors in green cowpea (*Vigna unguiculata*) pods. J Food Sci Technol 4(7):579–581

Dhanasekar P, Reddy KS (2015) In: Proceedings of the National Conference on Pulses: Challenges and Opportunities under Changing Climatic Scenario, September 20- October 1, 2014, ISPRD, JNKVV, Jabalpur, pp. 316–320

Dhanasekar P, Reddy KS (2017) Role of seed Raffinose family oligosaccharides and Phytic acid in better performance potential of cowpea under water stress conditions. J Basic Appl Plant Sci 1 (2017):106

Dhanasekar P, Souframanien J, Suprasanna P (2021) Breeding cowpea for quality traits: A genetic biofortification perspective. In: Gupta DS, Gupta S, Kumar J (eds) Breeding for enhanced nutrition and bio-active compounds in food legumes. Springer, Cham, pp 157–179. https://doi.org/10.1007/978-3-030-59215-8_7

Dhole VJ, Reddy KS (2016) Association of phytic acid content with biotic stress tolerance in mungbean (*Vigna radiata* L. Wilczek). Phytoparasitica 44:261–267

Doblado R, Frias J, Vidal-Valverde C (2007) Changes in vitamin C content and antioxidant capacity of raw and germinated cowpea (*Vigna sinensis* var. *carilla)* seeds induced by high pressure treatment. Food Chem 101:918–923

Dugje IY, Omoigui LO, Ekeleme F, Kamara AY, Ajeigbe H (2022) Farmers' Guide to Cowpea Production in West Africa; IITA: Ibadan, Nigeria, 2009; Available online: http://www.icrisat.org/tropicallegumesII/pdfs/Cowpea.pdf

EDITS-Cowpea (2022). https://www.jircas.go.jp/en/database/edits-cowpea/introduction. Accessed on 07-08-2022

Eshwarage IS, Herath T, Gunathilake T (2017) Dietary fibre, resistant starch and in-vitro starch digestibility of selected eleven commonly consumed legumes (mung bean, cowpea, soybean and horse gram) in Sri Lanka. Res J Chem Sci 7:27–33

Fabbri ADT, Crosby GA (2016) A review of the impact of preparation and cooking on the nutritional quality of vegetables and legumes. Int J Gastron Food Sci 3:2–11

FAO (2017) The future of food and agriculture–trends and challenges. FAO, Rome

FAO (2020) World Food and Agriculture - Statistical Yearbook 2020, Rome

Felicio MR, Silva ON, Goncalves S, Santos NC, Franco OL (2017) Peptides with dual antimicrobial and anticancer activities. Front Chem 5:5

Fernandes Santos CA, Boiteux LS, Fernandes Santos CA et al (2015) Genetic control and transgressive segregation of zinc, iron, potassium, phosphorus, calcium, and sodium accumulation in cowpea (*Vigna unguiculata*) seeds. Genet Mol Res 14(1):259–268

Flores T, Karpova O, Su X et al (2008) Silencing of GmFAD3 gene by siRNA leads to low alpha-linolenic acids (18:3) of fad3-mutant phenotype in soybean [Glycine max (Merr.)]. Transgenic Res 17:839–850

Fróna D, Szenderák J, Harangi-Rákos M (2019) The challenge of feeding the world. Sustainability 11(20):5816. https://doi.org/10.3390/su11205816

Frota Kde M, dos Santos Filho RD, Ribeiro VQ, Arêas JA. (2015) Cowpea protein reduces LDL-cholesterol and apolipoprotein B concentrations, but does not improve biomarkers of inflammation or endothelial dysfunction in adults with moderate hypercholesterolemia. Nutr Hosp 31 (4):1611–9

Gerrano AS, van Rensburg WSJ, Ventera SL, Shargie NG, Amelework BA, Shimelis HA, Labuschagne MT (2019) Selection of cowpea genotypes based on grain mineral and total protein content. Acta Agric Scand Sect B Soil Plant Sci 69:155–166

Gerrano AS, Mbuma NW, Mumm RH (2022) Expression of nutritional traits in vegetable cowpea grown under various South African agro-ecological conditions. Plan Theory 11:1422

Gonçalves A, Goufo P, Barros A, Domínguez-Perles R, Trindade H, Rosa EA, Ferreira L, Rodrigues M (2016) Cowpea (*Vigna unguiculata* L. Walp), a renewed multipurpose crop for a more sustainable agri-food system: nutritional advantages and constraints. J Sci Food Agric 96(9): 2941–2951

González AM, Yuste-Lisbona FJ, Saburido S, Bretones S, De Ron AM, Lozano R et al (2016) Major contribution of flowering time and vegetative growth to plant production in common bean as deduced from a comparative genetic mapping. Front Plant Sci 7:1940

Gutierrez-Uribe JA, Romo-Lopez I, Serna-Saldivar SO (2011) Phenolic composition and mammary cancer cell inhibition of extracts of whole cowpeas (*Vigna unguiculata)* and its anatomical parts. J Funct Foods 3:290–297

Ha TJ, Lee M-H, Jeong YN, Lee HJ, Han S, Park HC et al (2010) Anthocyanins in cowpea [*Vigna unguiculata* (L.)Walp. ssp. *unguiculata*]. Food Sci Biotechnol 19:821–826

Hachibamba T, Dykes L, Awika J, Minnaar A, Duodu KG (2013) Effect of simulated gastrointestinal digestion on phenolic composition and antioxidant capacity of cooked cowpea (*Vigna unguiculata*) varieties. Int J Food Sci Technol 48:2638–2649

Herniter IA, Muñoz-Amatriaín M, Close TJ (2020) Genetic, textual, and archaeological evidence of the historical global spread of cowpea (*Vigna unguiculata* [L.] Walp.). Legume Sci 2:40–57

Horn L, Shimelis H, Sarsu F et al (2017) Genotype-by-environment interaction for grain yield among novel cowpea (*Vigna unguiculata* L.) selections derived by gamma irradiation. Crop J 6 (3):306–313

Iqbal A, Khalil IA, Ateeq N, Khan MS (2006) Nutritional quality of important food legumes. Food Chem 97:331–335

Jayathilake C, Visvanathan R, Deen A, Bangamuwage R, Jayawardana BC, Nammi S, Liyanage R (2018) Cowpea: an overview on its nutritional facts and health benefits running title: nutritional and health properties of cowpea. J Sci Food Agric 98:4793–4806

Ji J, Zhang C, Sun Z, Wang L, Duanmu D, Fan Q (2019) Genome editing in cowpea *Vigna unguiculata* using CRISPR-Cas9. Int J Mol Sci 20(10):2471

Kamara AY, Ewansiha SU, Ajeigbe HA, Okechukwu R, Tefera H, Boukar O, Omoigui LO (2010) Improvements in grain and fodder yield of cowpea (*Vigna unguiculata*) varieties developed in The Sudan savannas of Nigeria over the past four decades. In: Proceedings of the FifthWorld Cowpea Conference, Saly, Senegal, pp. 171–188

Kanetro B (2015) Hypocholesterolemic properties of protein isolate from cowpeas (*Vigna unguiculata*) sprout in normal and diabetic rats. Procedia Food Sci 3:112–118

Kapravelou G, Martínez R, Andrade AM, Chaves CL, López-Jurado M, Aranda P, Arrebola F, Cañizares FJ, Galisteo M, Porres JM (2015) Improvement of the antioxidant and hypolipidaemic effects of cowpea flours (*Vigna unguiculata*) by fermentation: results of in vitro and in vivo experiments. J Sci Food Agric 95:1207–1216

Khalid II, Elharadallou SB (2012) Functional properties of cowpea (*Vigna ungiculata* L. Walp), and Lupin (*Lupinus termis*) flour and protein isolates. J Nutr Food Sci 3:1–6

Kongjaimun A, Somta P, Tomooka N, Kaga A, Vaughan DA, Srinives P (2013) QTL mapping of pod tenderness and total soluble solid in yardlong bean [*Vigna unguiculata* (L.) Walp. subsp. *unguiculata* cv.-*gr. sesquipedalis*]. EUPHYTICA. 189(2):217–223

Laila O, Murtaza (2014) Seed sprouting: a way to health promoting treasure. Int J Curr Res Rev 6: 70–74

Lattanzio V, Terzano R, Cicco N, Cardinali A, Di Venere D, Linsalata V (2005) Seed coat tannins and bruchid resistance in stored cowpea seeds. J Sci Food Agric 85:839–846

Lazaridi E, Ntatsi G, Savvas D, Bebeli PJ (2016) Diversity in cowpea (*Vigna unguiculata* (L.) Walp.) local populations from Greece. Genet Resour Crop Evol 64:1529–1551

Liyanage R, Perera OS, Wethasinghe P, Jayawardana BC, Vidanaarachchi JK, Sivaganesan R (2014) Nutritional properties and antioxidant content of commonly consumed cowpea cultivars in Sri Lanka. J Food Legum Indian J Pulses Res 27:215–217

Lonardi S, Muñoz-Amatriaín M, Liang Q, Shu S, Wanamaker SI, Lo S, Tanskanen J, Schulman AH, Zhu T, Luo M-C, Alhakami H, Ounit R, Hasan AM, Verdier J, Roberts PA, Santos JR, Ndeve A, Doležel J, Vrána J, Hokin SA, Farmer AD, Cannon SB, Close TJ (2019) The genome of cowpea (*Vigna unguiculata* [L.] Walp.). Plant J 98:767–782

Mahalakshmi V, Ng Q, Lawson M, Ortiz R (2007) Cowpea [*Vigna unguiculata* (L.)Walp.] core collection defined by geographical, agronomical and botanical descriptor. Plant Genet Resour Charact Util 5:113–119

Marques MR, Soares Freitas RAM, Correa CAC, Siguemoto ES, Fontanari GG, Areas JAG (2015) Peptides from cowpea present antioxidant activity, inhibit cholesterol synthesis and its solubilisation into micelles. Food Chem 168:288–293

Marques MR, Maureira ADC, Fontanari GG, Pimenta DC, Soares-Freitas RM, Hirata HM et al (2018) Transport of cowpea bean derived peptides and their modulator effects on mRNA expression of cholesterol-related genes in Caco-2 and HepG2 cells. Food Res Int 107:165–171

Mekonnen TW, Gerrano AS, Mbuma NW, Labuschagne MT (2022) Breeding of vegetable cowpea for nutrition and climate resilience in sub-Saharan Africa: Progress, opportunities, and challenges. Plan Theory 11(12):1583. https://doi.org/10.3390/plants11121583

Mir RR, Kumar A, Pandey MK, Isobe SN (2021) Editorial: achieving nutritional security and food safety through genomics-based breeding of crops. Front Nutr 8:638845

Mohammed SB, Dzidzienyo DK, Umar ML, Ishiyaku MF, Tongoona PB, Gracen V (2021) Appraisal of cowpea cropping systems and farmers' perceptions of production constraints and preferences in the dry savannah areas of Nigeria. CABI Agric Biosci 2:25

Monteiro Junior JE, Valadares NF, Pereira HD, Dyszy FH, Da Costa Filho AJ, Uchoa AF et al (2017) Expression in *Escherichia coli* of cysteine protease inhibitors from cowpea (*Vigna unguiculata*): the crystal structure of a single-domain cystatin gives insights on its thermal and pH stability. Int J Biol Macromol 102:29–41

Muchero W, Diop NN, Bhat PR, Fenton RD, Wanamaker S, Pottorff M et al (2009) A consensus genetic map of cowpea [*Vigna unguiculata* (L.) Walp.] and synteny based on EST-derived SNPs. Proc Natl Acad Sci U S A 106:18159–18164

Muñoz-Amatriaín M, Mirebrahim H, Xu P, Wanamaker SI, Luo M, Alhakami H, Alpert M, Atokple I, Batieno BJ, Boukar O, Bozdag S, Cisse N, Drabo I, Ehlers JD, Farmer A, Fatokun C, Gu YQ, Guo Y-N, Huynh B-L, Jackson SA, Kusi F, Lawley CT, Lucas MR, Ma Y, Timko MP, Wu J, You F, Barkley NA, Roberts PA, Lonardi S, Close TJ (2017) Genome resources for climate-resilient cowpea, an essential crop for food security. Plant J 89:1042–1054

Nedumaran S, Abinaya P, Jyosthnaa P, Shraavya B, Rao P, Bantilan C (2015) Grain Legumes Production, Consumption and Trade Trends in Developing Countries, Working Paper Series 60. ICRISAT, Patancheru, pp 1–64

Oboh HA, Agu K (2010) The effects of various traditional processing methods on the glycemic index and glycemic load of cowpeas (vigna unguiculata). Journal of Food Biochemistry 34:1332–1342

Odeigah PGC, Osanyinpeju AO, Myers GO (1998) Induced mutations in cowpea, *Vigna unguiculata* (Leguminosae). Rev Biol Trop, San José 46(3)

Ojwang LO, Yang L, Dykes L, Awika J (2013) Proanthocyanidin profile of cowpea (*Vigna unguiculata*) reveals catechin-O-glucoside as the dominant compound. Food Chem 139:35–43

Ojwang LO, Banerjee N, Noratto GD, Angel-Morales G, Hachibamba T, Awika JM, Mertens-Talcott SU (2015) Polyphenolic extracts from cowpea (Vigna unguiculata) protect colonic myofibroblasts (CCD18Co cells) from lipopolysaccharide (LPS)-induced inflammation–modulation of microRNA 126. Food Funct 6(1):146–54

Onyeka EU (2007) Glycemic and physiochemical properties of five common cowpea (*Vigna unguiculata*) cultivars in Nigeria. J Food Process Preserv 31:618–631

Owade JO, Abong G, Okoth M, Mwang'ombe AW (2020) A review of the contribution of cowpea leaves to food and nutrition security in East Africa. Food Sci Nutr 8:36–47

Oyewale RO, Bamaiyi LJ (2013) Management of cowpea insect pests. Sch Acad J Biosci Sch Acad J Biosci 1:217–226

Padhi SR, Bartwal A, John R, Tripathi K, Gupta K, Wankhede DP, Mishra GP, Kumar S, Archak S, Bhardwaj R (2022) Evaluation and multivariate analysis of cowpea [*Vigna unguiculata* (L.) Walp] germplasm for selected nutrients—mining for nutri-dense accessions. Front Sustain Food Syst 6:888041. https://doi.org/10.3389/fsufs.2022.888041

Pandey AK, Madhu P, Bhat BV (2019) Down-regulation of CYP79A1 gene through antisense approach reduced the cyanogenic glycoside Dhurrin in [Sorghum bicolor (L.) Moench] to improve fodder quality. Front Nutr 6:122

Pasquet RS, Feleke Y, Gepts P (2021) Cowpea [Vigna unguiculata (L.) Walp.] maternal lineages, chloroplast captures, and wild cowpea evolution. Genet Resour Crop Evol

Pathirana R, Carimi F (2022) Management and utilization of plant genetic resources for a sustainable agriculture. Plan Theory 11:2038. https://doi.org/10.3390/plants11152038

Perera O, Liyanage R, Jayawardana BC, Vidanarachchi JK, Fernando P, Sivaganesan R et al (2016) Modulating effects of cowpea incorporated diets on serum lipids and serum antioxidant activity in Wistar rats. J Natl Sci Found Sri Lanka 44:69

Popova A, Mihaylova D (2019) Antinutrients in plant-based foods: A review. Open Biotechnol J 13:68–76

Punniyamoorthy D, Reddy KS, Dhanasekar SP (2007) IANCAS bulletin, Nov 2007, pp. 299–307

Raina A, Laskar RA, Wani MR, Jan BL, Ali S, Khan S (2022) Gamma rays and sodium Azide induced genetic variability in high-yielding and biofortified mutant lines in cowpea [*Vigna unguiculata* (L.) Walp.]. Front Plant Sci 13:911049. https://doi.org/10.3389/fpls.2022.911049

Santos CAF, Boiteux LS (2013) Breeding biofortified cowpea lines for semi-arid tropical areas by combining higher seed protein and mineral levels. Genet Mol Res 12:6782–6789

Santos CAF, da Costa DCC, da Silva WR, Boiteux LS (2012) Genetic analysis of total seed protein content in two cowpea crosses. Crop Sci 52:2501–2506

Tadele Z (2019) Orphan crops: their importance and the urgency of improvement. Planta 250:677–694

Talabi AO, Vikram P, Thushar S, Rahman H, Ahmadzai H, Nhamo N, Shahid M, Singh RK (2022) Orphan crops: A best fit for dietary enrichment and diversification in highly deteriorated marginal environments. Front Plant Sci 13:839704

The Kirkhouse Trust. http://www.kirkhousetrust.org/

Trehan I, Benzoni NS, Wang AZ, Bollinger LB, Ngoma TN, Chimimba UK et al (2015) Common beans and cowpeas as complementary foods to reduce environmental enteric dysfunction and stunting in Malawian children: study protocol for two randomized controlled trials. Trials 16:520

Udenigwe CC, Rouvinen-Watt K (2015) The role of food peptides in lipid metabolism during dyslipidemia and associated health conditions. Int J Mol Sci 16:9303–9313

Wu X, Islam ASMF, Limpot N, Mackasmiel L, Mierzwa J, Cortés AJ, Blair MW (2020) Genome-wide SNP identification and association mapping for seed mineral concentration in mung bean (Vigna radiata L.). Front Genet 11:656

Xiong S, Yao X, Li A (2013) Antioxidant properties of peptide from cowpea seed. Int J Food Prop 16:1245–1256