Cowpeas: Nutritional profile, processing methods and products—A review

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Abstract
Cowpea (Vigna unguiculata L. Walp) is an important pulse crop grown in sub-Saharan Africa and in parts of Asia and the Americas. It is a major starchy legume consumed widely in sub-Saharan Africa as an affordable source of nutrients including protein. The global production of cowpeas has increased 2.7-folds since 2000. Cowpea is a nutritious food source, rich in protein, digestible and nondigestible carbohydrates, and potassium with very low lipids and sodium content. Cowpeas also contain a number of essential amino acids, and polyphenols with antioxidant activity. The main objectives of this review are to provide information on the nutritional composition of cowpeas, processing techniques used, and consequent effect on nutritional and sensory quality. It focuses on specific processing techniques including traditional processes and the production of cowpea-based ingredients for potential industrial applications. Additionally, an extensive review of typical foods made from cowpeas is included. Recent developments in cowpea research, notably the use of novel processes and product applications, have also been reviewed.

Keywords
cowpeas, nutrients, processing techniques, utilization

1 | INTRODUCTION
Cowpea, Vigna unguiculata L. Walp., belonging to the family Papilionaceae (Fabaceae or Leguminosae), originated in sub-Saharan Africa (Brink & Belay, 2006). Cowpea is grown not only in the tropical lowlands, especially in dry areas, but also in warm temperate regions. Cowpea production in Africa is mainly by subsistent farmers. Seed color is diverse and varies from white, cream to red to black to mottled (Figure 1). The seed coat ranges from thick and loose to thick and tightly adhering to thin, wrinkled, and tightly adhering.

Cowpea is an important pulse/starchy legume crop in sub-Saharan Africa, with parts of Asia and the Americas representing other regions of consumption. The total world production of cowpeas in 2019 was 8.9 million metric tons (Food and Agriculture Organization [FAO], 2021), representing 2.7-folds increase since 2000. Nigeria (40.2%), Niger (26.8%), and Burkina Faso (7.3%) contributed 74.3% of total cowpea production. Cowpea is a nutritious food source rich in protein (~24%), dietary fiber (~11%), and potassium (1112 mg/100 g) while low in lipids (<2%) and sodium (16 mg/100 g) (U.S. Department of Agriculture [USDA], 2021). Cowpea protein has appreciable amounts of essential amino acids except cysteine and methionine.

This review covers cowpea composition, nutritional profile, processing methods including traditional techniques, and physical, functional, and sensory quality attributes of cowpea-based ingredients/foods. The growing interest in plant-based diets as a strategy to reduce intake of foods from animal sources makes this a timely review as it highlights potential novel applications of cowpeas.
The composition and nutritional profile of raw and cooked cowpeas is summarized in Table 1 (USDA, 2021). The composition can vary due to varietal differences, climatic conditions, and agronomic practices.

### 2.1 Proteins, amino acids, and protein classification

Cowpea protein is a rich source of essential amino acids except cysteine and methionine (Table 2), which is typical of other legumes. Table 2 also shows the current amino acid scoring patterns for infants, children, and adults. Although cowpea protein is deficient in sulfur-containing amino acids (cysteine and methionine) for infants, it satisfies the requirements suggested for young children and adults (USDA, 2005). The recommended reference intake of methionine + cysteine is 3.8 g/100 g protein for infants, but cowpeas provide only 2.5 g/100 g protein. However, the recommended reference intake of cysteine + methionine for young children and adults is 2.5 g/100 g protein (USDA, 2005).

Chan and Phillips (1994) extracted defatted California Blackeye flour with 0.1-M Na$_3$PO$_4$, 0.01-N NaOH, and 70% ethanol. The major protein fractions were globulin (66.6% of total) and albumins (24.9%) whiles alkali-extractable glutelins comprised 4.7% and alcohol-soluble prolamins, 0.7%. As shown by SDS-PAGE, globulins had major bands at 65, 60, 56, and 50 kDa and 28–42 kDa minor bands. The albumin fraction contained 99, 91, 32, and 30 kDa subfractions; the glutelin fraction, 101, 68, 31, and 29 kDa; and the prolamin fraction, 105, 62, 50, and 54 kDa subunits. All fractions were rich in aspartic and glutamic acids (9.1–11.8%), with comparable amounts of serine, proline, isoleucine, methionine, tyrosine, and histidine. Albumins contained the highest and glutelins the lowest lysine (9.2 and 7.6 g/100 g protein, respectively). Freitas et al. (2004) reported cowpea protein fractions of 51% globulins, 45% albumins, 3% glutelins, and 1% prolamin.

Teka et al. (2020) confirmed the predominant protein fractions were globulin (38.4–49.1%) and albumin (19.6–22.5%), followed by glutelins (6.4–10.4%) and prolamins (1.0–1.14%). In vitro protein digestibility of cowpea flour ranged between 68.7% and 72.0% and had significant but negative correlation with phytic acid ($r = -0.673$) and globulins ($r = -0.846$) and no correlation with tannins. Except for isoleucine and histidine, the amino acid score of the cowpea was below the FAO/WHO requirement for essential amino acids for infants and preschool children. Tryptophan was the first limiting amino acid, followed by the sulfur-containing amino acids.

### 2.2 Carbohydrates

Cowpeas contain significant content of both digestible and nondigestible carbohydrate (Table 1). Tuan and Phillips (1991) employed gelatinization, amylose/amylopectinase hydrolysis, and glucose analysis for measuring starch concentration in California...
Blackeye #5 seeds. Starch content of 48% (control) and 45–54% (stored seeds, at variable temperature and relative humidity) was observed following different pretreatments. Oluwatosin (1998) reported that starch content was 43–64% in 15 Nigerian cultivars grown in three locations. Mallillin et al. (2008) found 34% dietary fiber (TDF) in cowpea, which was comparable with other legumes. Approximately 80% of TDF was reported as insoluble. Raffinose and stachyose content of 0.45 and 3.30 g/100 g, respectively, were reported in cowpea by Nnanna and Phillips (1988). These galacto-oligosaccharides (GOS), also present in other legumes, have negative reputation as flatulence-causing compounds. Various soaking and processing treatments have been suggested to eliminate or significantly reduce their content. However, galacto-oligosaccharides are now widely recognized as having prebiotic potential, as growth promoters of beneficial intestinal bacteria (Macfarlane et al., 2008).

### 2.2.1 Resistant starch and starch digestibility

Starch is the major component (22%–45%) of legumes and has received recent recommendations as an alternative to cereal or tuber starches due to low digestibility and hence low glycemic index (Ma et al., 2017). Cowpea starch granules exhibit the characteristic C-type crystalline structure of legume starches with oval or ellipse shapes. Hamid et al. (2015) reported granule diameters between 20.9 and 48.6 μm. Apparent amylose content ranged from 15.5% to 39.4% with average amylopectin branch chain length between 21.1 to 23.0 (Hamid et al., 2015; Ratnaningsih et al., 2020).

| TABLE 1 Proximate, minerals, and vitamins composition of raw and cooked cowpeas (per 100 g) |
|---------------------------------------------------------------|-----------------|-----------------|
| **Composition**                                               | **Mature seeds** | **Immature seeds** |
|                                                               | Raw             | Cooked/boiled   | Frozen, cooked |
| Proximate                                                     |                 |                 |                |
| Water (g)                                                     | 11.95           | 70.00           | 66.10          |
| Energy (kcal)                                                 | 336             | 116             | 132            |
| Protein (g)                                                   | 23.52           | 7.73            | 8.49           |
| Total lipid/fat (g)                                           | 1.26            | 0.53            | 0.66           |
| Ash                                                           | 3.24            | 0.94            | 0.99           |
| Carbohydrate (g)                                              | 60.03           | 20.80           | 23.80          |
| Total dietary fiber (g)                                       | 10.6            | 6.5             | 6.4            |
| Total sugars (g)                                              | 6.90            | 3.30            | 4.46           |
| Minerals                                                      |                 |                 |                |
| Calcium (mg)                                                  | 110             | 24              | 23             |
| Iron (mg)                                                     | 8.27            | 2.51            | 2.12           |
| Magnesium (mg)                                                | 184             | 53              | 50             |
| Phosphorus (mg)                                               | 424             | 156             | 122            |
| Potassium (mg)                                                | 1112            | 278             | 375            |
| Sodium (mg)                                                   | 16              | 4               | 5              |
| Selenium (mg)                                                 | 9.0             | 2.5             | 3.4            |
| Zinc (mg)                                                     | 3.37            | 1.29            | 1.42           |
| Vitamins                                                      |                 |                 |                |
| Vitamin C<sup>b</sup> (mg)                                    | 1.5             | 0.4             | 2.6             |
| Niacin (mg)                                                   | 2.06            | 0.50            | 0.73           |
| Pantothenic acid (mg)                                         | 1.50            | 0.41            | 0.21           |
| Total folate (μg)                                             | 633             | 208             | 141            |
| Total choline (mg)                                            | 94.7            | 32.2            | 45.6           |
| Vitamin A, RAE (μg)                                           | 3               | 1               | 4              |
| β-Carotene (μg)                                               | 30              | 9               | 45             |
| Vitamin K (μg)                                                | 5.0             | 1.7             | 36.8           |

Source: USDA (2021).

<sup>a</sup>Thiamin, riboflavin, vitamin B<sub>6</sub>, and vitamin E: all <1.0 mg/100 g in raw, cooked, and frozen-cooked cowpeas.

<sup>b</sup>Total ascorbic acid.
Cowpea starch is rich in resistant starch (RS) fraction, which is the portion of dietary starch that is not rapidly digested and absorbed; instead, RS enters the large intestine where it is fermented partially or wholly (Rengadu et al., 2020). RS was isolated from five cowpea cultivars and assessed for its potential prebiotic effect. The RS content was 9.3–12.1%, and it significantly stimulated the growth of beneficial bacteria. Further, the starch was sufficiently fermentable by the gut microbes under in vitro conditions. Thus, it was concluded that RS could find potential applications as a prebiotic to maintain the digestive system and improve gastrointestinal health (Rengadu et al., 2020).

Ratnaningsih et al. (2020) assessed the effect of 1, 3, or 5 autoclaving-cooling cycles on the physicochemical properties, in vitro starch digestibility, and estimated glycemic index (GI) of cowpea starch. They observed an increase in amylose content, particle size, and thermal properties and decreased pasting temperature and final and setback viscosities due to the autoclave-cooling cycles. The crystalline structure was also modified from C-type into a mixture of B and V-types possibly due to the loss of the amylopectin crystalline region during heating and reassociation of the starch chains within the granules. Further, a decrease in GI was observed, confirming the categorization as a low GI food. The single autoclave-cooling cycle was proposed as a potential processing technique to produce RS with improved thermal stability and low GI for use in functional foods.

### 2.3 Lipids, minerals, and vitamins

The lipid component of cowpea consists largely of cell membrane-bound constituents. Ukhun (1984) reported lipid extracted from cowpea flour as palmitic, 35.2%; linoleic, 27.8%; linolenic, 13.6%; oleic, 13.2%; stearic, 7.4%; and arachidic, 2.78%. Both environment and genotype were significant causes of variation.

Cowpea is potentially an important source of specific vitamins and minerals (Table 1). It is an especially excellent source of thiamin and folate, where 100 g of cowpea provides 57% and over 150% of the daily requirement, respectively, as part of a 2000-kcal diet. Similarly, cowpeas are rich sources of selected of minerals, for example, 100 g provides 41–76% of phosphorous, magnesium, iron, copper, and manganese.

### 2.4 Bioactive compounds and antinutrients

Cowpea dry seeds contain a number of biofunctional non-nutrients, for example, phytic acid/phytates, flavonoids, and tannins (Avanza et al., 2013). Phytic acid, classified as an antinutrient, chelates essential minerals (calcium, iron, and zinc) thereby making them unavailable. Further, it may potentially bind protein and starch; however, it can act as an anticancer agent and may help against heart disease and diabetes (Campos-Vega et al., 2010). Phytate content of 0.5–3.0% has been reported in cowpeas (Avanza et al., 2013; Oboh, 2006).

Tannins have traditionally been considered antinutrient factors. However, in recent years, they have been shown to possess health promoting properties, for example, antioxidant, anticarcinogenic, antimutagenic, and antimicrobial properties. Laurena et al. (1984) reported negative correlation between in vitro protein digestibility (IVD) and condensed tannins in cowpeas. Tannins concentration was 7–14% and 0.1–1% in seed coat and whole seed, respectively, while IVD ranged from ~76% (white and light brown cultivars) to 71–74.5% (dark red and one black cultivars). Avanza et al. (2013) also quantified tannins in cowpeas, showing similar values. Pigmented cowpea seeds

| Essential amino acids | Content (g/100 g) | Reference pattern (g) |
|-----------------------|-------------------|-----------------------|
|                       | Infants | Preschool children | Adults |
| Histidine             | 3.1     | 2.3                 | 1.8    | 1.7 |
| Isoleucine            | 4.1     | 5.7                 | 2.5    | 2.3 |
| Leucine               | 7.7     | 10.1                | 5.5    | 5.2 |
| Lysine                | 6.8     | 6.9                 | 5.1    | 4.7 |
| Methionine            | 1.4     | –                   | –      | –   |
| Cystine               | 1.1     | –                   | –      | –   |
| Met + Cys             | 2.5     | 3.8                 | 2.5    | 2.3 |
| Phenylalanine         | 5.8     | –                   | –      | –   |
| Tyrosine              | 3.2     | –                   | –      | –   |
| Phe + Tyr             | 9.1     | 8.7                 | 4.7    | 4.1 |
| Threonine             | 3.8     | 4.7                 | 2.7    | 2.4 |
| Tryptophan            | 1.2     | 1.8                 | 0.7    | 0.6 |
| Valine                | 4.8     | 5.6                 | 3.2    | 2.9 |

Note: Nonessential amino acid content (g/100 g): arginine (6.9), alanine (4.6), aspartic acid (12.1), glutamic acid (18.9), glycine (4.1), proline (4.5), and serine (5.0).

Source: USDA (2021).

Source: USDA (2005).
have been associated with higher tannins, total phenolic, total flavonoid content, ferric reduction ability, and antilipid peroxidation activities than unpigmented seeds (Apea-Bah et al., 2017; Oboh, 2006). Makoi et al. (2010) evaluated flavonoids and anthocyanins in 45 cowpea accessions. Flavonoids and anthocyanins varied from 1.07 to 7.45 Abs/g and from nondetectable to 0.81 Abs/g on dry-matter basis, respectively.

Antinutritional proteins in cowpeas were reviewed by Roy et al. (2010), who reported that proteins undergo heat denaturation during cooking and thermal processing. Carbohydrate-binding proteins, lectins, are also present in food legumes. Lectins, especially in their native state, bind to the gut wall and thereby interfering with nutrients absorption, which, in severe cases, can slow down growth and may ultimately result in death. However, more recently, lectins have been reported to help prevent obesity, potentially act against tumor cells, and strengthen the immune system.

Trypsin and chymotrypsin enzymes inhibitors in cowpea, which bind to proteases, thereby reducing digestion of proteins and causing pancreatic hypertrophy, have also been reported to possess anticancer and anti-inflammatory properties. Marconi et al. (1993) reported <10 to 47 TIU/mg trypsin inhibitor activity in 22 cowpea cultivars, whereas chymotrypsin inhibitor activity was 6.7 to 56 units/mg. Lectins, assessed as hemagglutination activity (HA), ranged from 13 to 400 HA units.

Frota et al. (2008) reported that cowpea protein isolates (CPIs) and whole cowpea seeds exhibited significant cholesterol-lowering potential in animal models. Guang and Phillips (2012) reported cowpea protein were a source of peptides known to inhibit hypertensive Angiotensin-I converting enzyme.

Figure 2 summarizes approaches for converting dry cowpea seeds to human foods. Typically, cowpeas are consumed as whole cooked or in soups and stews. A major processing challenge is the hard-to-cook (HTC) phenomenon, which develops during improper storage (Bassett et al., 2021; Jombo et al., 2021; Liu et al., 1993; Sefa-Dedeh et al., 1979). In West Africa, besides traditional cooking practices, alkali salts, trona, karwa, and potash are used to overcome HTC effect and soften cowpeas (Uzogara et al., 1988). Similarly, phosphates are added in the soak water during commercial processing of cowpeas.

3 | COWPEA PROCESSING

3.1 | Traditional processing—Whole seed

Traditional processing utilized whole cowpea seeds, flours or meals, and pastes. Over 20 home-cooked foods are made by the Hausa, Yoruba, and Fulani peoples across West Africa, and other ethnic groups in Ghana (Dovlo et al., 1976). The traditional recipes utilize many processes to prepare soups, stews, steamed or fried cakes, and sauces. Other staples or ingredients are also added, for example, maize, gari, rice, sorghum, meats, fish, eggs, and selected vegetables and herbs.

In West Africa, fried cowpea paste, akara, is a popular food. In India, cowpeas are used in papad, a traditional snack food (Bhagirathi et al., 1992), extruded and fried dough—sev (Annapure et al., 1998), idhli, and dhosal/dosa (Enwere & Ngoddy, 1986). In Brazil, acaraje (fried fritter like akara) is sold by street vendors. In the United States (mainly in the southeast), cowpea is sold in raw/dry, canned, or frozen...
forms and consumed primarily as cooked whole seeds. Typically, cowpeas consumption forms part of meals with different vegetables and/or fried corn cakes or baked corn bread.

3.2 | Soaking and boiling

Soaking in water or salt solution (to facilitate softening) is a common first step in cowpea processing. Tuan and Phillips (1991) reported that the HTC defect reduced nutritional quality of California Blackeye #5 cowpea due to lower ileal protein digestibility (67%) than control or non-HTC seeds (77%). Boiling cowpeas for 45 min significantly reduced in vitro protein digestibility, 90-min boiling reversed this effect. According to Torres, Peters, and Montoya (2019), although boiling impacted nutritional indices (nutrient ileal and total tract digestibility, short chain fatty acids), the effect depends on the variety. The apparent ileal proline digestibility increased in boiled red hull cowpeas whereas only apparent total tract cellulose digestibility was increased in pink hull cowpeas. White hull cowpeas generally exhibited higher nutrient apparent ileal and total tract digestibilities.

Torres et al. (2016) had earlier indicated that autoclaving soaked pink and white hull cowpeas for 5 min reduced the comparative difference in in vitro degree of protein hydrolysis from 23% to 9% between the two varieties. This was attributed to conformational changes and reduction of antinutritional factors. A reduction in the degree of starch hydrolysis was also reported in unsoaked, boiled pink and white hull cowpeas whereas an increase was recorded in red hull cowpeas irrespective of treatment (boiling, soaked or unsoaked) (Torres, Muñoz, et al., 2019).

Onwuka (2006) showed significant reduction in trypsin inhibitors (TIA) and phytohemagglutinin (PHA) activity in cowpeas after 13-h soaking, boiling alone, or soaking followed by 40-min boiling. The effect of different processing methods on TIA in various cowpea products is shown in Figure 3. Processing methods also significantly affect raffinose, stachyose, phytic acid, and tannins (Table 3).

Coffigniez et al. (2019) used cytohistological investigations to study structural changes in soaked cowpeas. Thin sections obtained

![FIGURE 3 Effect of processing on trypsin inhibitor activity in cowpea products, assayed as trypsin inhibitor units (TIU). Based on data from Ogun et al. (1989)](image)

| Antinutrient | Raw | Dehulled | Soaked Cold water | Hot water | Moin-moin | Ewa-Ibeji |
|--------------|-----|----------|-------------------|-----------|-----------|----------|
| Phytic acid  | 1.0–1.4 | 1.0–1.3 | 1.0–1.3 | 1.0–1.3 | 0.9–1.2 | 0.9–1.2 |
| Tannins      | 0.05–0.15 | ND* | 0.03–0.09 | 0.04–0.11 | ND | 0.04–0.09 |
| Raffinose    | 0.9–2.8 | 0.6–1.8 | 0.8–1.8 | 0.6–1.8 | 0.5–1.6 | 0.5–1.7 |
| Stachyose    | 2.6–3.5 | 2.4–2.9 | 2.4–2.9 | 2.2–2.8 | 1.8–2.0 | 1.9–2.1 |

Source: Adapted from Ogun et al. (1989).

*Not detected.
from seeds soaked (30°C–95°C) were treated to observe starch, proteins, cellulose, and pectin. Water uptake and dry matter loss were also monitored. Parenchymatous cells of cotyledons changed significantly with soaking temperature and water uptake occurred either through the micropyle (30°C, 60°C) or testa (95°C).

3.3 Germination and fermentation

Germination or fermentation of the hydrated cowpeas can enhance nutritional quality and remove/reduce antinutrients. Nnanna and Phillips (1988, 1990) reported that germination resulted in an increase in the activity of alpha-galactosidase, alpha-amylase, and protease (within 12–24 h). Germination (25°C and 30°C, for 24 h) decreased flatulence by 77% and improved digestibility of protein and starch. Niacin, thiamin, and riboflavin content increased but total protein and carbohydrates were unaffected. Wang et al. (1997) observed that 8-h presoaking and 52-h germination at 25°C significantly reduced galacto-oligosaccharides (GOS) and trypsin inhibitors, with minimal total solids loss. Similar results were reported for cowpea fermentation by Devi et al. (2015).

Madodé et al. (2013) reported that, compared with soaking/boiling cowpeas in alkaline solution, fermentation reduced GOS content significantly. Prinyawiwatkul et al. (1996), using Rhizopus microspores var. oligosporus (Rmo), fermented cowpea at 30°C for 24 h. The dry matter loss and flour pH increased with increasing fermentation time, but proximate composition was unaffected. Fermentation by endogenous organisms rapidly decreased raffinose and stachyose, which, after 15 h, reached undetectable levels, whereas verbascose was reduced by 80% in 24 h. Fermentation significantly increased folacin, niacin, and riboflavin, with a slight decrease in thiamin.

Imbart et al. (2016) reported that germination improved emulsifying properties of cowpea proteins resulting in more stable emulsions as compared with fermentation where microbial degradation of proteins resulted in destabilization of emulsions.

3.4 Flours and air-classified fractions

Diverse culinary practices have led to the removal of the seed coat and hilum/“black-eye” (i.e., decortication) to produce traditional foods. The seed coat is reported to reduce digestibility and cause abdominal distress, especially in children (Enwere & Ngoddy, 1986). The seed coat type is a major consideration for decortication; for example, crowder and blackeye are the two major cowpeas in the United States. Crowder has thick, smooth, loosely adhering seed coats that are easily removed by cracking and aspiration.

In West Africa, decortication of seeds with tightly adhering seed coats is traditionally done using a wet process and rubbing soaked seeds manually or in a mortar. Phillips (1982) reported cotyledon yield of 88% after decortication of crowder-type cowpeas. The cotyledon fraction (CF) had 25.8% crude protein while the seed coat fraction (SCF) had 10.9%. Acid detergent fiber was 2.5% and 45.1% in CF and SCF, respectively. Amino acid profiles of CF and SCF were similar, suggesting the presence of residual cotyledon material in SCF. The CF contained nondetectable content of tannins and 11 TIU/mg while the SCF contained 5.3% tannin and 123 TIU/mg, suggesting that tannins and other phenolics present in the dark brown seed coats were potent trypsin inhibitors.

Physical and functional properties of decorticated cowpeas and flour have been reported widely: color (Jarrard et al., 2007), flours/meals functionality (Akissoé et al., 2021; Kethireddipalli et al., 2002), and particle size, specific gravity, water absorption, pasting viscosity, protein solubility, and thiamin and riboflavin content (McWatters et al., 1988). Table 4 shows selected functional properties of raw, germinated, fermented, and heat-treated cowpea flours. Proximate analysis of raw and preprocessed (whole and defatted) cowpea flours is presented in Table 5.

Gunawardena et al. (2011) reported that coarse (starch-rich) and fine (protein-rich) fractions of milled legume/cereal flours can be separated by air-classification, based on density and particle size. Cloutt et al. (1986) air-classified cowpea flour that was observed to contain a high proportion of small starch. This process produced

| Table 4 | Physical and function properties cowpea flour processed by different treatments |
|---|---|---|
| **Flour samples** | **Bulk density (g/ml)** | **Foam capacity (ml)** | **Crude protein (%)** | **Water absorption capacity (g/g)** | **Oil absorption capacity (g/g)** |
| Raw flour (control) | 0.34 | 141.0 | 25.2 | 2.6 | 10.3 |
| Germinated cowpea flour (29°C–30°C, 72 h) | 0.10 | 145.0 | 26.1 | 1.5 | 5.7 |
| Fermented cowpea flour (29°C–30°C, 72 h) | 0.22 | 110.5 | 25.6 | 1.0 | 3.9 |
| Heat-treated cowpea flour (121°C, 15 min) | 0.30 | 125.0 | 24.7 | 3.4 | 13.8 |

Source: Adapted from Giani (1993).

Dry weight basis.

Crude protein (N x 6.25).
fines with a higher starch content in cowpea flour than other legumes studied.

### 3.5 Cowpea protein concentrates/isolates

Cowpea protein concentrates (CPCs) and CPIs are produced using wet-milling, extraction, precipitation, and concentration processes. Typically, protein concentrates and isolates have 40–60% and >90% protein content, respectively. Aremu (1990) extracted CPC from decorticated cowpea flour at pH 9.0, followed by precipitation at pH 4.0, centrifuging, and drying under vacuum. The CPC had 82% protein or 66% of original proteins. The CPC had protein efficiency ratio (PER) of 2.44 and its amino acid profile was similar to the starting meal; however, the digestibility was significantly improved (89% vs. 79% from meal). Campbell et al. (2016) prepared CPIs from defatted cowpea flour. Denatured CPI was obtained by exposing the CPI to thermal treatment. Cowpea flour slurry was heat-treated prior to protein isolation to obtain glycated CPI (GCPI), which was less susceptible to thermal denaturation than CPI. This effect was attributed to the higher glycation degree and higher carbohydrate content of GCPI as demonstrated by glycoprotein staining of SDS-PAGE gels.

Zhang et al. (2009) isolated cowpea 7S globulin using pH 7.6 sodium phosphate buffer extraction of defatted meals and precipitation with 55% saturated ammonium sulfate. The precipitate was fractionated by gel filtration. The proteins comprised of 50 and 52 kDa subunits as observed with SDS-PAGE. Protein solubility, emulsifying capacity, and thermal stability were higher over a wider pH range.

### 3.6 Extrusion processing

Extrusion processing has been used to prepare cowpea-based nutritious weaning foods. Cowpea flour/meal, alone or in combination with other ingredients, can be extruded to produce snack products and weaning foods. Phillips et al. (1984) extruded cowpea meal at 20–40% moisture content (MC) and 150°C–200°C in a single-barrel extruder and evaluated physical and rheological properties of the extrudates. The highest and lowest expansion ratio was observed at 20% and 40% MC, respectively. The 20% MC/175°C extrudate had the highest expansion and the lowest in bulk density, both considered suitable for a snack product. Texture analysis showed that crisper product was produced at higher temperatures/lower MC, whereas lower temperatures/higher MC produced softer product.

Falcone and Phillips (1988) extruded sorghum and cowpea (67:33) at 20.5–25% MC and 175°C–205°C using a pilot-scale single-screw extruder. The process parameters (MC and temperature) models were derived relating effect on expansion ratio, density, and rheological properties. Temperature was most significant, whereas MC was more important as cowpea ratio increased. Product textures ranged between that of fried corn snacks and pretzel sticks. Extrusion of cowpea blends also have been reported with maize (Sefa-Dedeh & Saalia, 1997) and rice (Marengo et al., 2017).

### 3.7 Innovative processing of cowpeas

The effect of high hydrostatic pressure (HHP) at 200, 400, and 600 MPa and 70°C and 90°C thermal treatments was studied on physicochemical/functional properties of CPIs extracted at pH 8.0 and pH 10.0 (Peyrano et al., 2016). Both thermal and HHP treatments induced unfolding and denaturation of proteins. HHP was found to be more efficient than thermal treatments to enhance gelation and water holding capacities, whereas solubility of CPIs was not affected. It was concluded that functional properties were significantly improved by 70°C thermal and 200-MPa HPP treatments.

Adjei-Fremah et al. (2019) used microfluidization to successfully disintegrate the cotyledon and seed coat of cowpeas to obtain starch, proteins, and fiber fractions. The high pressure and high shear stress of the process induced major structural changes in proteins as observed by reduced intensity of protein bands in SDS-PAGE. Improved swelling and water- and oil-holding capacity, and water extractable total proteins was achieved by microfluidization process; however, mean particle size and bulk density decreased significantly. Microfluidization has potential to produce high-quality functional cowpea flour with improved physicochemical properties for use in diverse food applications with enhanced nutritional properties and health benefits.
4 | COWPEA-BASED FOOD PRODUCTS

4.1 | Akara

Akara, also called koose or ata (deep-fried, ball-shaped fritters), is a commonly consumed cowpea-based breakfast/snack food in Nigeria, Niger, Ghana, and other West African countries. The decorticated and fully hydrated cotyledons are manually ground into a paste. The paste is then diluted with water, whipped (with added salt, onion, and/or pepper) and deep-fried to crisp texture and golden-brown color. Akara is commonly prepared by female street vendors all across West Africa (Lowenberg-DeBoer & Ibro, 2008). Wet-milled hydrated cotyledons produce a superior quality akara compared with dry-milled flour (McWatters, 1983). Phillips and Baker (1987) reported that protein quality of akara is comparable with other heat-processed cowpea foods. Cowpeas with HTC defect produce a poor quality product (McWatters et al., 1988). The frying process significantly reduces the phenolic content and radical scavenging capacity of the product (Apea-Bah et al., 2017).

4.2 | Moin-moin, cowpea stew, and waakye

Moin-moin (Atele), a steamed cowpea paste, is major cowpea dish, especially in Nigeria. Except for whipping, other initial preparation steps are similar to akara. Fish/crayfish or egg may be added along with pepper, onion, tomato puree, and oil. The paste is portioned into tins, or leaves, and steamed until the product sets/gel. Jarrard et al. (2007) reported that cowpea flour makes a firmer, stickier gel than the traditional coarser meal or whole cowpea.

Cowpea stew or Red-Red, a popular dish in Ghana, is served with fried plantain. Cooked whole red cowpeas are combined with a sauce prepared from fish, shrimp, onion, pepper, tomato, palm oil, and salt. Waakye is another popular dish, where cowpeas are boiled with rice and eaten with a meat stew, pepper sauce, and optional vegetables.

4.3 | Baking-composite flours

McWatters (1982) reported that adding cowpea meal into cake doughnut recipes increased the density and color intensity of doughnuts but increased fat absorption and slightly decreased sensory scores. McWatters (1986) observed that up to 30% wheat flour could be replaced with finer cowpea flour in cake doughnut and sugar cookie formulations. McWatters et al. (1995) optimized nutritional and sensory quality of Chinese noodles, muffins, and tortillas using wheat, cowpea, and peanut flour blends. Sharma et al. (1999) studied the rheological properties, baking, and sensory quality of bread, chapatti, cookies, and muffins by 5–25% substitution of wheat flour with cowpea flour. Cowpea flour addition lowered peak viscosity and gelatination time, and loaf volume and sensory acceptability of bread were reduced with >15% cowpea flour, whereas 5% cowpea flour addition improved loaf volume and sensory acceptability of muffins and chapatti, and cookie quality was acceptable up to 15% substitution.

de Souza et al. (2020) prepared and evaluated the quality of gluten-free cookies from a 70:30 blend of rice and cowpea flour. High amylose rice yielded lighter color, lower hardness, and greater sensory preference. The composite flour also provided a good balance of essential amino acids. Dovi et al. (2018) compared sensory profiles of sorghum-cowpea composite biscuits and a commercial refined wheat biscuits. The composite biscuits had stronger flavors (sorghum, beany, and nutty) and were hard, brittle, gritty, dry, and rough textured. However, a substantial proportion of consumers liked the biscuits. The composite biscuits had higher dietary fiber content but similar protein quality as the standard.

Campbell et al. (2016) investigated the sensory acceptability and textural properties of leavened wheat bread and sponge cake fortified with CPIs, denatured and glycated by thermal treatment. Addition of CPI improved water absorption of dough resulting in softer texture but significantly increased bread crumb hardness than the control. Higher sensory acceptability scores were recorded for bread containing glycated CPI.

Beany flavor in legumes, including cowpeas, has been reported to be a negative sensory attribute that can potentially impact consumer acceptance of products made with cowpea composite. One notable exception is Moin-moin, a traditional cowpea product, where beany flavor is preferred by consumers (McWatters, 1990; Okaka & Potter, 1979; Xu et al., 2020). A preliminary steaming treatment of cowpea flour was shown to lessen the beany aroma and flavor of biscuits made with the cowpea flour (McWatters, 1990). Okaka and Potter (1979) reported that acidified water soaking of cowpeas, followed by blanching, reduced the beany flavor of cowpea powders prepared by drum drying. Xu et al. (2020) reported that the use of germination as an extraction pretreatment was effective in reducing the characteristics beany flavor of pulse ingredients.

4.4 | Other cowpea-based products

Other cowpea-based products reported in the literature include the following: griddled snack chips (Kerr et al., 2001), noodles (Ritika et al., 2016), fish nuggets with cowpea flour (Jayasinghe et al., 2013), and chicken nuggets with fermented cowpea flour (Prinyawiwatkul et al., 1997).

Ritika et al. (2016) used composite flours of refined wheat, malted and fermented cowpeas (up to 20%) to produce noodles with improved nutritional quality, acceptable cooking time and textural attributes. Malting and fermentation increased the protein content of the cowpea flour, and this was reflected in the blend in addition to improved water absorption capacity. Composite flour noodles required less cooking time, exhibited lower solid loss, hardness, adhesiveness, and cohesiveness but increased cooking yield. The faster moisture penetration and thus a shorter cooking time of noodles was due possibly to the disruption of gluten network by cowpea flour addition.
Jayasinghe et al. (2013) produced nuggets from minced Tilapia fish with legume flours (lentil, chickpea, and cowpea) added as extenders and to mask unpleasant sensory attributes. Addition of legume flour significantly increased the protein content from 14.72% to 20.28%. Cowpea flour resulted in the highest cooking yield (78.89%), high moisture retention ability (34.15%), low diameter shrinkage (6.42%), good textural properties, and retention of quality observed after 3 months of frozen storage without preservatives.

5 | FUTURE OUTLOOK

Cowpea is an important protein-rich and starchy grain legume in sub-Saharan Africa and parts of Asia and America. Findings from the review reveal that the potential of cowpeas as functional ingredients in developing new and nutritionally enhanced versions of food products has not been fully harnessed. The shifting consumer trends toward sustainable plant-based proteins offer potential to expand cowpea utilization beyond traditional regions of consumption. There are several opportunities to utilize the high protein content, slow digesting starch and dietary fiber in value-added, affordable, and culturally acceptable products such as complementary snacks to help combat persistent protein-energy malnutrition.

CONFLICT OF INTEREST

No conflict of interest exists.

AUTHOR CONTRIBUTION

R.D. Phillips: Conceptualization and preparation of original draft; F.K. Saalia: Revision and technical guidance; and N. Sharon Affrifah: Writing and revision of original draft.

DATA AVAILABILITY STATEMENT

The manuscript reviewed previously published research; therefore, data sharing/accessibility statement does not apply.

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