World Journal of Advanced Research and Reviews

eISSN: 2581-9615 CODEN (USA): WJARAI

Cross Ref DOI: 10.30574/wjarr

Journal homepage: https://wjarr.com/

(Research Article)

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Physicochemical, bioactive compounds and functional properties of flours from three cultivars of dehydrated cowpea seeds (*Vigna unguilata* (L.) Walp.)

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World Journal of Advanced Research and Reviews, 2025, 27(03), 1043-1053

Publication history: Received on 08 August 2025; revised on 14 September 2025; accepted on 17 September 2025

Article DOI: https://doi.org/10.30574/wjarr.2025.27.3.2941

Abstract

Cowpea are a strategic food for combatting food insecurity in the face of strong population growth worldwide, as well as for addressing the sustainability challenges in the livestock sector. Thus, this study examined the physicochemical and functional properties as well as the bioactive compounds of three local cowpea cultivar flours (white, red and black). Regarding the proximal composition, the cowpea flours exhibited a neutral pH (between 7.37 - 7.58) and contained higher amounts of protein (> 21.55 %), crude fiber (> 18.58 %), carbohydrate (> 36.14 %) with lower fat content (< 1.5 %). White and black cowpea flours displayed higher moisture content than the indicated limit (10 %). Regarding minerals, white and black cowpea flours showed higher potassium, phosphorus, and calcium contents compared to red cowpea flour which also did not contain microelements such as sodium, copper, manganese, zinc and iron in trace states. Moreover, the contents of bioactive compounds such as total polyphenol and tannins were found to be low (< 0.06 %) in these flours with a total absence of flavonoids. However, among the anti-nutritional factors, only phytate showed the highest content (> 227 mg/100g) in these cowpea flours. Functional property assessments revealed higher WAC, WSI and HLB values in red and black cowpea flours that varied significantly from 240.57 – 301.04 %, 33.14 – 35.58 % and 3.28 – 4.22, respectively while the bulk density ranged from 0.91 to 1.11 g.cm^{-3}. These results suggest that these dehydrated cowpea flours are promising ingredients for designing nutritionally enhanced foods with low-fat index.

Keywords: Cowpea; Flours; Physicochemical; Bioactive; Functional; Properties

1. Introduction

The cowpea (*Vigna unguilata* (L.) Walp.) is an annual herbaceous plant that can be creeping, climbing or bushy in form [1, 2]. Originally native to West Africa [3, 2, 4], it is one of the most important legume crops worldwide, particularly in sub-Saharan [5, 6]. Cowpeas are a staple food in Africa, Latin America and Asia, where they contribute significantly to food security and nutrition. They are either consumed before maturity as green beans [7, 8, 9], or after maturity as dry cowpea [10, 7]. In Africa, dry cowpeas are a major dietary component in western, central, eastern and southern regions. The total world production of cowpeas in 2019 was 8.9 million metric tons [11], 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. In Côte d'Ivoire, cowpeas are cultivated in the north of the country. However, production is relatively low compared to that of the main food crops, such as yams, cassava, maize and rice [12, 13].

Cowpeas are characterized by their low-fat content, high dietary fibre and protein contents, making them a valuable source of plant protein, especially in low-income populations with limited access to animal protein. They also contain high levels of essential amino acids, such as leucine, lysine, phenylalanine, isoleucine, threonine, methionine and tryptophan [14, 15]. As well as starch and important minerals such as iron and zinc [16, 17, 18, 19]. Given the growing global population and on the challenges of food insecurity particularly in Côte d'Ivoire, combined with sustainability

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concerns in the livestock sector, there is a pressing need to diversify vegetable protein sources. Legumes such as cowpeas with their high nutritional value, represent a promising option for addressing protein-energy deficiencies. They could play an important role in the diversifying diets, helping to combat hunger and malnutrition, especially in rural areas and among low-income communities, and contributing to poverty reduction. However, most studies on Legumes in Côte d'Ivoire have focused on varieties grown in the southeast [12, 13], leaving a gap in the knowledge regarding those cultivated in the northern regions. Thus, to address this gap, the present study examines the nutritional and functional composition of three cowpeas cultivars (white, red and black) grown in the department of Korhogo to identify the most nutrient-rich varieties to inform selection program.

2. Material and Methods

2.1. Plant material

The samples of cowpeas used in this study were purchased at the central market of Korhogo, Côte d'Ivoire. Three cultivars distinguished by seed coat color (white, red and black) were selected. For each cultivar, about 1 kg of grains with good visual quality was collected per cultivar from three market women.

2.2. Methods

2.2.1. Bean seed flours production

For each cowpea variety, 500 g of seeds were rinsed first with tap water, then with distilled water. The cleaned seeds were dried in a ventilated oven at 45 °C for 24 hours, ground using an analytical mill, and sieved through a 100 µm mesh screen. The resulting flours, white cowpea flour (WCF), red cowpea flour (RCF), and black cowpea flour (BCF) were stored in plastic containers at room temperature (25 °C) until use.

2.2.2. pH determination

The pH of cowpea flours was measured immediately on the homogenate at room temperature (25 °C) using a potentiometric technique according to the Official Methods of [20].

2.2.3. Proximate analysis

The proximate composition of the dry cowpea flours from each cultivar was determined according to the procedures of the Association of Official Analytical Chemists (AOAC, 2005). Protein content was determined using the Kjeldahl method with a conversion factor of 6.25. Lipid content was measured by gravimetry method using Soxhlet extraction with *n*-Hexane as the solvent. Moisture content was determined by gravimetry after drying samples in a vacuum oven at 105°C to constant weigh. Crude fibre was quantified by digesting and incinerating the sample residue in a muffle furnace at 550°C for 6 hours. Ash content was determined by gravimetry after incineration of the samples at 550°C for 6h. Carbohydrate content was calculated by difference using the following equation:

$$\text{Carbohydrate (\%)} = 100 - (\text{moisture (\%)} + \text{protein (\%)} + \text{lipid (\%)} + \text{ash (\%)} + \text{crude fibre (\%)}).$$

2.2.4. Determination of mineral Content

Mineral analyses focused on phosphorus (P), potassium (K), calcium (Ca), nitrogen (N), magnesium (Mg), copper (Cu), zinc (Zn), boron (B), iron (Fe) and manganese (Mn). The analyses were performed using an ICAP 61E Plasma spectrometer (Thermo Jarrel Ash Corporation, country). Raw samples were digested in a perchloric nitric acid solution (3:1 mixture of 65% nitric acid and 72% perchloric acid). Mineral concentration was then determined by inductively coupled plasma emission spectrometry.

2.2.5. Determination of bioactive compounds

Extraction process

The extraction of bioactive compounds from white, red and black cowpea flours was carried out according to the method described by [21]. A sample of 4 g of flour was dissolved in 2 mL of n-hexane and 4 mL of methanol/water solution (60:40, v/v). After vortex stirring, the suspension was centrifuged at 5000 rpm for 3 min, and the pellet was re-extracted according to the same procedure. The resulting supernatants were combined, washed with 4 mL of n-hexane to remove residual oil and concentrated using a rotary evaporator.

Total polyphenols

Total polyphenols content was determined using the Folin-Ciocalteu reagent method described by [22] with modification. Briefly, 2.5 mL of the diluted Folin-Ciocalteu reagent (1/10) was added to 5 ml phenolic extract. After stirring, the mixture was left to stand in the dark for 3 min, followed by the addition of 1.5 ml of 20 % Na_2CO_3 to the mixture. The mixture was then shaken and incubated in dark at room temperature (25 °C) for 30 minutes. Absorbance was measured at 725 nm using a spectrophotometer (Shimadzu, Japan). Gallic acid was used as a standard, and the results were expressed in milligrams of equivalent gallic acid per 100g of dry matter (mg GAE/100g DM).

Total flavonoid

The flavonoid content was determined using the aluminium trichloride ($AlCl_3$) calorimetric method proposed by [23]. A standard curve of C quercetin (10–80 µg/mL) was used, and the results were expressed as milligrams of quercetin equivalents per 100 grams of dry matter (mg QE/100 g DM).

Tannins

Tannin content was determined by the method of [24]. One mL extract was mixed with 5 mL of Folin-Dennis reagent in an alkaline medium. Absorbance of the mixture was read at 760 nm, and the tannin content was determined using a calibration curve prepared with tannic acid concentrations.

Antioxidant activity (DPPH)

The antioxidant activity was determined using 1,1-diphenyl-2-picrylhydrazyl (DPPH) radical-scavenging method described by [25], with modifications. Briefly, 200 µl of extract was mixed with 3.8 ml of 70% methanolic DPPH solution. After incubation in the dark for 30 min, absorbance was measured at 517 nm using a spectrophotometer (Ultraspec 200, Pharmacia Biotech Piscataway, NJ) against a methanol blank. The control consisted of 200 µl of acetone/water (80:20, v/v) mixed with 3.8 mL of DPPH solution.

2.2.6. Anti-nutritional factors

Phytates

Phytate content was determined according to the method described [26]). Briefly, 0.25 g of flour was extracted with 12.5 mL of hydrochloric acid (3 %) and incubated in a water bath at 30 °C for 45 min. After incubation, the mixture was centrifuged at 4000 rpm for 10 minutes. To the supernatant solution, 4 mL of $FeCl_3{\cdot}6H_2O$ were added, and the absorbance of the resulting mixture was read at 822 nm using a spectrophotometer.

Oxalate

Oxalate content was determined by the potassium permanganate ($KMnO_4$) titration method described by [20]. One (1) gram of flour was dissolved in 75 mL of 15 N sulfuric acid. The mixture was homogenized for one hour and filtered through Whatman filter paper. An aliquot of 1.25 mL was titrated with 0.005 M of potassium permanganate solution

2.2.7. Determination of functional properties

Flours Bulk density

Bulk density was determined using the procedure of [27]. Fifty grams (50 g) of cowpea flour were placed into a 100 ml graduated measuring cylinder and tapped gently until a constant volume was obtained. Bulk density (g/cm^3) was calculated using the following equation:

Bulk density (g/cm^3) = weight of flour (g) / volume (cm^3) of flour.

Water absorption capacity, water solubility, Index, the oil absorption capacity

The water absorption capacity (WAC), water solubility (WSI) Index and the oil absorption capacity (OAC) were determined according to the method described by [28]. One gram of cowpea flour was dispersed in 10 ml distilled water or refined palm oil in a pre-weighed 20 ml centrifuge tube. The slurry was agitated for 2 min, allowed to stand at room temperature (25 °C) for 30 min, and then centrifuged at 500 rpm for 20 min. The WAC and OAC were expressed as a percentage (%) of the initial flour weight. The WSI was obtained by drying the supernatant after centrifugation and expressing the soluble solids as a percentage of the original flour weight.

Hydrophilic-lipophilic ratio

The hydrophilic-lipophilic ratio (HLR) was calculated using the equation proposed by [29], which consist of dividing water absorption capacity by the oil absorption capacity.

HLR = Water Absorption Capacity (WAC) / Oil Absorption Capacity (OAC)

3. Results and discussion

3.1. pH

The pH values of white, red, and black dry cowpea flours are presented in Table 1. The results showed that, although slightly lower in white cowpea flours (7.37) compared to black (7.50) and red cowpea flours (7.58), pH values were not significantly different ($p > 0.05$). These results corroborate the findings of [30], who also observed a neutral pH in legumes. Similarly, several studies reported that a neutral pH is a common characteristic of legumes [31]. Moreover, pH level plays a crucial role in determining the functional properties of cowpea flours, as it influences the charge of amino acid side groups in proteins. A pH range of 7.37-7.58, which is slightly alkaline and close to neutral, could enhance the functional properties of cowpea flours, particularly their capacity to absorb water, their solubility, emulsifying power, foaming ability, and gelling ability [32].

3.2. Proximate composition

Table 1 showed the proximate composition of the flours from white, red and black dried cowpeas. The moisture content varied significantly from 8.45 ± 1.34 to 16.10 ± 4.10 %. Red cowpea flour showed the lowest value (8.45 ± 1.34 %), followed by black cowpea flour (13.71 ± 4.15 %), while the white cowpea flour showed the highest value (16.10 ± 4.10 %). Moisture content among other intrinsic compositions play an important role in the stability of a flour product, as it directly affects s food products shelf-life [33, 34]. In general, it should be below 10 % for better storage stability of food products. Thus, the high moisture content of white and black cowpea flours (≥10 %) observed in this study suggest insufficient drying, which could reduce their shelf life. By contrast, the low moisture content of red cowpea flour (<10 %) suggested better storage potential, as it can limit physicochemical changes, microbial growth, and enzymatic activity [35, 33].

Protein content differs significantly between flours. The highest value was observed with black cowpea flour (24.93 ± 0.05 %), followed by white cowpea flour (24.26 ± 0.05%) and red bean flour (21.55 ± 0.07 %). Similar results are reported by [36] Reyes et *al.* (2010) and [37] on common cowpea flour. In addition, the protein content of the studied cowpea flours was above 20%, suggesting that they may be potential sources of protein with the ability to compensate for protein deficiencies in certain foods [38, 39]. They could likewise be used to supplement low-protein staple foods.

Lipid contents were low, ranging from 1.04 ± 0.01 to 1.54 ± 0.01 %. Similar results have been reported by [37] in common cowpea cultivars were reported. However, the values in this study were lower than those observed by [40] in three cowpea varieties (3.99 ± 0.06 - 92.50 ± 0.03 %). Such low lipid content found in this study suggests that cowpeas are a suitable food for people with low-fat diets.

As for the crude fibre content, red cowpea flour had a significantly higher value (21.33 ± 0.28%) ($p < 0.05$) than those of white (18.26 ± 0.68%) and black (18.53 ± 0.05%) cowpea flours. These results are consistent with those reported by [41] on different cultivars of carioca and black bean grown in Brazil (17.63 ± 1.63 – 23.36 ± 0.96%) and to those of [42] (17.95 ± 0.39 – 22.07 ± 0.02%) reported on improved dry bean varieties grown in Ethiopia. Furthermore, the high fiber content highlights the potential of cowpeas as a rich source of dietary fiber. Indeed, dietary fibers contribute to satiety and regulate intestinal transit. They also reduce blood cholesterol, help regulate blood sugar and weight management, and promote digestive health and chronic disease prevention [43, 44].

Carbohydrate contents also varied of studied flours differed significantly ($P < 0.05$). Red cowpea flour showed the highest content (43.49 ±1.84%), compared to black (37.36 0.92) and white (36.14 ± 1.31%) seed flours. Consequently, red cowpea flour provided the highest energy value they generate (269.04 ± 7.23 kcal), while white and black flours provided 255.39 ± 5.29 kcal and 260.60 ± 3.84 kcal respectively

Finally, ash contents ranged from 3.70 ± 0.11 to 4.21 ± 0.30 %, with significant differences among flours. These values are comparable to those reported by [41] (3.93 ± 0.00 to 4.39 ± 0.06%) for carioca and black bean cultivars cultivated in Brazil. High ash contents generally reflect higher mineral content, as indicated by [45].

Table 1 Proximate composition of white, red and black cowpea flours

Parameters	**WCF**	**RCF**	**BCF**
pH	7.37 ± 0.20 [a]	7.58 ± 0.10[a]	7.50 ± 0.15[a]
Moisture (%)	16.10 ± 4.10 [c]	8.45 ± 1.34 [a]	13.71 ± 4.15 [b]
Proteins (%)	24.26 ± 0.05 [b]	21.55 ± 0.07 [a]	24.93 ± 0.05 [c]
Lipids (%)	1.54 ± 0.01 [b]	1.04 ± 0.01[a]	1.26 ± 0.08 [c]
Crude fibre (%)	18.26 ± 0.68 [a]	21.33 ± 0.28 [b]	18.53 ± 0.05 [a]
Ash (%)	3.70 ± 0.11 [a]	4.14 ± 0.20 [b]	4.21 ± 0.30 [b]
Carbohydrate (%)	36.14 ± 1.31 [a]	43.49 ± 1.84[b]	37.36 ± 0.92 [a]
Energy (Kcal)	255.39 ± 5.29[a]	269.0.4 ± 7.23 [a]	260.60 ± 3.84 [a]

WCF, RCF and BCF denote to white, red and black cowpea flour respectively; The values with different superscripts within each row are significantly different (p < 0.05)

3.3. Mineral content

Macro and micro element composition of white, red and black dried cowpea flours was analyzed, and the results are presented in Table 2. Significant differences were observed among cultivars (P < 0.05). For macro elements, potassium ranged from 0.29 ± 0.00 (RCF) to 112.61 ± 0.00 mg/100g (BCF); phosphorus, from 8.45 ± 0.00 (RCF) to 16.10 ± 0.00 mg/100g (WCF); calcium, from 0.13 ± 0.00 (RCF) to 45.59 ± 0.00 mg/100g (WCF); magnesium, from 0.02 ± 0.00 (BCF) to 18.95 mg/100g (RCF) and sodium from 0.00 (RCF) to 2.77 ± 0.00 mg/100g (WCF). Overall, WCF exhibited the highest content of macro elements, while RCF had the lowest content. Regarding trace elements, copper, manganese, zinc, and iron were quantified. Only iron was detected in the RCF at a level of 0.01 ± 0.00 mg/100g, whereas the other two flours contained all four trace elements. BCF showed higher concentrations of iron (9.24 ± 0.00 mg/100g) and manganese (3.03 ± 0.00 mg/100g), while WCF had higher levels of copper (0.64 ± 0.00 mg/100g) and zinc (3.06 ± 0.00 mg/100g). These observed differences in macro and trace elements among bean cultivars can be attributed to the botanical and genetic background of the plant and the soil characteristics [46, 47].

Table 2 Mineral composition of white, red and black cowpea flours

Parameters (mg/100g)	**WBF**	**RBF**	**BBF**
Potassium (K)	100.48 ± 0.00[b]	0.29 ± 0.00 [a]	112.61±0,00[c]
Phosphorus (P)	16.10 ± 4.10 [c]	8.45 ± 1.34 [a]	13.71 ± 4.15 [b]
Calcium (Ca)	45.59 ± 0,00[c]	0,13 ± 0,00[a]	45.41± 0 .00[b]
Magnesium (Mg)	13.29 ± 0,00[b]	18,95±0,00[c]	0.02 ± 0.00[a]
Sodium (Na)	2.77± 0,00[c]	0.00[a]	2.24 ± 0,00[b]
Iron (Fe)	5.78 ± 0,00[b]	0.01 ± 0,00[a]	9.24 ± 0.00[c]
Copper (Cu)	0.64 ± 0.00[c]	0.00[a]	0.57 ± 0.00[b]
Manganese (Mn)	1.62 ± 0.00[b]	0.00[a]	3.03 ± 0.00[c]
Zinc (Zn)	3.06 ± 0.00[c]	0.00[a]	2.74 ± 0.00[b]

WCF, RCF and BCF denote to white, red and black cowpea flours respectively; The values with different superscripts within each row are significantly different (p < 0.05).

3.4. Phenolic compounds

Table 3 presents the phenolic compounds of white, red and black cowpea flours. The total polyphenol contents were very low and varied significantly, ranging from 0.03 ± 0.00 to 0.06 ± 0.00 mg GAE/100g in white and black cowpea flours, respectively. However, flavonoids were not detected in any of the studied varieties.

The tannin contents were very low across all samples. These results suggest that the consumption of these cowpea varieties does not pose anti-nutritional problems, as highlighted by [48]. Indeed, tannins are complex polyphenolic compounds, widely distributed in certain cereals, legumes, and forages, with a strong affinity for proteins. Due to these properties, tannins can interfere with digestion by binding to dietary proteins or inactivating digestive enzymes, particularly those involved in protein digestion. Therefore, the low tannin content in the studied flours may improve nutritional value by enhancing nutrient bioavailability and overall digestibility of the seeds [49].

Concerning phytate contents, significant differences were found among flours ($p < 0.05$). The white cowpea had the highest phytate content (270.66 ± 0.36 mg/100g), whereas red and black cowpea flours exhibited similar phytate contents (227.41 ± 1.06 mg/100g and 226.54 ± 2.06 mg/100g). Phytates are a complex class of naturally occurring compounds that can strongly influence the functional and nutritional properties of foods by chelating dietary minerals such as calcium, magnesium, iron, zinc, copper, and manganese, thereby reducing their bioavailability [50, 51]. These minerals are vital for children during growth, as well as for pregnant or lactating women. In addition, phytates have also been reported to inhibit digestive enzymes such as proteases and alpha amylases [52, 53, 54]. To overcome these effects, [55] recommended processing techniques such as soaking, fermentation, germination, and cooking, which can significantly reduce phytate content in the food and improve mineral bioavailability. Nevertheless, despite their anti-nutritional effects, phytates also possess antioxidant activity, which can help reduce the risk of chronic diseases, such as cardiovascular disease and certain cancers [56].

Oxalates are natural compounds found in many plant-based foods, including dried cowpeas. At high concentrations in foods, they may contribute to calcium oxalate kidney stones formation. In this study, oxalate contents varied significantly among flours. The red cowpea flour had the highest value (12.98 ± 0.14 mg/100) ($p < 0.05$) compared to white and black cowpea flours which have similar values (12.64 ± 0.03 mg/100 and 12.48 ± 0.04 mg/100, respectively). The values observed in this study were significantly lower than those reported by [57] for white beans (*Phaseolus vulgaris* L.; 547.9 mg/100 g) and sweet potatoes (*Ipomoea batatas*; 495.6 mg/100 g). Furthermore, oxalates contents in foods can be reduced through food processing methods such as soaking in water prior to cooking, thereby improving mineral absorption and reducing the risk of kidney stone formation.

The studied flours exhibited significantly different antioxidant activities (DPPH assay, $p < 0.05$). White-cowpea flour exhibited the lowest antioxidant activity (39.81 ± 0.36 meq/100g), followed by red cowpea flour (42.12 ± 3.23 meq/100g), whereas black cowpea flour had the highest antioxidant activity (47.08 ± 1.72 meq/100g), The high antioxidant activity observed in red and black cowpea flours can be attributed to their higher phenolic compound contents. Indeed, antioxidants improve the nutritional properties of foods by reducing oxidative stress, thereby contributing to the prevention of chronic diseases. The incorporation of antioxidant-rich flours into food formulations could improve product stability, extend shelf life and increase nutritional value due to their phenolic content [58, 59]. These results are in agreement with previous studies reporting that polyphenols in common beans exhibit antioxidant properties and various biological activities [60].

Table 3 Phenolic compounds of white, red and black bean flours

Parameters	WCF	RCF	BCF
Total phenols mg GAE/100 g	0.03 ± 0.01 ^{a}	0.05 ± 0.01 ^{b}	0.06 ± 0.00 ^{c}
Flavonoids (mg QE/100g)	0.00	0.00	0.00
Tannins (mg TAE/100 g)	0.04 ± 0.01 ^{a}	0.01 ± 0.01 ^{a}	0.01 ± 0.01 ^{a}
Oxalate (mg/100g)	12.64 ± 0.03 ^{a}	12.98 ± 0.14 ^{b}	12.48 ± 0.04 ^{a}
Phytate (mg/100g)	270.66 ± 0.36 ^{a}	227.41 ± 1.06^{b}	226.54 ± 2.06^{b}
Antioxidant activity (meq/100g))	39.81 ± 0.36^{a}	42.12 ± 1.23^{b}	47.08 ± 1.72 ^{c}

WCF, RCF and BCF denote to white, red and black bean flours respectively; The values with different superscripts within each row are significantly different ($p < 0.05$).

3.5. Functional properties

The functional properties analyzed in this study included bulk density, water absorption capacity (WAC), oil absorption capacity (OAC), water solubility index (WSI) and hydrophilic-lipophilic balance (HLB). The results are presented in Table 4.

Bulk density values significantly varied among flours, ranging from 0.92 to 1.11 g.cm^{-3} (P > 0.05). Red cowpea flour exhibited the highest value, while white and black cowpea flours showed similar values. These values were higher than those reported by [40] for cowpea varieties (0.69 - 0.80 g. cm^{-3}). Bulk density values between 0.9 and 1 g/cm^3, as observed in this study, suggest that these flours are relatively heavy, occupying less space per unit of weight but presenting challenges in transportation and packaging, as they would require more packaging material [61].

Water absorption capacity (WAC) differed significantly different among the flours (P < 0.05). The highest value is observed with black cowpea flour (304.01 ± 15.31 %), followed by red cowpea flour (269.76 ± 14.61 %) and white cowpea flour (240.57 ± 28.34 %). By contrast, no significant difference was observed with the water solubility index, which ranged from 33.14 ± 2.1% in white cowpea to 35.58 ± 4.61 in red cowpea flour. The WAC results obtained in this study were considerably higher than those reported by [62] for wheat (113.00 ± 5.65 %,), oat (121.00 ± 3.64 %), corn (169.67 ± 5.09 %) and barley flours (132.15 ± 2.78%). Indeed, the high water absorption capacity of cowpea flours studied may be attributed to their protein content, as protein bind water through hydrophilic retention interactions. This property is particularly valuable for the food industry, where water retention contributes to textural improvement and yield. In addition, these flours could be incorporated into bakery products to improve dough handling and their mechanical properties [63].

Unlike WAC, oil absorption capacity (OAC) did not vary significantly (p > 0.05) among white (81.17 ± 11.16%), red (69.31 ± 3.57%) and black (71.87 ± 0.74%) cowpea flours. However, these values were lower than those obtained by [62] for wheat (108.00 ± 5.00%), oats (102.00 ± 6.12%), corn (101.00 ± 3.03%) and barley (126.00 ± 4.08%).

Differences in oil absorption capacity among the studied flours may be attributed to variations in protein content, particularly the composition of hydrophobic amino acids side chain and the protein structure [64, 65].

The Hydrophilic-lipophilic balance (HLB) is an essential factor in food formulation, especially for emulsions, encapsulations and other dispensing systems. It reflects the ratio between hydrophilic and lipophilic components in a formulation, which influences stability, texture, bioavailability, and organoleptic properties [66, 67]. In this study, HLB values varied significantly from 3.28 ± 0.17 % (for white cowpea flour) to 4.22 ± 0.16% (for black cowpea flour) (P > 0.05). These values, falling between 3 and 4, suggest a higher affinity for water than oil, suggesting that the studied flours are suitable for formulations requiring high water absorption capacity, such as baked and extruded products.

Table 4 Functional properties of white, red and black cowpea flours

Parameters	WCF	RCF	BCF
Bulk density (g.cm^{-3})	0,92 ± 0,00 ^{a}	1,11 ± 0,00 ^{b}	0,91 ± 0,00^{a}
WAC (%)	240.57 ± 28.34 ^{a}	269.76 ± 14.61^{b}	304.01 ± 15.31^{c}
WSI (%)	33.14 ± 2.11^{a}	35.58 ± 4.61^{a}	35.02 ± 1.73^{a}
OAC (%)	81,17 ± 11,16^{a}	69,31 ± 3,57^{a}	71,87 ± 0,74^{a}
HLR	3.28 ± 0.17 ^{a}	3.86 ± 0.17 ^{b}	4.22 ± 0.17 ^{b}

WCF, RCF and BCF denote to white, red and black bean flours respectively; The values with different superscripts within each row are significantly different (p < 0.05).

4. Conclusion

This study revealed significant variations in the composition as well as the physicochemical, nutritional, and functional properties of cowpea flours. White, red and black cowpea flours were found to be rich in protein and crude fiber but poor in lipids. In addition, they exhibited antioxidant activity and contained moderate levels of carbohydrates. In addition, these cowpea varieties were characterized by high levels of phytate and oxalates, but low levels of flavonoids, tannins, and total phenols. Moreover, these flours were rich in potassium, phosphorus and calcium. However, white and red cowpea flours particularly presented higher levels of magnesium. In terms of microelements, the flours of white and black seeds demonstrated significant levels of iron, copper, manganese, and zinc, whereas the red cowpea flour was comparatively poorer in these elements. As for the functional properties, the flours displayed high water and oil absorption capacity, solubility index, and HLB values. These attributes make cowpea flours produced suitable for food formulations aimed at enhancing nutritional quality, particularly enriching protein and dietary fiber contents while maintaining fat content and glycemic index low. However, the high phytate and oxalate levels, which may reduce mineral bioavailability, could be corrected by simple and appropriate processing methods such as soaking, fermentation or cooking.

Compliance with ethical standards

Disclosure of conflict of interest

The authors declare no conflicts of interest

Funding

This study was funded by personal contributions from authors.

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