



Research Article

Pseudocereals: Processing effects on the nutritional and bioactive properties of *Celosia argentea* seed

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Abstract *Celosia argentea* is known for its nutritious leafy vegetable, and its seeds are classified as a pseudocereal. The pseudocereal potential of the seed remained underexplored, due to limited information on the effect of processing on the flour samples. This study evaluated the influence of processing on the nutritional and bioactive properties of *Celosia argentea* seed (CAS) flour. The seed was autoclaved, fermented, germinated, nixtamalized, defatted, and roasted using standard methods. Nutritional and antioxidant properties of CAS samples were determined using standard procedures. Bioactive profiling of CAS methanolic extracts was carried out using GC-MS. Nutritional components determined were protein (13.18-17.18%), fat (2.14-9.66%), crude fibre (1.26-2.13%), ash (2.43-15.22%), carbohydrate (51.93-72.91%), calcium (0.26-0.92 mg/g), magnesium (0.32-0.41 mg/g), sodium (0.94-1.61 mg/g), iron (0.31-2.4 mg/g) and zinc (0.03-0.05 mg/g). The antioxidant properties were total antioxidant capacity (0.93-6.49 mg GAE/g), total flavonoid (1.35-3.34 mg/g), total phenolic (12.52-36.74 mgGAE/g), ferric reducing antioxidant power (0.77-1.73 mg/g), and 1,1-diphenyl-2-picrylhydrazyl (0.36-50.28%). The 58 compounds detected in CAS samples have antioxidant, anti-inflammatory, antimicrobial, and antifungal properties. The protein content of CAS was significantly improved by fermentation and germination. Nixtamalization significantly ($p < 0.05$) increased the ash, calcium, magnesium, sodium, and total antioxidant capacity of CAS. Processed CAS flour is a promising pseudocereal to produce nutrient-dense and bioactive-rich cereal-based products.



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Keywords bioactive, *Celosia argentea*, nutritional, processing, pseudocereal, processing

1. Introduction

Adequate human nutrition is dependent on leafy vegetables due to their numerous micronutrient and food security roles. Some of these leafy vegetables produce seeds, which can also be explored for other food uses. For example, the seed of amaranth has been explored for consumption as a snack and as a major source of gluten-free flour (Solarov et al., 2022). *Celosia argentea* plant is a relished source of leafy vegetables that is widely consumed for its nutritional benefits (Adegbenro et al., 2021). A part of the *Celosia argentea* plant is its seed, which also serves as a means of propagation (Olawuyi et al., 2024). The *Celosia argentea* seed (CAS) has been indicated as a pseudocereal due to its numerous components (Nagar et al., 2022).

Pseudocereals have been mostly explored as alternatives to cereals that belong to the grass family (Poaceae) due to their unique nutraceutical and nutritional properties (Nandan et al., 2024; Zhang et al., 2024). For example, amaranth, quinoa, and buckwheat seeds are well known to be

nutrient-dense and have been found suitable for developing foods void of gluten such as soup, pastries, and noodles (Sofi et al., 2023). *Celosia argentea* seed, derived from a leafy vegetable commonly known as Lagos spinach or “soko yokoto” in Nigeria, is a small, dark seed traditionally underutilized despite its nutritional potential (Ayodele, 2021). So far, CAS use has been limited to folklore preparation of antidiabetic decoction (Duarte et al., 2023; Luo et al., 2024).

Celosia argentea seeds possess promising nutritional and functional properties that make them valuable for the food industry. The seeds are rich in proteins, essential amino acids, unsaturated fatty acids, and micronutrients, including iron and zinc (Ibrahim et al., 2024). Their antioxidant and anti-inflammatory phytochemicals also offer health-promoting benefits, supporting their incorporation into functional foods, flours, and nutraceuticals. Additionally, *C. argentea* seed oil has been explored as a potential edible oil source, while the flour can enhance the nutritional profile of baked and weaning foods (Azeez et al., 2024). These attributes underscore its potential use in tackling malnutrition and developing value-added products, especially in regions where the crop is underutilized.

Despite its potential, several barriers hinder the broader adoption of *Celosia argentea* seeds in mainstream food processing. These include limited agronomic data and standardization in cultivation, low public awareness, lack of commercial-scale processing technologies, and minimal research on its processing and regulatory approval. Furthermore, consumer acceptance is affected by unfamiliarity and cultural preferences. Addressing these challenges through targeted research, food safety assessments, and value chain development is necessary for scaling up the use of *C. argentea* seeds in the food industry.

Pseudocereals, like other cereals, undergo mild and severe processing operations, which depend on the desired product. Processing unit operations, depending on the level of severity, potentially influence the nutritional, antinutritional, and functionality of raw materials (Singh et al., 2023). Processing operations have been adopted to enhance or reduce the bioavailability of micro- and macro-nutrients. Utilisation and nutritional benefit of pseudocereals have been increased by adopting various food processing unit operations such as fermentation, germination, and roasting, among others. As such, CAS can attain its full utilisation domestically and commercially by evaluating the effect of pretreatment unit

operations on the nutritional and bioactive properties of its flour. Hence, our study evaluated the influence of processing on the nutritional and bioactive properties of *Celosia argentea* seed flour.

2. Materials and methods

2.1. Materials

Celosia argentea seed was obtained from local vegetable farmers in Sango market, Saki West, Oyo state, Nigeria. All chemicals used were of analytical grade.

2.2. Raw material preparation

2.2.1. *Celosia argentea* seed preliminary treatment

The matured CAS were separated from the immature seeds and other extraneous materials. The sorted CAS were washed with clean water and allowed to drain in a sieve, followed by being thinly spread on trays. The cleaned and drained CAS were thinly spread on trays and allowed to dry for 2 days at ambient temperature. The dried CAS were subdivided into 8 parts with each weighing 500 g. Each part was subjected individually to nixtamalization, germination, autoclaving, blanching, roasting, fermentation, and defatting, while the last 500 g was stored in the Ziploc bag kept inside a plastic container at ambient temperature.

2.2.2. Nixtamalization of CAS

Nixtamalization of CAS was done following the method of Ogunbusola et al. (2021) with slight modification. Analytical grade Calcium hydroxide (20 g) was dissolved in 2,000 mL of clean water, followed by the steeping of 500 g of CAS before being allowed to boil for 30 minutes. The cooked CAS was drained of water before drying at 50°C for 6 h. The dried CAS were milled into flour, cooled, and sieved with a mesh size of 80 µm. The nixtamalized celosia flour was packaged in a Ziploc bag before being placed in an airtight plastic container at ambient temperature until when needed for analysis.

2.2.3. Germination of CAS

Cleaned CAS was germinated using the method described by Chima and Fasuan (2021) with slight changes. The cleaned CAS was steeped in hot water for 4 h and

immediately spread thinly on a previously cleaned and moist jute bag. The CAS thinly placed on the moist jute bag was well covered with another jute bag which was also kept moist. The jute bags with the CAS were moistened twice a day and allowed to germinate for 8 days at ambient temperature. The germinated CAS were dried at 50°C for 6 h. The radicles and plumules from the germinated CAS were removed by handpicking winnowing before milling into flour. The milled CAS flour was sieved using 80 µm mesh before being packaged in a Ziploc nylon and subsequently placed in an airtight plastic container at ambient temperature.

2.2.4. Autoclaving of CAS

Autoclaving of CAS was done by soaking 500 g of previously cleaned CAS in water for 1 h, autoclaving at 121°C for 15 min, and cooling. The autoclaved CAS was dried at 50°C for 6 h, milled into flour, cooled, and sieved with 80 µm mesh before packaging into Ziploc nylon. The packaged autoclaved CAS flour was placed in an airtight plastic container until required for analysis.

2.2.5. Blanching of CAS

The method of Mandliya et al. (2023) was used for the blanching of CAS with slight modifications. The cleaned CAS was dipped in a hot water bath operating at 80°C for 5 min. Before being ground into flour, the blanched CAS was drained, allowed to cool, and then put in a hot air oven set to 50°C for eight hours. After being sieved using an 80 µm mesh screen, the CAS flour was wrapped in a Ziploc nylon. The blanched CAS flour that was packaged was kept at room temperature in an airtight container.

2.2.6. Roasting of CAS

The cleaned *Celosia argentea* seeds were spread uniformly in pre-heated trays and roasted at 160°C for 25 min. The *Celosia argentea* roasted seed was ground into flour. The flours were then passed through an 80 µm mesh screen, packaged in Ziploc nylon, and stored in an air-tight plastic container for further use.

2.2.7. Fermentation of CAS

The fermentation of CAS was done using the method of Olawoye and Gbadamosi (2020) with modifications. Briefly, the previously cleaned CAS was boiled for 3 h. The boiled

CAS were then transferred into banana leaves wrapped in a sack and allowed to ferment for 72 h. Following fermentation, the seeds were dried for eight hours at 50°C in a hot-air oven. The dried CAS was ground into flour, allowed to cool, sieved through an 80 µm mesh screen, and then sealed in Ziploc nylon and stored in an airtight plastic container until used.

2.2.8. Defatting of CAS

The cold extraction procedure highlighted by Manickam and Kuca (2024) was used to defat *Celosia argentea* flour. The defatted flour was packed in a Ziploc nylon bag and stored in an airtight plastic container on the laboratory shelf.

2.2.9. Untreated sample (control) of CAS

The cleaned and dried CAS was milled to obtain flour. The flour was then passed through an 80 µm mesh screen, packaged in a Ziploc nylon stored in an air-tight plastic container placed at ambient temperature.

2.3. Chemical analysis

2.3.1. Proximate composition

The proximate composition of *Celosia argentea* seed flours—including moisture content, crude protein (determined by the Kjeldahl method), crude fat (solvent extraction), crude fibre, and ash—was analysed following the standard methods of the Association of Official Analytical Chemists (AOAC, 2005). N-free extract = 100 - (% moisture + % crude protein + % crude fat + % crude ash + % crude fiber) was used to calculate the content of nitrogen (N)-free extract.

2.3.2. Mineral determination

The sample ash was dissolved in 10 mL of 2 M HNO₃, boiled for five minutes, and filtered into a volumetric flask. The filtrate was then diluted to 50 mL with distilled water. Magnesium (Mg), manganese (Mn), iron (Fe), and zinc (Zn) concentrations were determined using an atomic absorption spectrophotometer (Model 220GF, Buck Scientific Inc., Norwalk, CT, USA). Standard curves for each mineral were prepared using known concentrations (AOAC, 2005). A Jenway flame photometer was used to measure the sodium levels.

2.3.3. Antioxidant analysis

The procedure of Osunrinade et al. (2024) that utilises

methanol to extract bioactive content was adopted for CAS flour samples. The CAS extracts were used to quantify total phenolic content (TPC), and total flavonoid content (TFC) of CAS as influenced by processing. The Folin-Ciocalteu reagent was used to quantify the TPC of the CAS extract with the use of a garlic acid-fitted standard curve (Osunrinade et al., 2022). Also, the Osunrinade (2021) method was used to evaluate the TFC of CAS extracts spectrophotometrically.

The antioxidant potential of CAS extracts was established by the spectrophotometric measurement of the 1,1-diphenyl-2-picrylhydrazyl (DPPH), ferric reducing antioxidant power (FRAP), and total antioxidant capacity (TAC) as outlined by Azeez et al. (2024).

2.3.4. Profiling of CAS bioactive compounds using GC-MS

Bioactive compounds present in the methanolic extract of processed CAS were profiled using the method described by Azeez et al. (2024). Briefly, 1 μ L of methanolic extract of CAS samples was injected into the Pegasus 4D model of Shimadzu gas chromatography-mass spectrometer (GC-MS) instrument (LECO Corporation, based in St. Joseph, MI, USA) that used a fused silica column and helium carrier gas at a 1 mL/min flow rate. The temperature increase was set at 10°C each minute, and the injector temperature was set at 250°C. By comparing mass spectra with the spectra databases of the National Institute of Standards and Technology, substances were identified. Literature survey was used to establish the bioactivity of detected compounds.

2.4. Data analysis

Analysis of variance (ANOVA) was performed on the gathered data in triplicate using IBM-SPSS (version 21.0). The Duncan's multiple range test was used to distinguish treatment means, and $p < 0.05$ was used to establish significant differences. Software from SAS Institute Inc. (NC, USA) called JMP Pro 17 was used to analyze principal component analysis.

3. Results and discussion

3.1. Proximate composition of CAS flour influenced by processing

Table 1 displays the outcome of how processing techniques affected the proximate composition of *Celosia argentea* seed flour. The moisture content of CAS samples ranged from 5 to 7% with a roasted sample having the lowest moisture content. When compared with the untreated CAS, all pretreatment reduced the moisture content of the CAS. This could be linked to the alteration in the cellular structure of the CAS that led to the ease of removal of moisture. This is like the findings of Olawoye & Gbadamosi (2020), who outlined a decrease in the moisture content of amaranth flour due to autoclaving, blanching, and defatting. More importantly, the moisture content of less than 10% reported in all samples is an indication of the storability of CAS irrespective of the pretreatment used.

The processed *Celosia argentea* seed sample had a protein

Table 1. Proximate composition (%) of processed *Celosia argentea* seed flour

Samples ¹⁾	Moisture	Protein	Fat	Crude fiber	Ash	N-free ext.
IXT	6.99 \pm 0.00 ^{2)ab3)}	15.41 \pm 0.00 ^c	7.04 \pm 0.08 ^c	1.46 \pm 0.02 ^c	14.04 \pm 0.83 ^a	55.06 \pm 0.88 ^c
INA	6.76 \pm 0.01 ^b	15.54 \pm 0.06 ^c	5.67 \pm 0.01 ^f	1.66 \pm 0.01 ^{bc}	5.62 \pm 0.01 ^d	64.76 \pm 0.02 ^b
TOL	7.36 \pm 0.01 ^{ab}	14.79 \pm 0.12 ^d	7.62 \pm 0.10 ^d	1.48 \pm 0.04 ^d	9.93 \pm 0.86 ^c	58.81 \pm 0.81 ^d
CHG	6.78 \pm 0.04 ^b	14.27 \pm 0.12 ^c	7.90 \pm 0.15 ^c	1.69 \pm 0.04 ^b	15.22 \pm 0.61 ^a	54.15 \pm 0.66 ^{ef}
OAS	5.08 \pm 0.96 ^c	15.93 \pm 0.25 ^b	9.66 \pm 0.07 ^a	1.26 \pm 0.09 ^e	12.30 \pm 0.68 ^b	56.38 \pm 0.04 ^d
MER	7.13 \pm 0.04 ^{ab}	17.60 \pm 0.12 ^a	9.04 \pm 0.09 ^b	2.13 \pm 0.04 ^a	11.57 \pm 0.70 ^b	51.93 \pm 0.88 ^f
FTD	6.38 \pm 0.60 ^b	14.84 \pm 0.06 ^d	2.14 \pm 0.12 ^h	1.31 \pm 0.01 ^f	2.43 \pm 0.18 ^e	72.91 \pm 0.23 ^a
RMC	7.53 \pm 0.04 ^a	13.18 \pm 0.19 ^f	3.59 \pm 0.11 ^g	1.58 \pm 0.04 ^c	11.38 \pm 0.24 ^b	62.75 \pm 0.23 ^c

¹⁾IXT, nixtamalized *Celosia argentea* seed flour; INA, germinated *Celosia argentea* seed flour; TOL, autoclaved *Celosia argentea* seed flour; CHG, blanched *Celosia argentea* seed flour; OAS, roasted *Celosia argentea* seed flour; MER, fermented *Celosia argentea* seed flour; FTD, defatted *Celosia argentea* seed flour; RMC, untreated *Celosia argentea* seed flour.

²⁾All values are mean \pm SD (n=3).

³⁾Different superscript letters (^{a-h}) in the same column indicate significant differences ($p < 0.05$).

content ranging from 13.18 to 17.18%; the fermented CAS had the highest protein content, while the untreated CAS had the lowest (13.18%). Generally, CAS samples had significantly higher protein content when compared to the untreated CAS. The high protein content in fermented CAS could be due to the activity of microorganisms that synthesise amino acids from carbohydrates. Hence, fermented CAS can be used to enrich cereal-based or plant-based foods, helping combat protein-energy malnutrition, especially in low-income populations. The protein content of CAS as influenced by pretreatment is in the range of protein content (8.98-18.01%) reported by Olawoye and Gbadamosi (2020) for pretreated amaranth seed.

The fat content of *Celosia argentea* ranged from 2.14-9.66%, where defatted CAS flour had the least fat, while roasted CAS had the highest fat content. Generally, processing increased the fat content of CAS except for the case of defatting. The significant increase in fat extracted from roasted CAS results from the thermal degradation of cellular membranes and structural components during roasting. This process releases bound lipids, enhancing their mobility and facilitating extraction from the flour. A similar result was reported by Olawoye & Gbadamosi (2020), who observed the lowest percentage of fat (1.95%) in defatted amaranth flour. Among the pretreatments, germination resulted in significantly lower fat content in CAS flour. The activity of lipolytic enzymes during germination, which resulted in the breakdown of fat into fatty acids and glycerol, may be the source of this decrease in fat content. Hence, germinated CAS flour could be a source of low-fat flours that are less prone to rancidity, thus enhancing the storage stability and shelf life of products made from the flour without the need for preservatives. The germinated CAS flour could be useful in low-fat diets for individuals with conditions, such as pancreatitis, gallbladder disease, or hyperlipidemia.

The crude fibre content of the processed CAS flour ranged from 1.26-2.13%, where fermented CAS flour had the highest fibre content, while roasted CAS flour had the lowest fibre content. Pretreatments, which included fermentation, germination, and blanching, increased the fibre content of CAS flour. As reported by Adebo et al. (2022), the increase in crude fibre due to fermentation could be due to the production of cellulases and hemicellulases by lactic acid bacteria and yeasts, which degrade grain cell walls, releasing insoluble fibres (cellulose, hemicellulose) that were previously bound

to other compounds. Singh et al. (2015) also reported that fermentation converts insoluble fibres into soluble fibres (e.g., β -glucans, fructans), which are more bio-accessible and measurable as total fibre. During germination amylases and proteases break down starch and proteins, increasing the relative proportion of fibre, while brief heat treatment could soften cell walls, making insoluble fibres (e.g., cellulose) more detectable by breaking matrix bonds (Hübner and Arendt, 2013).

The ash content of nixtamalized, blanched, roasted, and fermented CAS flour was significantly higher than the untreated CAS flour. Blanched CAS flour had the highest ash content (15.22%) while defatted CAS flour had the lowest value (2.43%). The high ash in blanched CAS flour is an indication of post-blanching mineral retention, possibly due to reduced leaching of ash and increased leaching of non-mineral components. The removal of the oil-bound minerals (phospholipids) during defatting could have been responsible for the decrease in the ash content of defatted CAS flour (Grasso et al., 2019). The ash content results of CAS flour obtained in this study are higher than the ash content of whole-grain amaranth flour (2.28-2.53%) reported by De Bock et al. (2021). Higher ash content in CAS flour suggests that the seed is a good source of essential minerals such as calcium, iron, magnesium, and zinc, contributing to bone health, oxygen transport, and immune function when included in food products.

The N-free extract ranged from 51.93-72.91%, with fermentation having the greatest reducing effect on the CAS flour carbohydrate content, followed by blanching and nixtamalization. The significantly lower N-free extract content observed in fermented *Celosia argentea* seeds compared to raw or processed forms can be attributed to the biochemical and microbial mechanisms where lactic acid bacteria (LAB) metabolize available carbohydrates as energy sources, converting them into organic acids and simple sugars. A similar decrease in N-free extract due to fermentation was reported for amaranth seed (Olawoye and Gbadamosi, 2020). As expected, due to the removal of fat components, defatted CAS flour had the highest N-free extract content. The changes in proximate composition, such as increased protein and reduced moisture, are important for improving the storage stability and nutritional value of CAS flour. These improvements can enhance its use in the food and pharmaceutical industries.

3.2. Mineral composition of CAS flour as influenced by processing

Table 2 shows the findings of the mineral content analysis of the processed *Celosia argentea* seed flour. Calcium (0.26-0.92 mg/g), magnesium (0.32-0.41 mg/g), sodium (0.94-1.61 mg/g), iron (0.31-2.4 mg/g), and zinc (0.03-0.05 mg/g) were the minerals identified in the processed CAS flour. Nixtamalized CAS flour had the highest values of calcium, magnesium, and sodium, while the blanched sample had the highest iron content (4.14 mg/g). Nixtamalization enhances mineral content through alkaline infusion, structural modifications, and antinutrient reduction, while the higher iron content due to blanching could be associated with the fact that blanching increases measurable iron primarily by removing inhibitors and the disruption of the CAS cell walls, releasing bound iron from the aleurone layer and bran fractions. The result from these studies was lower when compared with the report of Olawoye and Gbadamosi (2020) who reported the magnesium, sodium, calcium, and iron of processed amaranthus flour to be 0.60-1.02 mg/g, 1.02-2.52 mg/g, 1.03-2.26 mg/g and 3.03-7.13 mg/g respectively. Minerals support the body's anabolic and catabolic functions; thus, the minerals found in processed *Celosia argentea* are nutritionally significant. Additionally, sodium, iron, and calcium are crucial for preventing anaemia, preventing osteoporosis, and managing hypertension, respectively (Martiniakova et al., 2022; Yang et al., 2023), while zinc is essential for immune response, and it plays a key role in cell growth and repair.

3.3. Antioxidant properties of pretreated CAS flour

To assess the antioxidant properties of *Celosia argentea* seed flour produced from different processing methods, various parameters, including total antioxidant capacity, total flavonoid content, total phenolic content, ferric reducing antioxidant power (FRAP), and DPPH, were evaluated, and the results are presented in Table 3. Pre-treatment of CAS significantly ($p<0.05$) influenced all the antioxidant properties studied. The total antioxidant capacity of *Celosia argentea* seed flour ranged from 0.93-6.49 mg GAE/g, where the highest TAC (6.49 mg GAE/g) was obtained from the nixtamalized sample, while the lowest value (0.93 mg GAE/g) was from the roasted sample. Nixtamalization could have increased the TAC by releasing bound antioxidants (phenolics, flavonoids), neutralizing anti-nutrients (tannins, phytates), and generating new antioxidants through Maillard reactions (Gaytán-Martínez et al., 2017). Whereas roasting degrades heat-sensitive phenolic acids (e.g., chlorogenic acid, ferulic acid) and flavonoids, which are primary contributors to antioxidant activity in grains (Mestanza et al., 2023).

Secondary plant compounds called flavonoids have a variety of pharmacological properties, including antiviral, anti-inflammatory, anticancer, and capillary fragility effects (Farhan et al., 2023). The total flavonoid content ranged from 1.35 to 3.34 mg/g, with a significant difference ($p<0.05$) between the unprocessed and processed CAS flour. Among the processed samples, germinated CAS flour had the highest TFC (3.24 mg/g) while roasted CAS flour had the lowest

Table 2. Mineral composition (mg/g) of pretreated CAS flour

Samples ¹⁾	Ca	Mg	Na	Fe	Zn
IXT	0.92±0.00 ^{2)a3)}	0.36±0.00 ^b	1.61±0.00 ^a	0.31±0.00 ^f	0.04±0.00 ^b
INA	0.28±0.00 ^g	0.33±0.00 ^c	1.00±0.00 ^d	0.69±0.00 ^e	0.03±0.00 ^c
TOL	0.49±0.00 ^b	0.41±0.00 ^a	1.10±0.00 ^c	0.19±0.00 ^g	0.05±0.00 ^a
CHG	0.33±0.01 ^d	0.33±0.00 ^c	1.10±0.00 ^c	4.14±0.00 ^a	0.04±0.00 ^b
OAS	0.29±0.00 ^f	0.34±0.00 ^d	1.27±0.00 ^b	0.85±0.00 ^d	0.03±0.00 ^c
MER	0.31±0.00 ^e	0.35±0.00 ^c	1.10±0.00 ^c	2.40±0.00 ^b	0.03±0.00 ^c
FTD	0.26±0.00 ^g	0.32±0.00 ^f	1.22±0.00 ^b	2.20±0.00 ^c	0.04±0.00 ^b
RMC	0.36±0.00 ^c	0.34±0.00 ^d	0.94±0.00 ^c	0.17±0.00 ^h	0.03±0.00 ^c

¹⁾IXT, nixtamalized *Celosia argentea* seed flour; INA, germinated *Celosia argentea* seed flour; TOL, autoclaved *Celosia argentea* seed flour; CHG, blanched *Celosia argentea* seed flour; OAS, roasted *Celosia argentea* seed flour; MER, fermented *Celosia argentea* seed flour; FTD, defatted *Celosia argentea* seed flour; RMC, untreated *Celosia argentea* seed flour.

²⁾All values are mean±SD (n=3).

³⁾Different superscript letters (^{a-h}) in the same column indicate significant differences ($p<0.05$).

Table 3. Antioxidative properties of CAS flour as influenced by pretreatment

Sample ¹⁾	TAC (mg GAE/g)	TFC (mg Quercetin/g)	TPC (mg GAE/100 g)	FRAP (mg/g)	DPPH (%)
IXT	3.93±0.43 ^{2)ab3)}	3.12±0.18 ^c	28.30±0.19 ^a	1.31±0.04 ^{bc}	0.63±0.03 ^g
INA	6.49±0.33 ^a	3.24±0.35 ^b	17.97±2.92 ^b	1.53±0.03 ^{ab}	40.89±0.08 ^c
TOL	3.97±0.47 ^{ab}	3.01±0.24 ^{ab}	17.94±1.40 ^b	1.06±0.01 ^{cde}	42.50±0.57 ^b
CHG	1.83±0.07 ^b	1.54±0.07 ^{cd}	12.52±0.78 ^b	0.77±0.02 ^f	0.36±0.03 ^g
OAS	0.93±0.12 ^b	1.35±0.10 ^d	15.05±3.44 ^b	0.98±0.04 ^{def}	2.52±0.11 ^f
MER	3.18±0.56 ^{ab}	2.86±0.12 ^{ab}	36.74±2.66 ^a	1.73±0.21 ^a	32.85±0.63 ^d
FTD	4.05±0.76 ^{ab}	2.25±0.05 ^{bc}	33.20±3.41 ^a	0.94±0.01 ^{ef}	50.28±0.35 ^a
RMC	4.32±0.79 ^{ab}	3.34±0.43 ^a	31.29±5.32 ^a	1.22±0.05 ^{cd}	8.11±0.10 ^c

¹⁾IXT, nixtamalized *Celosia argentea* seed flour; INA, germinated *Celosia argentea* seed flour; TOL, autoclaved *Celosia argentea* seed flour; CHG, blanched *Celosia argentea* seed flour; OAS, roasted *Celosia argentea* seed flour; MER, fermented *Celosia argentea* seed flour; FTD, defatted *Celosia argentea* seed flour; RMC, untreated *Celosia argentea* seed flour.

²⁾All values are mean±SD (n=3).

³⁾Different superscript letters (^{a-h}) in the same column indicate significant differences (p<0.05).

(1.34 mg/g) value of TFC. The high TFC could be because germination triggers the expression of enzymes like phenylalanine ammonia-lyase (PAL), chalcone isomerase (CHI), and flavonol synthase (FLS), which drive flavonoid synthesis through the phenylpropanoid pathway (Zhang et al., 2022). The result of TFC further explained the reducing effect of roasting, which could be primarily through thermal degradation of polyphenols and oxidative losses that might have occurred during roasting.

The main components of cereal grains' antioxidant capacity are phenolic chemicals, which are also crucial for the prevention and management of degenerative disorders (Fărcaș et al., 2021). The maximum total phenolic compound (TPC) was found in fermented CAS flour (36.74 mgGAE/g), according to changes in TPC as influenced by various treatments. Blanching of CAS had a reducing effect on the TPC. The observed reduction in the total phenolic compound could be the result of some thermal processing-induced phenolic compound degradation. Olawoye and Gbadamosi (2020) also reported the total phenolic content of blanched amaranthus seed to be lower compared to other processing methods.

The FRAP assay quantifies the reducing potential of an antioxidant that produces a coloured ferrous tripyridyl triazine by reacting with a ferric tripyridyl triazine (Fe₃⁺-TPTZ) complex. In general, the existence of chemicals that break the chain of free radicals by donating a hydrogen atom is linked to their reducing characteristics. At low pH, the Fe₃⁺-TPTZ combination is reduced to a blue-coloured

Fe₂⁺-TPTZ (Medalcho et al., 2025). There was a significant difference (p<0.05) in the FRAP value of CAS flour samples based on the various pretreatments. In this study, only fermentation and germination caused a significant increase in the CAS flour ferric reducing antioxidant power, while other processes led to a significant reduction. Fermentation increases FRAP by releasing bound phenolics, while germination increases FRAP by activating enzymes that enhance antioxidant availability. Thermal degradation and leaching are major factors causing FRAP decline during processing (Collins et al., 2024).

A stable free radical molecule, DPPH, is frequently used to evaluate a variety of samples' capacity to scavenge free radicals. It has an adsorption peak at 517 nm and is a stable organic free radical. When an electron or a free radical species is accepted, adsorption vanishes, causing a significant discolouration from purple to yellow (Girish et al., 2023). The scavenging activity of processed CAS flour samples was significantly different at p<0.05. The highest percentage inhibition of the DPPH radical determined for defatted, autoclaved, germinated, and fermented CAS flour was 50.28, 42.50, 40.89, and 32.85%, respectively. The extractability of bioactive antioxidants brought on by thermal processing may be the cause of autoclaving's increased DPPH radical inhibition (Sharma et al., 2022).

3.4. Bioactive compounds detected in pretreated CAS flour

Table 4 presents the bioactive compounds detected in CAS

Table 4. Bioactive compounds detected in CAS flour as influenced by processing, analyzed by GC-MS

S/N	Compound	Retention time (min)	Peak area (%)	Similarity (%)	Sample ¹⁾	Reported activities
1	n-Hexadecanoic acid	15.213	28.38	96	FTD	Antioxidant, anti-inflammatory, antimicrobial, and anticancer activities
		15.031	1.25	98	TOL	
		15.524	48.01	99	IXT	
		15.036	2.51	96	RMC	
		15.026	17.14	98	OAS	
		15.109	4.41	93	CHG	
2	Hexadecanoic acid methyl ester	14.647	6.40	98	FTD	Anti-inflammatory, anti-fibrotic effects.
		14.626	0.31	97	IXT	
		14.626	3.23	97	CHG	
		14.616	23.42	97	INA	
3	Hexadecanoic acid ethyl ester	15.280	8.61	95	INA	Anti-inflammatory properties and anti-fibrotic effects
		15.306	10.55	98	RMC	
		15.301	12.62	97	MER	
		15.348	31.17	99	CHG	
4	10-Methylnonadecane	12.245	1.19	91	RMC	Antimicrobial, antifungal, and antioxidant properties. It is also known to have anticancer, hypocholesterolemic, and nematocidal activities.
		13.329	0.31	91	IXT	
		12.240	1.55	90	MER	
		20.126	3.38	91	CHG	
5	Hexadecane	11.114	0.22	96	IXT	Emulsion stabilization
		11.103	1.11	93	MER	
		11.108	0.93	93	RMC	
		16.282	4.47	94	CHG	
7	9,12-Octadecadienoic acid methyl ester	16.271	5.67	99	FTD	Antioxidant, anti-inflammatory, antimicrobial, anti-cholesterolemic and anti-carcinogenic, antiviral and antifungal.
		16.308	0.36	99	IXT	
		14.626	3.23	97	CHG	
7	69-Octadecenoic acid(Z)-, methyl ester	16.328	5.67	99	FTD	Antioxidant, antibacterial, and antifungal activities, as well as potential anti-inflammatory and anti-cancer properties
		16.359	0.45	98	IXT	
		16.292	6.03	95	INA	
8	9,12-Octadecadienoic acid (Z,Z)-	16.837	32.06	93	FTD	Antioxidant, anti-inflammatory, and antimicrobial properties, as well as being a potential starting material for drug development
		16.712	1.25	94	TOL	
		17.174	28.27	98	IXT	
9	Heptadecane	12.234	4.81	94	INA	Antioxidant and anti-inflammatory properties.
		18.041	4.10	94	CHG	
		13.319	1.00	94	MER	
10	2,4-Di-tert-butylphenol	10.118	0.43	97	IXT	Antibacterial, antifungal, and anticancer effects.
		10.107	2.58	94	INA	
		10.112	1.15	96	MER	
11	Cyclohexadecane	11.020	1.67	94	RMC	Antifungal, antibacterial and antioxidant components
		11.015	3.95	98	INA	
		11.036	1.07	95	IXT	
12	Cis-Vaccenic acid	16.671	0.25	98	MER	Potential anti-inflammatory properties
		16.837	32.06	91	FTD	
		16.712	1.25	95	TOL	
13	6-Octadecenoic acid, methyl ester	16.328	5.67	99	FTD	Antioxidant, antimicrobial, and anti-inflammatory activities, as well as potential anticancer effects
		16.292	6.03	92	INA	
14	Tetratetracontane	14.351	3.23	91	CHG	Hypoglycemic, anti-oxidant, and antibacterial effects.
		13.319	1.00	94	MER	
15	Pentadecanoic acid	15.965	0.20	90	FTD	Protecting cardiometabolic, immune, and liver health, including anti-inflammatory, anti-fibrotic, and anti-cancer effects
		14.056	0.30	96	IXT	

(continued)

S/N	Compound	Retention time (Min)	Peak area (%)	Similarity	Sample	Reported activities
16	9,12-Octadecadienoic acid ethyl ester	16.857 16.852	7.26 1.36	99 98	RMC MER	Anti-inflammatory and other biological activities,
17	9-Octadecenoic acid	16.671 16.998	0.25 3.45	98 93	MER FTD	Anti-inflammatory, antimicrobial, and anti-cancer effects
18	Hexadecanoic acid butyl ester	17.060 17.060	0.82 1.16	98 97	RMC MER	Antifungal, anti-inflammatory, hypocholesterolemic, and hepatoprotective effects
19	(E)-9-Octadecenoic acid ethyl ester	16.982 16.920	4.38 7.26	99 99	CHG RMC	Potential anti-inflammatory and antioxidant properties
20	Ethyl 9-hexadecenoate	16.982 16.915	4.38 8.53	91 95	CHG MER	Antioxidant and anti-inflammatory activities
21	Ethyl oleate	16.915 16.920	8.53 7.26	95 99	MER RMC	Antibacterial, cytotoxic, antioxidant, and anti-inflammatory properties
22	(E)-9-Octadecanoic acid ethyl ester	16.920 16.982	7.26 4.38	99 99	RMC CHG	Potential anti-inflammatory effects
23	9-Octadecene	11.036 11.020	1.07 1.79	93 91	IXT MER	Antibacterial, antidiarrhoeal, analgesic, and cytotoxic effects.
24	9- Hexadecenoic acid methyl ester	14.424	0.28	94	FTD	Antioxidant activities
25	11- Hexadecenoic acid methyl ester	14.424	0.28	93	FTD	A source of bioactive compounds with antimicrobial and antioxidant properties
26	Heptadecenoic acid	15.965	0.20	93	FTD	Potential anti-tumor activity.
27	10-Octadecenoic acid(Z)-, methyl ester	16.365	0.42	99	FTD	Antioxidant, anti-inflammatory, and antimicrobial properties
28	Ar-tumerone	11.954	0.39	93	FTD	Anti-inflammatory, anti-proliferative, and antifungal properties
29	Methyl tetradecanoate	12.546	0.20	95	FTD	Plant metabolite, flavour agent, and fragrance.
30	Cetene	11.020	1.67	96	RMC	Antimicrobial and antioxidant effects
31	1-Heptadecene	11.020	1.67	94	RMC	Antimicrobial activity and it plays a role in fruit ripening and the metabolism of aromatic compounds in animals
32	Carbonic acid, prop-1-en-2-yl trideyl ester	12.245	1.19	93	RMC	Antibacterial and antimalarial activities
33	Bromloacetic acid, pentadecyl ester	13.251	2.04	99	RMC	Antifungal activity
34	Linoleic acid ethyl ester	16.857	0.98	99	RMC	Reduce total and low-density lipoproteins(LDL) cholesterol levels
35	Undecanoic acid, ethyl ester	13.277	2.51	94	CHG	Antifungal, insect repellent, and solvent properties
36	Heptadecane, 2,6-dimethyl-	12.307	2.38	90	CHG	Antibacterial and antimalarial activities.
37	Ethyl tridecanoate	13.277	2.51	90	CHG	Antibacterial and antifungal properties
38	Hentriacontane	13.324	1.77	90	CHG	Immunomodulatory, antioxidant, protects from gamma radiation, antifibrinolytic, adaptogenic, antibacterial activities.
39	2-Pentadecanone,6,10,14-tri-methyl	13.822	5.64	99	CHG	Hypocholesterolemic, anti-inflammatory, antibacterial, anti-nociceptive, antioxidant, and lubricating effects

(continued)

S/N	Compound	Retention time (Min)	Peak area (%)	Similarity	Sample	Reported activities
40	Tricosane	18.980	5.30	95	CHG	Antibacterial, antioxidant, and photocatalytic degradation properties
41	Tettracontane	16.282	4.47	95	CHG	Antimicrobial and antioxidant activities
42	E-15-Heptadecenal	13.246	2.08	91	MER	Antibacterial activity
43	E-14-Hexadecenal	13.226	2.08	91	MER	Antifungal activity, particularly against some phytopathogenic fungi
44	Linoleic acid ethyl ester	16.852	1.36	98	MER	Anti-inflammatory, anti-arthritis, anti-acne, and anti-bacterial effects
45	Linolaidic acid	16.852	1.36	95	MER	Anti-cancer, anti-inflammatory, and antimicrobial effects
46	Phenol,2,6-bis(1,1-dimethylethyl)	10.118	0.43	93	IXT	Antioxidant and stabilizer in various applications
47	Trans-13-Octadecenoic acid, methyl ester	16.359	0.45	98	IXT	Potential antioxidant, anti-inflammatory, and antimicrobial properties
48	D-Limonene	3.751	1.02	96	IXT	Antioxidant, anti-inflammatory, antibacterial, and anti-cancer effects
49	Pentadecanoic acid, 14-methyl,methyl ester	14.626	0.31	97	IXT	Antifungal, antimicrobial, and antioxidant activities, and is a component of food flavour and a lubricant
50	Limonene	3.751	1.02	93	IXT	Antimicrobial, anticancer, antioxidant, and neuroprotective properties
51	10,13-Octadecadienoic acid, methyl ester	16.308	0.36	99	IXT	Antimicrobial, anti-inflammatory, and potential anticancer effects
52	Cis-13-Octadecenoic acid, methyl ester	16.359	0.45	95	IXT	Antiviral, antifungal, and antimicrobial properties.
53	Bis(2-ethylhexyl)phthalate	21.040	0.57	91	IXT	Bis(2-ethylhexyl)phthalate
54	Nerolidol	10.730	1.01	93	TOL	Antimicrobial, antioxidant, anti-inflammatory, and anti-cancer properties
55	9,17-Octadecadienal, (Z)-	16.712	1.25	98	TOL	Antimicrobial properties
56	1,3,3-Trimethyl-2-hydroxymethyl-3,3-dimethyl-4-(3-methylbut-2-enyl)-cyclohexene	16.800	0.45	94	TOL	Antibacterial and antioxidant activities
57	Gingerol	18.995	1.67	93	TOL	Anticancer, antioxidant, antimicrobial, and anti-inflammatory properties.
58	Cyclotetradecane	13.241	3.93	95	INA	Antimicrobial and antiproliferative effects

¹⁾IXT, nixtamalized *Celosia argentea* seed flour; INA, germinated *Celosia argentea* seed flour; TOL, autoclaved *Celosia argentea* seed flour; CHG, blanched *Celosia argentea* seed flour; OAS, roasted *Celosia argentea* seed flour; MER, fermented *Celosia argentea* seed flour; FTD, defatted *Celosia argentea* seed flour; RMC, untreated *Celosia argentea* seed flour.

flour as influenced by processing. A total of 58 bioactive compounds with a library similarity above 90% were identified in CAS flour samples. Specifically, 15 compounds were detected in the unprocessed CAS flour, while the remaining

43 compounds were detected only after processing. Compounds unique to the untreated CAS flour (RMC) included cetene, 1-heptadecene, carbonic acid prop-1-en-2-yl tridecyl ester, bromoacetic acid pentadecyl ester, and linoleic acid ethyl

ester. Most of the compounds detected in the CAS samples exhibited significant health benefits, including antioxidant, anti-inflammatory, antimicrobial, and antifungal properties.

n-Hexadecanoic acid was detected in all CAS samples except the fermented and germinated ones. This compound has been reported to possess various health benefits, including anti-inflammatory, antioxidant, antimicrobial, and anticancer properties (Aparna et al., 2012; Ganesan et al., 2024). The presence of 9,12-octadecadienoic acid methyl ester in defatted, nixtamalized, and blanched CAS samples suggests its potential health benefits, which include anti-inflammatory, antimicrobial, anticholesterolemic, and anticarcinogenic effects (Ayoola et al., 2020; Krishnaveni et al., 2014). Notably, this compound was identified in bread made from whole and refined wheat supplemented with *Celosia argentea* seed flour (Azeez et al., 2024).

Hexadecanoic acid methyl ester, detected in defatted, nixtamalized, blanched, and germinated CAS samples, exhibits therapeutic potential against oxidative stress-related diseases, fibroids, and possesses antioxidant, anti-inflammatory, and other health-beneficial properties (Abubacker and Deepalakshmi, 2013; Shaaban et al., 2021). Nixtamalization facilitated the presence of pentadecanoic acid, 14-methyl-, methyl ester in CAS samples. This compound has demonstrated potential antifungal and antimicrobial effects, along with antioxidant properties, and serves as a food flavour component (Godwin et al., 2015; Momodu et al., 2022). Additionally, pentadecanoic acid has been reported to exhibit anti-obesity effects (Robinson et al., 2024) and anti-inflammatory properties, which may improve insulin sensitivity and reduce the risk of type 2 diabetes (Robinson et al., 2024; Venn-Watson and Schork, 2023). Furthermore, Trieu et al. (2021) identified pentadecanoic acid as a reliable biomarker for dairy fat intake, with an inverse association with cardiometabolic disease risk.

Hexadecanoic acid butyl ester, which has been reported to exhibit antibacterial, anticancer, and anti-inflammatory properties, was detected in germinated, untreated, fermented, and blanched CAS samples. The hexadecane compound, present in nixtamalized, fermented, untreated, and blanched CAS samples, has demonstrated antibacterial and antioxidant activities (Shaaban et al., 2021). Additionally, 10-methylnonadecane, identified in untreated, nixtamalized, fermented, and blanched CAS samples, has been reported to possess antimicrobial and antioxidant properties. This compound has also been

associated with other biological effects, including antiviral, anticancer, hypocholesterolemic, and neurostimulant activities (Kumosani et al., 2024).

Linoleic acid ethyl ester, which has been reported for its significant health benefits in reducing total low-density lipoprotein (LDL) cholesterol (Huang et al., 2010), was detected in both untreated and fermented CAS samples. Trisocane, a straight-chain alkane hydrocarbon found in various plant extracts, exhibits antimicrobial activity and antioxidant properties (Baltacı et al., 2022). This compound was detected only in the blanched CAS sample. Additionally, hentriacontane, which has been reported to possess pharmacological effects such as anti-inflammatory, anti-tumour, and antimicrobial activities (Hamed et al., 2025), was also found exclusively in the blanched CAS sample. In contrast, the autoclaved CAS sample contained gingerol, a major bioactive compound in ginger (Dalsasso et al., 2022). Gingerol has been associated with numerous potential health benefits, including anticancer, antioxidant, antimicrobial, and anti-inflammatory effects (Zhang et al., 2021).

4. Multivariate analysis of the influence of processing on proximate, mineral, and antioxidant properties of CAS flour

Multivariate analysis using principal component analysis is a veritable tool to establish the relationship between dependent and independent variables (Osunrinade et al., 2023). Presented in Table 5 is the summary of principal component analysis showing the percentage variance contributed by each principal component. The first two components accounted for over 50% of the variance, while the first four components described

Table 5. Principal components of multivariate analysis for influence of processing on CAS flour

Number	Eigenvalue	Variance (%)
1	4.646288	29.039
2	3.520447	22.003
3	2.91173	18.198
4	1.722683	10.767
5	1.511708	9.448
6	1.161904	7.262
7	0.525241	3.283

80% of the total variation in the influence of processing methods on the proximate, mineral, and antioxidant properties of CAS flour.

Visibly from Fig. 1, the biplot indicated that all the antioxidants' properties were positively correlated with fermented, germinated, autoclaved and untreated CAS flour as they were all on the positive side of the first principal component. Interestingly, the first principal component had the crude fibre showing a positive correlation with all the antioxidant properties evaluated. The positive correlation of the crude fibre to antioxidant properties could be attributed to the high percentage of antioxidant potential in the bran and aleurone layers of grains, which contribute significantly to the fibre content.

The biplot (Fig. 1) established the influence of nixtamalization on grains by having ash, calcium, magnesium, sodium, and protein on the positive side of the second principal component, which also has the nixtamalized sample (IXT). Being on the same side of these parameters is an indication of correlation, which indicates the influence of nixtamalization on the mineral and protein content of the CAS flour. However, the negative side of the second principal component was iron, showing a correlation with roasted and blanched CAS flour.

As such, roasting and blanching are the two-unit operations that improve the quantity of iron detectable in CAS flour.

5. Conclusions

Processing methods used in this study significantly influenced the nutritional and bioactive components of *Celosia argentea* seed flour. The protein content of CAS was significantly improved by fermentation and germination, while N-free extract content was reduced. All the processing methods increased the fat content except defatting. Nixtamalized CAS flour had the highest values of calcium, magnesium, and sodium, while the blanched sample had the highest iron content. Nixtamalization increased the total antioxidant capacity of CAS flour, while the total flavonoid content, total phenolic content, and ferric-reducing antioxidant power were significantly increased by fermentation and germination. GC-MS analysis detected 58 bioactive compounds, which have been reported to possess antioxidant, anti-inflammatory, antimicrobial, and antifungal properties. As such, processed CAS has the potential as a viable pseudocereal for the production of nutrient-dense and bioactive-rich cereal-based products.

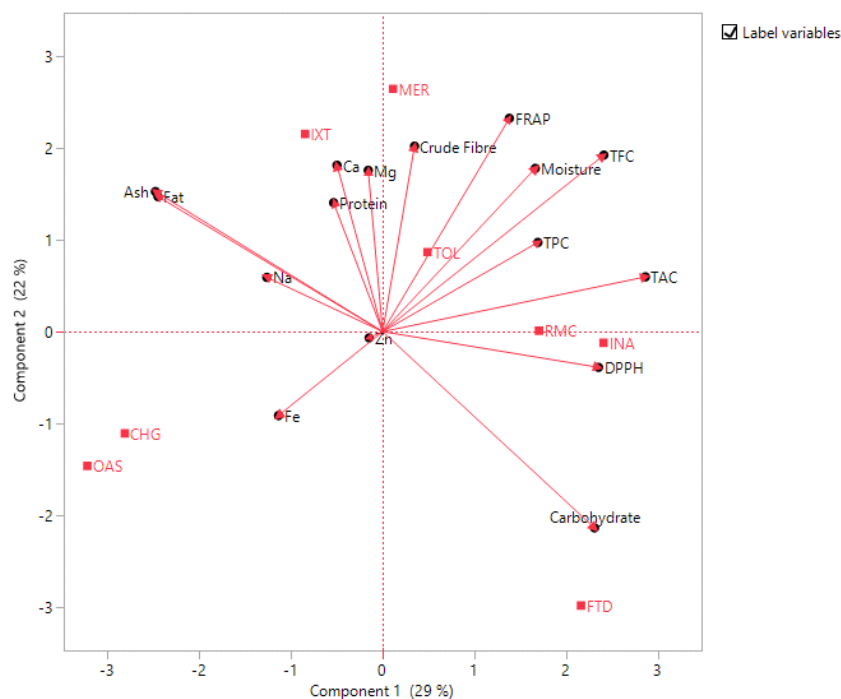


Fig. 1. Biplot showing the influence of processing on proximate, mineral and antioxidant properties of CAS flour.

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Conflict of interests

The authors declare no potential conflicts of interest.

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Ethics approval

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References

- Abubacker MN, Deepalakshmi T. *In vitro* antifungal potential of bioactive compound methyl ester of hexadecanoic acid isolated from *Annona muricata* Linn (Annonaceae) leaves. *Biosci Biotechnol Res Asia*, 10, 879-884 (2013)
- Adebo JA, Njobeh PB, Gbashi S, Oyedeji AB, Ogundele OM, Oyeyinka SA, Adebo OA. Fermentation of cereals and legumes: Impact on nutritional constituents and nutrient bioavailability. *Fermentation*, 8, 63-71 (2022)
- Adegbenro AA, Salawu SO, Akindahunsi AA. Antioxidant activities of *Celosia argentea* Linn and *Gongronema latifolium* Benth and the antihyperlipidemic effect of the vegetable supplemented diets on fat induced hyperlipidemic rats. *J Food Meas Characteriz*, 15, 425-436 (2021)
- AOAC. Official Method of Analysis. 18th ed. AOAC, Washington DC, USA (2005)
- Aparna V, Dileep KV, Mandal PK, Karthe P, Sadasivan C, Haridas M. Anti-inflammatory property of n-hexadecanoic acid: Structural evidence and kinetic assessment. *Chem Biol Drug Design*, 80, 434-439 (2012)
- Ayodele OP. Growth, yield and nutritional quality of Lagos spinach (*Celosia argentea* L.) as influenced by the density of goat weed (*Ageratum conyzoides* L.). *J Plant Protec Res*, 61, 18-25 (2021)
- Ayoola AA, Ekunseitan DA, Muhammad SB, Oguntoye MA, Adejola YA. Phytochemicals analysis and GC-MS determination of ethanolic extracts of *Azadirachta indica* and *Mangifera indica* stem bark and their biological potentials. *Pac J Sci Technol*, 21, 219-222 (2020)
- Azeez LA, Babalola KA, Osunrinade OA. Antioxidant properties, antidiabetic activity, and GC-MS phytochemical analysis of wheat-based bread fortified with *Celosia argentea* seed flour. *CRAS*, 11, 27-38 (2024)
- Baltacı C, Öz M, Fidan MS, Üçüncü O, Karataş ŞM. Chemical composition, antioxidant and antimicrobial activity of *Colchicum speciosum* Steven growing in Türkiye. *Pakistan J Agric Sci*, 59, 33-42 (2022)
- Chima JU, Fasuan TO. Antioxidants, nutritional, antinutrients and functional characteristics of black turtle bean (*Phaseolus vulgaris*): Synergistic and antagonistic interrelationship of epigeal germination periods. *Nutr Food Sci*, 51, 1029-1050 (2021)
- Collins A, Santhakumar A, Latif S, Chinkwo K, Francis N, Blanchard C. Impact of processing on the phenolic content and antioxidant activity of *Sorghum bicolor* L. Moench. *Molecules*, 29, 3626-3638 (2024)
- Dalsasso RR, Valencia GA, Monteiro AR. Impact of drying and extractions processes on the recovery of gingerols and shogaols, the main bioactive compounds of ginger. *Food Res Int*, 154, 111043 (2022)
- De Bock P, Daelemans L, Selis L, Raes K, Vermeir P, Eeckhout M, Van Bockstaele F. Comparison of the chemical and technological characteristics of wholemeal flours obtained from amaranth (*Amaranthus* sp.), Quinoa (*Chenopodium quinoa*) and Buckwheat (*Fagopyrum* sp.) seeds. *Foods*, 10, 651-661 (2021)
- Duarte GM, de Araújo FEA, da Rocha JMC, Idalina Neta F, do Rego ACM, Araújo Filho I, Pinheiro FI, de Azevedo EP, Cobucci RN, Guzen FP. Neuroprotective potential of seed extracts: Review of *in vitro* and *in vivo* studies. *Nutrients*, 5, 2502-2513 (2023)
- Fărcaș A, Drețcanu G, Pop TD, Enaru B, Socaci S, Diaconeasa Z. Cereal processing by-products as rich sources of phenolic compounds and their potential bioactivities. *Nutrients*, 13, 3934-3942 (2021)
- Farhan M, Rizvi A, Aatif M, Ahmad A. Current understanding of flavonoids in cancer therapy and prevention. *Metabolites*, 13, 481-492 (2023)
- Ganesan T, Subban M, Christopher Leslee DB, Kuppannan SB, Seedeve P. Structural characterization of n-hexadecanoic acid from the leaves of *Ipomoea eriocarpa* and its

- antioxidant and antibacterial activities. *Biomass Convers Biorefinery*, 14, 14547-14558 (2024)
- Gaytán-Martínez M, Cabrera-Ramírez ÁH, Morales-Sánchez E, Ramírez-Jimenez AK, Cruz-Ramírez J, Campos-Vega R, Velazquez G, Loarca-Pina G, Mendoza S. Effect of nixtamalization process on the content and composition of phenolic compounds and antioxidant activity of two sorghums varieties. *J Cereal Sci*, 77, 1-8 (2017)
- Girish YR, Sharath Kumar KS, Prashantha K, Rangappa S, Sudhanva MS. Significance of antioxidants and methods to evaluate their potency. *Mat Chem Horiz*, 2, 93-112 (2023)
- Godwin A, Akinpelu BA, Makinde AM, Aderogba MA, Oyedapo OO. Identification of n-hexane fraction constituents of *Archidium ohioense* (Schimp. Ex Mull) extract using GC-MS technique. *Br J Pharmaceut Res*, 6, 366-375 (2015)
- Grasso S, Omoarukhe E, Wen X, Papoutsis K, Methven L. The use of upcycled defatted sunflower seed flour as a functional ingredient in biscuits. *Foods*, 8, 305-314 (2019)
- Hamed AR, El-Rashedy AA, Nabih HK, Abdelmohsen MM, Hassanein HD, Abdelshafeek KA, Elsayed WM. Laboratory investigation of chemical constituents and anti-inflammatory activity of *Putranjiva roxburghii* Hexane fraction based on combined docking and molecular dynamics simulation study. *Chem Afr*, 8, 1801-1815 (2025)
- Huang CB, George B, Ebersole JL. Antimicrobial activity of n-6, n-7 and n-9 fatty acids and their esters for oral microorganisms. *Arch Oral Biol*, 55, 555-560 (2010)
- Hübner F, Arendt EK. Germination of cereal grains as a way to improve the nutritional value: A review. *Crit Rev Food Sci Nutr*, 53, 853-861 (2013)
- Ibrahim IM, Abubakar S, Sulaiman AM, Nkemakonam MO, Ndukaire VO. Assessment of nutraceutical profiles and FTIRS analysis of *Celosia argentea* (L.) aqueous leave extract. *Trends Pharmaceut Sci*, 10, 27-39 (2024)
- Krishnaveni M, Dhanalakshmi R, Nandhini N. GC-MS analysis of phytochemicals, fatty acid profile, antimicrobial activity of *Gossypium* seeds. *Int J Pharm Sci Rev Res*, 27, 273-276 (2014)
- Kumosani TA, Alnefayee A, Barbour E, Qari M, Ahmed T, Moselhi SS. Identification of bioactive ingredients of traditional medicinal plants *Psiadia arabica* Jaub. *Tamarix articulata*, *Terminalia arjuna* and *Rhazya stricta* by GC-MS in Saudi Arabia. *Pharmacog Res*, 16, 28-37 (2024)
- Luo Y, Xu Y, Zhang H, Zhang J, Qin X, Jin S. *Celosia cristata* L.: A review of its traditional uses, phytochemistry, pharmacology, toxicology, and quality control, along with network pharmacological analysis of its components and targets. *J Ethnopharmacol*, 12, 17-26 (2024)
- Mandliya S, Majumdar J, Misra S, Pattnaik M, Mishra HN. Evaluation of dry microwave and hot water blanching on physicochemical, textural, functional and organoleptic properties of Indian gooseberry (*Phyllanthus emblica*). *J Food Meas Characteriz*, 17, 2881-2891 (2023)
- Manickam RC, Kuca K. Non-edible fruit seeds: Nutritional profile, clinical aspects, and enrichment in functional foods and feeds. *Crit Rev Food Sci Nutr*, 64, 13298-13317 (2024)
- Martiniakova M, Babikova M, Mondockova V, Blahova J, Kovacova V, Omelka R. The role of macronutrients, micronutrients and flavonoid polyphenols in the prevention and treatment of osteoporosis. *Nutrients*, 14, 523-535 (2022)
- Medalcho TH, Ali KA, Augchew ED. Effects of spices mixture and cooking on antioxidant activity in Ethiopian spicy hot red pepper powder. *Scientific Reports*, 15, 5203 (2025)
- Mestanza M, Mori-Culqui PL, Chavez SG. Changes of polyphenols and antioxidants of arabica coffee varieties during roasting. *Front Nutr*, 10, 75-84 (2023)
- Momodu IB, Okungbowa ES, Agoreyo BO, Maliki MM. Gas chromatography-mass spectrometry identification of bioactive compounds in methanol and aqueous seed extracts of *Azanza garckeana* fruits. *Nigerian J Biotechnol*, 38, 25-38 (2022)
- Nagar P, Engineer R, Rajput K. Review on pseudo-cereals of India. *Pseudocereals*, 151, 87-96 (2022)
- Nandan A, Koirala P, Tripathi AD, Vikranta U, Shah K, Gupta AJ, Agarwal A, Nirmal N. Nutritional and functional perspectives of pseudocereals. *Food Chem*, 2024, 13907 (2024)
- Ogunbusola EM, Jaiyeoba C, Alabi O, Sanni TA, Araoye K, Ajayi OP. Characterization and utilization of nixtamalised rice flours in the production of cake. *Food Res*, 5, 127-133 (2021)
- Olawoye B, Gbadamosi SO. Influence of processing on the physiochemical, functional and pasting properties of Nigerian *Amaranthus viridis* seed flour: A multivariate analysis approach. *SN Appl Sci*, 2, 607-618 (2020)
- Olawuyi OJ, Misbahudeen HL, Odimayo OJ, Faneye AO, Olowe OM, Akanmu AO. Characterization of *Celosia argentea* Linn. germplasm using ISSR markers. *Studia Universitatis Babeş-Bolyai, Biologia*, 69, 16-28 (2024)
- Osunrinade O, Babalola JO, Adeoti OA, Raji AO. Protein, energy and antioxidant dense flaked breakfast cereal by response surface optimisation of composite flour components (yellow maize, soybean and mango peel). *CRPJFST*, 16, 30-49 (2024)
- Osunrinade OA. Identification and characterisation of flavourants associated with Ofada rice (*Oryza sativa*

- Linnaeus) paddy pre-treatments. University of Ibadan, Ibadan, Nigeria, p 50-51 (2021)
- Osunrinade OA, Phillips A, Alabi A. Physical properties, proximate composition and sensory acceptability of gluten-free cookies from sweet potato using shea butter as shortening. *Acta Per Tech*, 54, 165-175 (2023)
- Osunrinade OA, Taiwo OB, Adedokun SO. Anti-oxidative and sensory properties of rice cooked with *Thaumatococcus danielli* leaf extracts. *J Nutr*, 8, 1-8 (2022)
- Robinson MK, Lee E, Ugalde-Nicalo PA, Skonieczny JW, Chun LF, Newton KP, Schwimmer JB. Pentadecanoic acid supplementation in young adults with overweight and obesity: A randomized controlled trial. *J Nutr*, 154, 2763-2771 (2024)
- Shaaban MT, Ghaly MF, Fahmi SM. Antibacterial activities of hexadecanoic acid methyl ester and green-synthesized silver nanoparticles against multidrug-resistant bacteria. *J Basic Microbiol*, 61, 557-568 (2021)
- Sharma S, Kataria A, Singh B. Effect of thermal processing on the bioactive compounds, antioxidative, antinutritional and functional characteristics of quinoa (*Chenopodium quinoa*). *LWT*, 160, 113256 (2022)
- Singh AK, Rehal J, Kaur A, Jyot G. Enhancement of attributes of cereals by germination and fermentation: A review. *Crit Rev Food Sci Nutr*, 55, 1575-1589 (2015)
- Singh B, Pavithran N, Rajput R. Effects of food processing on nutrients. *Cur J Appl Sci Technol*, 42, 34-49 (2023)
- Sofi SA, Ahmed N, Farooq A, Rafiq S, Zargar SM, Kamran F, Dar TA, Mir SA, Dar BN, Mousavi Khaneghah A. Nutritional and bioactive characteristics of buckwheat, and its potential for developing gluten-free products: An updated overview. *Food Sci Nutr*, 11, 2256-2276 (2023)
- Solarov MB, Šimurina O, Kojić J, Krulj JA, Filipović JS, Cvetković BR, Ilić NM. Utilization of *Amaranthus* spp. grains in food. *Food Feed Res*, 49, 37-52 (2022)
- Trieu K, Bhat S, Dai Z, Leander K, Gigante B, Qian F, Korat AVA, Sun Q, Pan XF, Laguzzi F, Cederholm T, de Faire U, Hellénus ML, Wu JHY, Risérus U, Marklund M. Biomarkers of dairy fat intake, incident cardiovascular disease, and all-cause mortality: A cohort study, systematic review, and meta-analysis. *PLoS Medicine*, 18, e1003763 (2021)
- Venn-Watson S, Schork NJ. Pentadecanoic acid (C15:0), an essential fatty acid, shares clinically relevant cell-based activities with leading longevity-enhancing compounds. *Nutrients*, 15, 4607-4614 (2023)
- Yang J, Li Q, Feng Y, Zeng Y. Iron deficiency and iron deficiency anemia: Potential risk factors in bone loss. *Int J Mol Sci*, 24, 68-91 (2023)
- Zhang M, Zhao R, Wang D, Wang L, Zhang Q, Wei S, Lu F, Peng W, Wu C. Ginger (*Zingiber officinale* Rosc.) and its bioactive components are potential resources for health beneficial agents. *Phytother Res*, 35, 711-742 (2021)
- Zhang Q, Zheng G, Wang Q, Zhu J, Zhou Z, Zhou W, Xu J, Sun H, Zhong J, Gu Y, Yin Z, Du YL, Du JD. Molecular mechanisms of flavonoid accumulation in germinating common bean (*Phaseolus vulgaris*) under salt stress. *Frontiers Nutr*, 9, 928805 (2022)
- Zhang W, Boateng ID, Xu J, Zhang Y. Proteins from legumes, cereals, and pseudo-cereals: Composition, modification, bioactivities, and applications. *Foods*, 13, 1974 (2024)