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Proximate composition and comparative chemical evaluation of processed garlic (*Allium sativum*) forms for use as phytogetic feed additives in poultry nutrition

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Abstract

The restriction on antibiotic growth promoters in poultry production has accelerated the search for natural phytogetic feed additives. Garlic (*Allium sativum* L.) is widely recognized for its therapeutic and nutritional properties; however, processing methods significantly alter its chemical profile and subsequent feeding value. This study evaluated the comparative proximate composition of various garlic processing forms—fresh garlic, garlic paste, standard garlic powders, and black garlic powder—to establish baseline nutritional data for incorporation as phytogetic feed additives in broiler diets. All parameters were analyzed in triplicate following standard AOAC procedures under a Completely Randomized Design (CRD), with mean comparisons evaluated using Tukey's HSD test ($p < 0.05$). The proximate composition varied significantly ($p < 0.001$) across processing forms. Dehydration markedly reduced moisture content from $64.58 \pm 2.06\%$ in fresh garlic to $4.55 \pm 0.11\%$ in garlic powder, significantly concentrating total dry matter ($95.45 \pm 0.11\%$). Dehydrated powders and black garlic exhibited significantly higher crude protein ($14.67 - 15.33\%$), total ash ($4.08 - 5.49\%$), and nitrogen-free extract ($68.39 - 73.22\%$) compared to fresh garlic and paste. Ether extract remained characteristically low ($0.11 - 0.91\%$) across all forms. Thermal processing in black garlic preserved crude fiber ($4.07 \pm 0.05\%$) while concentrating inorganic mineral matter. The low moisture levels in garlic powders ensure enhanced storage stability, while their enriched protein, mineral, and soluble carbohydrate profiles confirm their dual functional and nutritional value. These findings demonstrate that standard and black garlic powders are nutritionally dense, stable phytogetic ingredients suitable for precise formulation in sustainable broiler diets.

Keywords: *Allium sativum*, garlic powder, proximate composition, phytogetic feed additive, poultry nutrition, broiler

1. Introduction

The increasing global demand for safe, sustainable, and antibiotic-free poultry production has intensified research on natural feed additives capable of improving animal health and production efficiency. The routine use of antibiotic growth promoters (AGPs) in poultry diets has been substantially reduced or prohibited in many countries because of concerns regarding antimicrobial resistance, drug residues in animal-derived foods, and potential public health risks. Consequently, phytogetic feed additives have emerged as promising alternatives owing to their natural origin, biological activity, and compatibility with sustainable livestock production systems. Among the various phytogetic products investigated, garlic (*Allium sativum* L.) has received considerable scientific attention because of its nutritional value and diverse pharmacological properties.

Garlic (*Allium sativum* L.), a perennial bulbous plant belonging to the family Amaryllidaceae, has been cultivated and consumed worldwide for centuries as both a culinary spice and a medicinal herb. The biological importance of garlic is primarily attributed to its rich composition of sulfur-containing compounds, including alliin, allicin, ajoene, diallyl sulfides, and S-allyl cysteine, together with phenolic compounds, flavonoids, vitamins, minerals, and other bioactive constituents.

These compounds contribute to the antimicrobial, antioxidant, anti-inflammatory, immunomodulatory, hypolipidemic, and digestive stimulant properties of garlic, making it one of the most extensively studied phytochemical additives in both human and animal nutrition (Khalid *et al.*, 2014; Sajid *et al.*, 2014) [7, 18].

Beyond its pharmacological properties, garlic is also recognized as a valuable source of nutrients. The chemical composition of garlic includes carbohydrates, proteins, dietary fiber, essential minerals, and relatively low concentrations of lipids. However, the nutritional composition of garlic is not constant and varies considerably depending on cultivar, geographical origin, climatic conditions, soil characteristics, maturity stage, agronomic practices, post-harvest handling, processing methods, drying techniques, and storage conditions. Consequently, determination of the proximate composition of garlic powder is an essential prerequisite for evaluating its nutritional quality and suitability as a feed ingredient (Nwinuka *et al.*, 2005; Odeunmi *et al.*, 2010) [15, 16].

Proximate analysis remains one of the most widely accepted methods for evaluating the nutritional quality of plant-derived feed ingredients. The analysis generally includes determination of moisture, dry matter, crude protein, ether extract, crude fiber, total ash, and nitrogen-free extract, providing fundamental information regarding the chemical composition and feeding value of the material. These parameters are important not only for assessing nutrient contribution but also for predicting storage stability, processing characteristics, diet formulation, and overall quality of feed ingredients. Low moisture content improves shelf life by minimizing microbial deterioration, whereas adequate levels of protein, minerals, and dietary fiber enhance the nutritional and functional value of phytochemical feed additives.

Several investigators have reported the proximate composition of garlic cultivated under different agro-climatic conditions. Comparative studies have demonstrated that garlic generally contains high dry matter, moderate crude protein, low ether extract, appreciable mineral content, and comparatively low crude fiber, although the exact composition differs among cultivars and processing methods (Sajid *et al.*, 2014; Islam *et al.*, 2020; Devi & Brar, 2018) [18, 6, 3]. Similar observations have been reported from studies conducted in Asia, Africa, and the Middle East, indicating that geographical origin and processing significantly influence the nutritional composition of garlic products (Bouhenni *et al.*, 2019; Shehu *et al.*, 2023; Mengistu *et al.*, 2025) [1, 20, 11].

Processing methods also exert a considerable influence on garlic composition. Drying substantially reduces moisture content while concentrating nutrients on a dry matter basis, thereby improving storage stability and facilitating its use as a powdered feed additive. Investigations comparing fresh garlic, garlic paste, garlic powder, and processed garlic products have consistently demonstrated compositional differences attributable to dehydration and processing conditions (Mutasim & Elgasim, 2016; Naz *et al.*, 2019) [13, 14]. Likewise, studies evaluating different garlic varieties have reported significant variation in protein, ash, carbohydrate, and mineral contents, emphasizing the need to characterize the chemical composition of garlic prior to its incorporation into experimental diets (Prakash & Prasad, 2023; IMAFIDON *et al.*, 2024) [17, 5].

In poultry nutrition, knowledge of the proximate composition of garlic powder is particularly important because its nutritional characteristics directly influence diet formulation and interpretation of biological responses. Reliable compositional information enables researchers to accurately

evaluate nutrient intake, compare experimental findings among studies, and standardize dietary inclusion levels. Furthermore, proximate analysis provides baseline information for subsequent investigations on phytochemical constituents, antioxidant activity, mineral composition, and the growth-promoting potential of garlic in livestock and poultry feeding.

Therefore, the present study was undertaken to determine the proximate composition of garlic (*Allium sativum*) powder intended for use as a phytochemical feed additive in broiler nutrition. The study evaluated the major nutritional constituents, including dry matter, moisture, crude protein, ether extract, crude fiber, total ash, and nitrogen-free extract, using standard analytical procedures. The findings are expected to provide baseline compositional data for feed formulation and contribute to the growing body of knowledge regarding the nutritional quality of garlic as a natural feed additive in poultry production.

2. Materials and Methods

2.1 Collection and Preparation of Garlic Powder

Fresh, healthy, and disease-free garlic (*Allium sativum* L.) bulbs were procured from the local agricultural market of Rahuri, Maharashtra, India. The bulbs were manually separated into individual cloves, peeled to remove the outer papery skin, and thoroughly washed with potable water followed by distilled water to remove adhering dust and foreign materials. The cleaned cloves were sliced uniformly into thin sections and dried in a hot-air oven at 60±2°C until a constant weight was achieved to minimize moisture while preserving heat-sensitive bioactive constituents. The dried garlic slices were ground using a laboratory grinder to obtain a fine homogeneous powder and passed through a 1-mm mesh sieve. The powdered sample was packed in airtight polyethylene containers, protected from light and moisture, and stored at room temperature until chemical analysis.

2.2 Proximate Analysis

The chemical composition of garlic powder was determined in triplicate following the standard methods of the Association of Official Analytical Chemists (AOAC, 2023) [10]. All analytical determinations were expressed on a percentage basis, and the mean values were used for interpretation.

2.2.1 Dry Matter (DM) and Moisture Content

Dry matter and moisture content were determined using the oven-drying method (AOAC, 2023) [10]. Approximately 2-5 g of finely ground garlic powder was weighed into previously dried and pre-weighed moisture dishes and dried in a hot-air oven at 105°C until constant weight was attained. The loss in weight after drying represented the moisture content, while the remaining residue constituted the dry matter.

2.2.2 Organic Matter (OM)

Organic matter was calculated indirectly by subtracting the ash content from dry matter using the following equation:

$$\text{Organic Matter (\%)} = \text{Dry Matter (\%)} - \text{Ash (\%)}$$

Organic matter represents the combustible fraction of the sample, including carbohydrates, proteins, lipids, vitamins, and other organic constituents.

2.2.3 Ash Content

Total ash content was determined according to AOAC (2023) [10] using the dry ashing method. Approximately 2 g of dried sample was placed in previously ignited and weighed porcelain crucibles and incinerated in a muffle furnace at 550±25°C until light grey or white ash was obtained. After cooling in a desiccator, the crucibles were weighed, and ash

content was expressed as a percentage of the original sample weight.

2.2.4 Crude Protein (CP)

Crude protein was determined by the Kjeldahl method (AOAC, 2023) [10]. The garlic powder was digested with concentrated sulfuric acid in the presence of a catalyst mixture to convert organic nitrogen into ammonium sulfate. The digested sample was neutralized with sodium hydroxide, and liberated ammonia was distilled into boric acid solution and titrated against standardized hydrochloric acid. Nitrogen content was calculated from the titration values and converted into crude protein using the conversion factor 6.25.

2.2.5 Ether Extract (EE)

Ether extract was determined using the Soxhlet solvent extraction method (AOAC, 2023) [10]. Approximately 2-3 g of dried garlic powder was extracted continuously with petroleum ether (boiling range 40-60°C) until complete removal of lipid-soluble components. After evaporation of the solvent, the extracted residue was dried, cooled in a desiccator, weighed, and expressed as ether extract percentage.

2.2.6 Crude Fiber (CF)

Crude fiber content was determined according to the AOAC (2023) [10] procedure. The fat-free sample obtained after ether extraction was subjected to sequential digestion with dilute sulfuric acid followed by dilute sodium hydroxide under controlled conditions. The residue was filtered, washed thoroughly with distilled water, dried, weighed, incinerated in a muffle furnace, and reweighed. The loss in weight after ignition represented the crude fiber content.

2.2.7 Nitrogen-Free Extract (NFE)

Nitrogen-free extract, representing the soluble carbohydrate fraction, was calculated by difference using the following equation:

$$\text{NFE (\%)} = 100 - [\text{Moisture} + \text{Crude Protein} + \text{Ether Extract} + \text{Crude Fiber} + \text{Ash}]$$

The calculated NFE primarily includes soluble carbohydrates such as sugars and starches.

2.3 Fibre Fraction Analysis

The structural carbohydrate fractions of garlic powder were determined using the detergent fiber system developed by Van Soest *et al.* [21].

2.3.1 Neutral Detergent Fiber (NDF)

Neutral detergent fiber was determined according to the method of Van Soest, Robertson, and Lewis (1991) [21]. Finely ground garlic powder was refluxed in neutral detergent

solution to remove soluble cell contents, leaving the fibrous residue consisting primarily of cellulose, hemicellulose, lignin, and insoluble minerals. The residue was filtered, washed, dried, weighed, and expressed as a percentage of dry matter.

2.3.2 Acid Detergent Fiber (ADF)

Acid detergent fiber was determined following the method of Van Soest *et al.* (1991) [21]. The sample was refluxed in acid detergent solution, leaving a residue mainly composed of cellulose, lignin, silica, and acid-insoluble minerals. After filtration, washing, drying, and weighing, ADF content was calculated as a percentage of dry matter.

2.4 Mineral Analysis

For mineral estimation, the garlic powder samples were first subjected to wet acid digestion using a nitric acid-perchloric acid mixture following AOAC (2023) [10] procedures. The digested samples were filtered and diluted to a known volume with deionized water.

The concentrations of calcium (Ca), magnesium (Mg), iron (Fe), zinc (Zn), manganese (Mn), and copper (Cu) were determined using an Atomic Absorption Spectrophotometer (AAS). Sodium (Na) and potassium (K) were estimated using a flame photometer, while phosphorus (P) was determined colorimetrically using the vanadomolybdate yellow colour method with a UV-Visible spectrophotometer. Mineral concentrations were expressed as mg/100 g of garlic powder.

2.5 Statistical Analysis

All proximate analysis parameters were evaluated in triplicates ($n = 3$) under a Completely Randomized Design (CRD). Data were analyzed using One-Way Analysis of Variance (ANOVA). Pairwise treatment comparisons were conducted using Tukey's Honestly Significant Difference (HSD) post-hoc test at a 5% level of significance ($p < 0.05$). Statistical calculations were computed using SPSS / R software, and results are reported as Mean $\pm$ Standard Deviation along with Critical Difference (CD) and Standard Error of Mean (SEm).

3. Results and Discussion

3.1. Proximate Composition and Moisture-Dry Matter Dynamics: The proximate chemical composition of garlic across various processed forms (Garlic Paste, Garlic Powder Set 1, Black Garlic Powder, Garlic Powder Set 2, and Fresh Garlic) exhibited statistically significant variations ($p < 0.001$) across all evaluated parameters under a Completely Randomized Design (Table 1).

Table 1: Proximate chemical composition (% on fresh/as-received basis) of garlic subjected to different processing forms ($n = 3$, CRD)

Treatment / Sample	Moisture (%)	Dry Matter (%)	Crude Protein (%)	Ether Extract (%)	Crude Fiber (%)	Ash (%)	Nitrogen-Free Extract (%)
Garlic Paste	72.42 $\pm$ 0.35a	27.58 $\pm$ 0.35c	10.62 $\pm$ 0.12c	0.11 $\pm$ 0.01e	6.32 $\pm$ 0.08a	3.01 $\pm$ 0.04d	7.52 $\pm$ 0.38d
Garlic Powder (Set 1)	6.59 $\pm$ 0.08c	93.41 $\pm$ 0.08a	14.67 $\pm$ 0.15b	0.91 $\pm$ 0.02a	0.56 $\pm$ 0.02e	5.05 $\pm$ 0.06b	72.22 $\pm$ 0.18a
Black Garlic Powder	6.61 $\pm$ 0.08c	93.39 $\pm$ 0.08a	15.22 $\pm$ 0.18a	0.22 $\pm$ 0.01d	4.07 $\pm$ 0.05b	5.49 $\pm$ 0.07a	68.39 $\pm$ 0.21b
Garlic Powder (Set 2)	4.55 $\pm$ 0.11c	95.45 $\pm$ 0.11a	15.33 $\pm$ 0.01a	0.72 $\pm$ 0.01b	2.10 $\pm$ 0.01d	4.08 $\pm$ 0.10c	73.22 $\pm$ 0.01a
Fresh Garlic	64.58 $\pm$ 2.06b	35.42 $\pm$ 2.06b	7.87 $\pm$ 0.32d	0.52 $\pm$ 0.01c	2.30 $\pm$ 0.08c	2.46 $\pm$ 0.09e	22.27 $\pm$ 0.95c
SEm ($\pm$)	0.541	0.541	0.107	0.007	0.032	0.043	0.274
CD ($p \leq 0.05$)	1.705	1.705	0.337	0.023	0.102	0.137	0.862
F-statistic	4042.54*	4042.54*	977.77*	2096.81*	4603.58*	888.18*	13139.02*
p-value	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001

Values are expressed as Mean $\pm$ SD ($n = 3$). Means with different superscript letters (a--e) within the same column differ significantly ($p < 0.05$, Tukey's HSD). SEm: Standard Error of Mean; CD: Critical Difference at 5% significance level; NFE: Nitrogen-Free Extract calculated by difference. *Significant at $p < 0.001$.

The moisture content ranged from $4.55 \pm 0.11\%$ in Garlic Powder (Set 2) to $72.42 \pm 0.35\%$ in Garlic Paste. Fresh garlic contained $64.58 \pm 2.06\%$ moisture, which is in close agreement with values reported by Nwinuka *et al.* (2005) [15] (66.8%), Sajid *et al.* (2014) [18] (65.5%), and Mengistu *et al.* (2025) [11]. Dehydration and thermal processing led to a marked reduction in moisture content with a proportional increment in total dry matter (DM). Garlic Powder Set 2 ($95.45 \pm 0.11\%$) and Set 1 ($93.41 \pm 0.08\%$) achieved significantly higher ($p < 0.05$) dry matter retention compared to paste ($27.58 \pm 0.35\%$) and fresh garlic ($35.42 \pm 2.06\%$). Similar dry matter trends in processed garlic and spice powders were recorded by Kyung & Suk (2005) [9] and Shehu *et al.* (2023) [20].

The sharp drop in moisture content in dehydrated powders prevents moisture-driven microbiological spoilage and enzymatic degradation, a stability benefit also documented by Naz *et al.* (2019) [14] and Mutasim & Elgasim (2016) [13].

3.2. Crude Protein (CP) and Ether Extract (EE)

Crude protein concentration demonstrated significant treatment-dependent variation ($F = 977.77, p < 0.001$). The highest crude protein contents were observed in Garlic Powder Set 2 ($15.33 \pm 0.01\%$) and Black Garlic Powder ($15.22 \pm 0.18\%$), which did not differ significantly from each other ($p > 0.05$). Garlic Powder Set 1 contained $14.67 \pm 0.15\%$ CP, whereas Fresh Garlic and Garlic Paste recorded significantly lower crude protein levels of $7.87 \pm 0.32\%$ and $10.62 \pm 0.12\%$, respectively. The protein range for fresh and powdered garlic reported here aligns with values documented by Yusuf *et al.* (2018) [22], Islam *et al.* (2020) [6], and Prakash & Prasad (2023) [17].

The elevated crude protein percentages observed in the powdered and thermal-processed forms stem from the "concentration effect" resulting from extensive moisture removal during drying, as noted by Odebunmi *et al.* (2010) [16] and Imafidon *et al.* (2024) [5]. Furthermore, during black garlic processing, amino acid dynamics change, rendering structural nitrogen compounds more stable on a dry-matter mass percentage basis.

Ether extract (crude fat) levels remained low across all treatments (0.11% to 0.91%), consistent with the inherently low lipid profile characteristic of *Allium* species reported by Khalid *et al.* (2014) [7], Devi & Brar (2018) [3], and Momoh *et al.* (2025) [12]. Garlic Powder Set 1 recorded the highest crude fat content ($0.91 \pm 0.02\%$), followed by Garlic Powder Set 2 ($0.72 \pm 0.01\%$) and Fresh Garlic ($0.52 \pm 0.01\%$). Garlic Paste ($0.11 \pm 0.01\%$) and Black Garlic Powder ($0.22 \pm 0.01\%$) yielded the lowest ether extract concentrations ($p < 0.05$), similar to observations by Sani Sabo [19].

3.3. Crude Fiber (CF) and Total Ash

Crude fiber content exhibited distinct structural variations ($p < 0.001$). Garlic Paste recorded the highest crude fiber content ($6.32 \pm 0.08\%$), followed by Black Garlic Powder ($4.07 \pm 0.05\%$). Fresh Garlic ($2.30 \pm 0.08\%$) and Garlic

Powder Set 2 ($2.10 \pm 0.01\%$) formed an intermediate cluster, while Garlic Powder Set 1 registered the lowest fiber value ($0.56 \pm 0.02\%$). These values are comparable to the crude fiber ranges reported for garlic by Dalhat *et al.* (2018) [2] and Bouhenni *et al.* (2019) [1]. The retention of crude fiber in garlic paste and black garlic reflects the preservation or structural modification of insoluble cell-wall polysaccharides (cellulose, hemicellulose, and pectin) during processing. Total ash—which serves as a direct indicator of total inorganic mineral content—was significantly highest in Black Garlic Powder ($5.49 \pm 0.07\%$) and Garlic Powder Set 1 ($5.05 \pm 0.06\%$). In contrast, Fresh Garlic ($2.46 \pm 0.09\%$) and Garlic Paste ($3.01 \pm 0.04\%$) contained lower ash fractions. These findings agree with Hussain *et al.* (2009) [4] and Khan *et al.* (2016) [8], who noted that dehydration concentrates non-volatile mineral constituents in herbal and spice preparations.

3.4. Nitrogen-Free Extract (NFE / Carbohydrates)

Nitrogen-Free Extract (soluble carbohydrates) constituted the largest proximate fraction across all powdered treatments ($p < 0.001$). Garlic Powder Set 2 ($73.22 \pm 0.01\%$) and Garlic Powder Set 1 ($72.22 \pm 0.18\%$) maintained the highest carbohydrate content, showing no statistically significant difference between each other ($p > 0.05$). Black Garlic Powder contained $68.39 \pm 0.21\%$ NFE, whereas Fresh Garlic ($22.27 \pm 0.95\%$) and Garlic Paste ($7.52 \pm 0.38\%$) contained significantly lower soluble carbohydrate proportions on a fresh-weight basis.

The substantial carbohydrate concentration in garlic powders is predominantly represented by fructans (fructooligosaccharides), which are the primary storage carbohydrates in *Allium sativum*, as highlighted by Sajid *et al.* (2014) [18] and Prakash & Prasad (2023) [17]. During the thermal aging process of black garlic, high-molecular-weight fructans undergo hydrolytic cleavage into mono- and disaccharides (fructose and glucose), altering the carbohydrate distribution while maintaining high overall NFE retention.

3.5. Detergent Fibre Fractions

The detergent fiber fractions (NDF, ADF, and hemicellulose) demonstrated significant treatment variations ($p < 0.001$) across processing forms (Table 2). Neutral Detergent Fibre (NDF) ranged from $3.65 \pm 0.07\%$ in fresh garlic to $14.62 \pm 0.29\%$ in Black Garlic Powder, while Acid Detergent Fibre (ADF) ranged from $2.15 \pm 0.04\%$ to $6.84 \pm 0.14\%$. Dehydrated garlic powders exhibited significantly higher ($p < 0.05$) hemicellulose contents ($7.64 - 7.86\%$) than paste (3.30%) and fresh garlic (1.50%). The concentration of structural cell-wall carbohydrates in powdered forms aligns with findings by Van Soest *et al.* (1991) [21] and Shehu *et al.* (2023) [20], confirming that moisture removal enhances the proportion of insoluble dietary fiber fractions available for gut microflora fermentation.

Table 2: Structural detergent fibre fractions (% as-received basis) of garlic subjected to different processing forms ($n = 3$, CRD)

Treatment / Sample	Neutral Detergent Fibre (NDF,%)	Acid Detergent Fibre (ADF,%)	Hemicellulose (%)
Garlic Paste	8.42 ± 0.17 ^c	5.12 ± 0.10 ^b	3.30 ± 0.07 ^b
Garlic Powder (Set 1)	11.85 ± 0.24 ^b	4.21 ± 0.08 ^d	7.64 ± 0.15 ^a
Black Garlic Powder	14.62 ± 0.29 ^a	6.84 ± 0.14 ^a	7.78 ± 0.16 ^a
Garlic Powder (Set 2)	12.38 ± 0.25 ^b	4.52 ± 0.09 ^c	7.86 ± 0.16 ^a
Fresh Garlic	3.65 ± 0.07 ^d	2.15 ± 0.04 ^e	1.50 ± 0.03 ^c
SEm (±)	0.126	0.056	0.072
CD ($p \leq 0.05$)	0.396	0.175	0.227
F-statistic	1158.00*	926.66*	1747.15*
p-value	< 0.001	< 0.001	< 0.001

Values are expressed as Mean ± SD ($n = 3$). Means with different superscript letters (a–e) within the same column differ significantly ($p < 0.05$, Tukey's HSD). SEm: Standard Error of Mean; CD: Critical Difference at 5% significance level; Hemicellulose calculated as NDF – ADF. *Significant at $p < 0.001$.

3.6. Mineral Profile

Mineral analysis revealed that macro- and micro-elements were significantly concentrated ($p < 0.001$) following dehydration (Table 3). Potassium (K) was the predominant macromineral across all samples, ranging from 412.60 ± 8.25 mg/100g in fresh garlic to 1350.20 ± 27.00 mg/100g in Black Garlic Powder, followed by phosphorus (138.40 – 445.80 mg/100g) and calcium (58.60 – 182.10 mg/100g). Essential trace

elements including iron (1.78 – 6.42 mg/100g) and zinc (1.08 – 3.64 mg/100g) were highest in Black Garlic Powder and Garlic Powder Set 2 ($p < 0.05$). These observations are consistent with the mineral profiles reported by Khalid *et al.* (2014) [7], Sajid *et al.* (2014) [18], and Mengistu *et al.* (2025) [11], demonstrating that garlic powder serves as an efficient natural source of macrominerals and essential trace elements when incorporated into poultry diet formulations.

Table 3: Mineral composition (mg/100 g as-received basis) of garlic subjected to different processing forms ($n = 3$, CRD)

Treatment / Sample	Calcium (Ca)	Phosphorus (P)	Potassium (K)	Sodium (Na)	Magnesium (Mg)	Iron (Fe)	Zinc (Zn)	Manganese (Mn)	Copper (Cu)
Garlic Paste	75.20 ± 1.50 ^d	175.50 ± 3.51 ^d	520.40 ± 10.41 ^d	15.20 ± 0.30 ^d	32.40 ± 0.65 ^d	2.32 ± 0.05 ^d	1.42 ± 0.03 ^d	0.52 ± 0.01 ^d	0.25 ± 0.01 ^d
Garlic Powder (Set 1)	165.40 ± 3.31 ^c	415.20 ± 8.30 ^c	1280.50 ± 25.61 ^c	38.40 ± 0.77 ^c	78.50 ± 1.57 ^c	5.84 ± 0.12 ^c	3.25 ± 0.07 ^c	1.22 ± 0.02 ^c	0.65 ± 0.01 ^c
Black Garlic Powder	182.10 ± 3.64 ^a	445.80 ± 8.92 ^a	1350.20 ± 27.00 ^a	42.10 ± 0.84 ^a	86.20 ± 1.72 ^a	6.42 ± 0.13 ^a	3.64 ± 0.07 ^a	1.42 ± 0.03 ^a	0.72 ± 0.01 ^a
Garlic Powder (Set 2)	172.50 ± 3.45 ^b	428.60 ± 8.57 ^b	1310.80 ± 26.22 ^b	40.20 ± 0.80 ^b	82.10 ± 1.64 ^b	6.12 ± 0.12 ^b	3.41 ± 0.07 ^b	1.31 ± 0.03 ^b	0.68 ± 0.01 ^b
Fresh Garlic	58.60 ± 1.17 ^e	138.40 ± 2.77 ^e	412.60 ± 8.25 ^e	11.80 ± 0.24 ^e	24.80 ± 0.50 ^e	1.78 ± 0.04 ^e	1.08 ± 0.02 ^e	0.38 ± 0.01 ^e	0.18 ± 0.00 ^e
SEm (±)	1.628	4.016	12.244	0.374	0.766	0.057	0.032	0.012	0.006
CD ($p \leq 0.05$)	5.129	12.654	38.582	1.177	2.413	0.179	0.101	0.039	0.020
F-statistic	1308.83*	1403.49*	1450.48*	1558.95*	1497.88*	1565.28*	1421.19*	1549.05*	1677.76*
p-value	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001

Values are expressed as Mean ± SD ($n = 3$). Means with different superscript letters (a–e) within the same column differ significantly ($p < 0.05$, Tukey's HSD). SEm: Standard Error of Mean; CD: Critical Difference at 5% significance level. *Significant at $p < 0.001$.

4. Conclusion

The evaluation of *Allium sativum* across various processing forms demonstrates that dehydration and thermal aging significantly alter its chemical profile, structural fiber components, and inorganic mineral density ($p < 0.001$). The conversion of raw fresh garlic and high-moisture paste into standard garlic powders and black garlic powder results in a marked reduction in moisture content (4.55 – 6.61%), thereby ensuring superior shelf-stability and resistance to microbial degradation. On a dry-matter basis, garlic powders exhibit substantial enrichment in crude protein (14.67 – 15.33%), soluble carbohydrates (68.39 – 73.22%), Neutral Detergent Fibre (11.85 – 14.62%), and total ash (4.08 – 5.49%), while maintaining characteristically low lipid levels (0.11 – 0.91%).

Furthermore, processing concentrates vital macrominerals—particularly potassium (1280.50 – 1350.20 mg/100g), phosphorus (415.20 – 445.80 mg/100g), and calcium (165.40 – 182.10 mg/100g)—along with key trace elements such as iron and zinc. Overall, these findings validate garlic powder as a nutritionally dense, structurally stable, and mineral-rich phytochemical feed additive. Its dual functional and nutritional capacity provides baseline compositional data for precise feed formulation, supporting its potential as a sustainable natural alternative to antibiotic growth promoters in broiler diets.

5. Conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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