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Nutritional Composition and Bioactive Profile of Lentil (*Lens culinaris Medikus*): Effect of Variety and Germination Stages

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Abstract
This study was conducted to characterize the nutritional profile of three lentil varieties (*Lens culinaris Medikus*) from Madagascar, coral, green, and black, and to determine the effects of germination stage on their nutritional and functional properties. Chemical analyses during germination measured macro and micronutrient contents, individual polyphenols, tannins, and antioxidant activities. Antifungal and antimicrobial activities were evaluated using the Broth Microdilution Method. The results showed that the crude protein content represents almost a quarter of the total composition on a dry matter basis, reaching 29.77 ± 0.01 g /100 g after germination. Carbohydrates remained at 53.89 ± 0.11 g/100 g, and lipids were at a low rate. Essential minerals were present, with particularly high levels of K (107.20 ± 0.02 mg/100g to 115.08 ± 0.06 mg/100g) and Mg (96.75 ± 0.47 mg/100 g to 104.87 ± 0.06 mg/100g), which increased after germination. The results indicated that lentils had anti-nutritional factors, but with acceptable quantities. The antimicrobial activities revealed that, after germination, lentils were highly effective against *Escherichia coli* and *Salmonella*. The study highlights significant differences ($p < 0.05$) in the nutritional composition of the three varieties and demonstrates that germination enhances their nutritional and functional potential.
***Keywords*:** nutrition composition, seed germination, legumes, protein, Madagascar

1. Introduction

Regarding food security and nutrition, dried beans are among the most common staple foods of several countries in the world [1, 2]. They are characterized as an important vegetal source of proteins, providing minerals and fiber with a low-fat content [2–4]. They could help meet protein needs to provide the human body with energy and ensure its function. In Madagascar, pulses such as common beans, peanuts, peas, and soya are mainly cultivated and gaining recognition in the South and South-West of the island [5].

With their small size, which allows a shorter cooking time than other beans, lentils are the most important source of plant-based proteins [6,7] and deserve a full place in the human diet. Compared to other beans, lentils (*Lens culinaris*

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Medik.) are mostly overlooked in favor of the other species, particularly *Phaseolus* sp. In several countries, they are cheap and widely consumed as a basic food. In contrast, in Madagascar, lentils are relatively expensive and which limits their accessibility and regular consumption despite their nutritional benefits. However, using pulses in infant nutrition has some limitations, including a high rate of anti-nutritional factors that reduce digestibility. For young children, sensitive digestion and high nutrient requirements make it crucial to improve the nutritional quality of legume-based products, including lentils [8]. Germination is a natural and low-cost way that can improve the nutritional profile of seeds. During this process, enzymatic activities increase minerals, proteins, and promote bioactive [9]. Even if germination improves lentil composition, research on local Malagasy varieties remains limited for their suitability for infant flour.

In this study, the aim focused on the nutritional characterization of three varieties of lentils *(Lens culinaris Medikus*) from Madagascar to determine the effects of variety and germination stage on their nutritional properties. Across different stages of germination, the physicochemical and phytochemical profile, followed by the antimicrobial potential of lentil, was analyzed.

2. Materials and methods

2.1. Sampling and germination

The study focuses on three varieties of lentils *(Lens culinaris Medikus*): coral, black, and green. Considering their local availability, they are collected in the form of dry seeds at the local market in Anosibe Antananarivo, Madagascar. They all originate from Morondava (Menabe region), and are harvested randomly depending on their color varieties. Samples of each variety were placed in a dark glass jar to protect them from any external environmental incidents and stored at room temperature [5]. Dry seeds of lentils were subjected to preliminary treatment, while damaged seeds and foreign elements were removed from the sample. 3000 seeds from each sample were used for the next process. To start germination, 2000 seeds from each sample were washed and soaked at room temperature for 12 hours in tap water at a ratio of 1:5. Half of the soaked seeds were collected and dried at 45°C for 2 days, and reduced to flour by GRINDOMIX GM200 mill to a size of 400 µm. The last half of the seed was placed in the plate with a cotton swab soaked in water to follow the final germination stage for 24 hours, at room temperature and near natural light. They were collected, dried in the same manner as the previous way, and ground to a size of 400µm [10–12].

Figure 1 presents the technological flow of germination during this study.

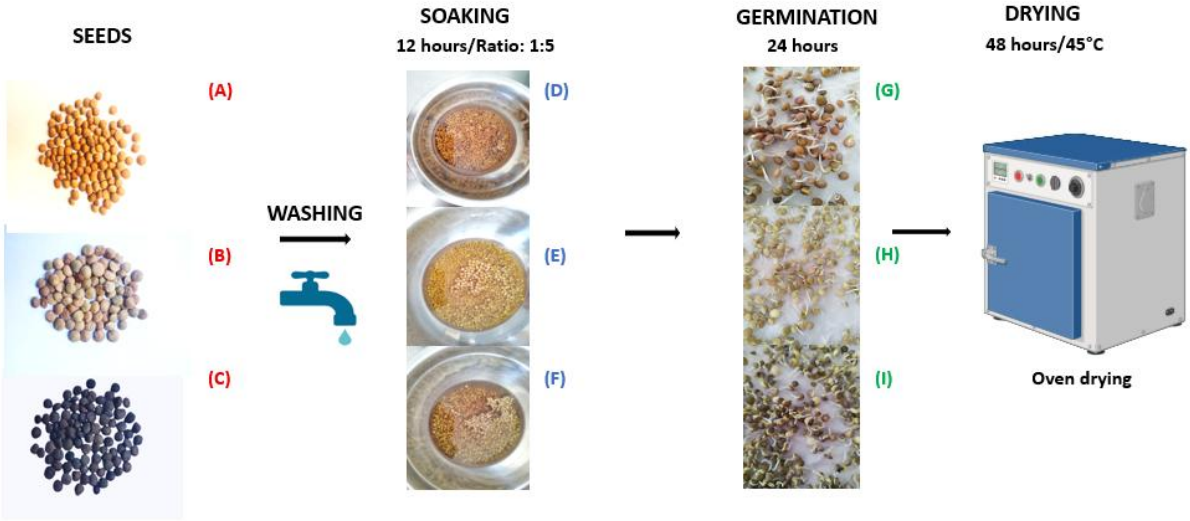

Figure 1. Germination process. Where (A) coral lentil seeds, (B) green lentil seeds, (C) black lentil seeds, (D) soaked coral lentils, (E) soaked green lentils, (F) soaked black lentils, (G) germinated coral lentils, (H) germinated green lentils, (I) germinated black lentils.

2.2. Nutritional analysis

2.2.1. Moisture content

Moisture components (M%) were determined through drying the powder sample of lentils in a Thermobalance (KERN MLB 50-3) at 130°C for 20 min. The water content was expressed automatically on the screen of the Thermobalance [13].

2.2.2. Ash content

Ash content (A%) in cereals, pulses, and derived products was determined with ISO 2171:2023 [14]. The sample was incinerated in a muffle furnace at 550°C for 5 hours until obtaining white ash. The ash content was calculated as a percentage ratio between the weight of ashes and the oven-dry weight.

2.2.3. Crude protein content

Crude protein content (P%) was evaluated from nitrogen content (N%) by using the Kjeldahl method. It was calculated by multiplying the total nitrogen content by an appropriate conversion factor of lentils (f) [15]. This content was presented by the following formula:

$$P\% = N\% \times f$$

2.2.4. Fat content

Crude fat content was determined by Soxhlet extraction using a solvent. The lipid content (L%) was calculated by weighing the fat residue after evaporation of the solvent relative to the initial sample weight [16]. This content was determined by using the formula:

$$L\% = \frac{w}{W} X\ 100$$

Where: L% = lipid percentage, w = weight of lipid, and W = weight of sample.

2.2.5. Fiber content

The relevant ISO 6541:1981 is the standard ISO for crude fiber determination. By this standard, crude fiber content (F%) was determined by quantifying the fiber residue after the ashing process. The method called the Weende method defines crude fiber as the insoluble and combustible substances remaining after treatment. This content was expressed as a percentage by mass relative to the dry matter content of the lentils. [17]

2.2.6. Carbohydrate content and nutritional value

The carbohydrate content was deduced from the difference between the total content of the elements and the sum of the protein, lipid, ash, and moisture contents. The percentage carbohydrate (C%) was presented by the formula [18]:

$$C\% = 100 - (\%\ moisture + \%\ ash + \%\ protein + \%\ lipid)$$

By summing up the caloric intake produced by the individual nutrients, the energy value of the products was determined, taking into account the following correlations: 1 g of lipids = 9 kcal, 1 g of carbohydrates = 4 kcal, 1 g of protein = 4 kcal, and 1 g of fiber = 2 kcal [18].

$$Energy\ value\ (kcal/100g) = (\%\ lipids \times 9) + (\%\ carbohydrates \times 4) + (\%\ proteins \times 4) + (\%\ fiber \times 2)$$

2.3. Determination of micronutrient contents

For this analysis, ash was preliminary prepared by incineration at 650°C in a muffle furnace (HERAEUS MR170 E). The resulting ash was dissolved in 20% hydrochloric acid and filtered to prepare the analysis solution. Micronutrients were measured by using atomic absorption spectroscopy (AAS). Calibration readings from the standard solution were used to create a calibration curve. It was related absorbance to concentration [12,19].

2.4. Phytochemical profile

For all phytochemical profiles, all analyses were performed in triplicate.

2.4.1. Total polyphenolic content

Total polyphenol content (TPC) was determined by the Folin-Ciocâlteu method. For each sample, an extract was prepared with ethanol 70%, shaking for 30 minutes, followed by filtration through a Whatman filter paper. The absorbance was measured and expressed as mg gallic equivalents (GAE) per 100 ml of sample. Individual polyphenols were analyzed by HPLC [12, 19, 20].

2.4.2. Determination of antioxidant activity

The antioxidant capacity was assessed using the DPPH radical scavenging assay. In the DPPH assay, antioxidant activity (AA) was calculated as the percentage of radical scavenging capacity using the formula [21, 22]:

$$AA\ (\%) = [(A_{control} - A_{sample})/A_{control}] \times 100$$

Where: $A_{control}$ and A_{sample} are the absorbance values of the control and the sample.

2.4.3. Tannin content

The total tannin content was determined by the method of Makkar (2003) with some

modifications. The analysis was related to the Folin-Ciocalteu method. It was assessed to separate tannin and non-tannin phenolics. The result was obtained after reading the absorbance at 725 nm [23].

2.4.4. Antifungal and antimicrobial activities

The antimicrobial activity was measured by the Broth microdilution method. Various concentrations of the extract were tested against reference strains of Gram-positive and negative bacteria, such as *Candida spp. Escherichia coli, Salmonella, Shigella, Staphylococcus aureus, Listeria monocytogenes, and Clostridium perfringens*. The Minimum Biofilm Inhibitory Concentration (MBIC) was defined as the lowest concentration that prevented biofilm formation. Absorbance was measured, and the results were presented as the percentage of bacterial inhibition [24].

2.5. Statistical analysis

To ensure accuracy and reproducibility, all measurements were conducted in triplicate, depending on the method. The mean value ± standard deviation (SD) was calculated for all measurements and compared using a one-way analysis of variance (ANOVA). Statistical analysis was done using RStudio 4.5.2 software. Differences were considered at a significance level of 0.05.

3. Results and discussions

3.1. Proximate physico-chemical composition and nutritional value

Three varieties of lentils were subjected to several analyses to establish their nutritional composition during each stage of germination. The results of these analyses are presented by the following Figure 2.

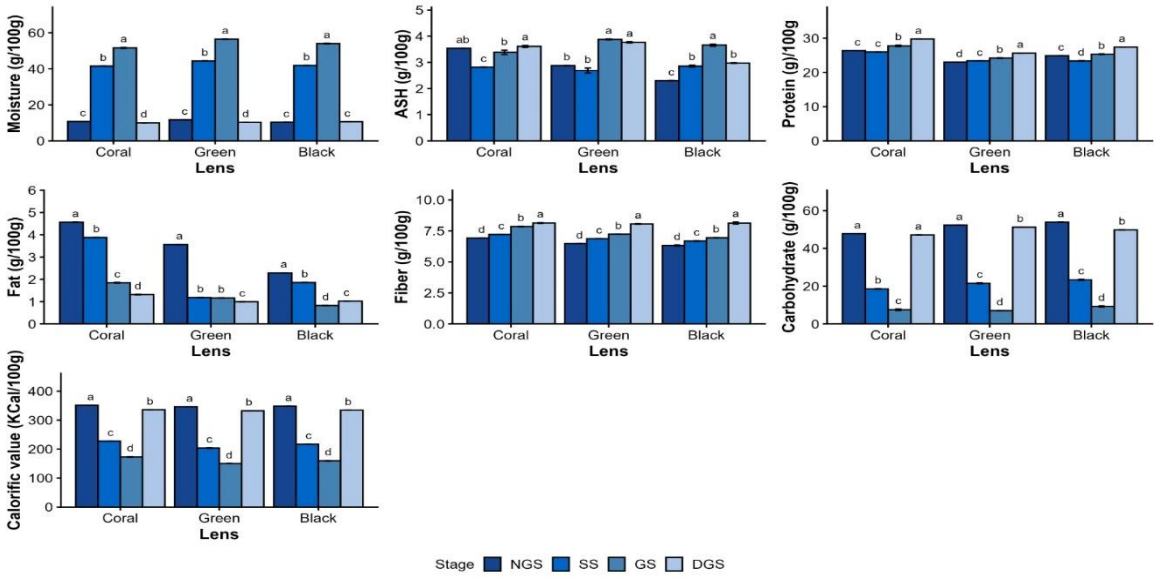

Figure 2. Nutritional value on a dry matter basis of three varieties of lentils for each stage of germination with NGS: Non-germinated Seeds, SS: Soaked Seeds, GS: Germinated Seeds, DGS: Dried Germinated Seeds.

Concerning the effect of variety on nutritional value, the result presented in Figure 2 highlights significant variation in the nutritional composition among the studied coral, black, and green lentils during germination. Specifically, the Non-Germinated Seeds (NGS) presented uniformly low initial moisture contents. On a fresh weight basis, the moisture content was measured at 10.78% for coral, 10.74 ± 0.01% for the green, and 10.71 ± 0.01% for black lentils. These results showed a low hygrometry with a maximum of around 10%, and confirmed that the moisture level is critical to maintain seed quality over a long post-harvest period. As it falls within the recommended 10 to 15% rate, it is a good way to minimize the microbial risk and biochemical deterioration [25].

Subsequently, due to the osmosis phenomenon [5, 26, 27], the moisture content increased significantly ($p < 0.05$) during the soaking stage, reaching approximately 41.5% for all three varieties. This huge amount of water was still increased to 51.17 ± 0.5% for coral, 51.52 ± 0.09% for green, and 51.65 ± 0.08% for black during germination. Soaking led to rehydration

[9, 27–29], and these values reflected that seeds absorbed water till reaching the maximal moisture state during embryo proliferation [30,31].

On the contrary, drying after germination (DGS) restored the moisture similarly to non-germinated seed (from 10.68 ± 0.01% to 10.72%). This result led to enhanced biochemical stability of germinated seed after germination [25]. Thus, statistical results presented that germinated and dried seed before and after germination were highly significantly different for all varieties ($p < 0.05$). It reflected the efficacy of the drying process.

Of particular interest was the high protein content observed in the final stage of dried germinated seeds. The content reached the maximum, dominated by black varieties 30.07 ± 0.03%, followed by green (29.89%) and 29.74 ± 0.03% for coral lentil. This difference is statistically significant ($p < 0.05$). This biochemical change was explained by the combination of the loss of moisture effect after drying and the concentration of protein synthesized during germination [30].

Earlier, for germinated seeds (GS), protein contents increased to 27.91 ± 0.04% for the coral, 28.09 ± 0.01% for the green, and 28.24 ± 0.04% for the black lentils. These results were driven by enzymatic activity, which promoted de novo protein synthesis for seedling development [37–39].

In contrast, soaking resulted in a statistically non-significant drop in protein concentration (25.97 ± 0.06% for coral lentils). This trend may be attributed to simple dilution from water absorption, which causes the loss of protein components [30, 32, 33].

Interestingly, even non-germinated lentils already contained around a quarter of the dry matter (26.35 ± 0.01% for the coral, 26.83 ± 0.01% for the green, and 26.86 ± 0.01% for the black). These initial differences between varieties were statistically significant ($p < 0.05$). They align well with other researchers, who reported that legume protein contents range from 20 to 40% [30,34,35]. Hence, lentils can be considered a good source of protein, even though their protein content is lower than soybeans, around 35% [34,36].

It should be noted that ash contents served as an indicator of the total inorganic mineral concentration. Before germination, coral lentils contained 3.54 ± 0.01% of ash compared to 3.57 ± 0.01% for the green and 3.60% for the black lentils. These results presented a comparable concentration of accumulated initial minerals [37]. However, these values changed, ranging around 2% during the soaking stage, with the most significant variation ($p < 0.05$). This marked leaching of soluble inorganic minerals such as potassium, sodium, magnesium, calcium, and phosphorus. This is a classic documented phenomenon during legume imbibition [30,36]. During the germination stage, ash levels had re-established compared to soaking, with the contents ranging between 3.41 ± 0.01% (black lentils) to 3.46% (coral lentils). This partial recovery can be explained by enzymatic activation that remobilizes certain minerals [38,41,42]. For the final stage, dried germinated seeds for all varieties reached the highest ash contents (3.07±0.03%). Like in all other stages, these results were significantly increased ($p < 0.05$). These results confirmed that drying after germination significantly increases mineral density of lentils and makes the final product a source of micronutrients. It was due to the reduction in moisture inside the seeds and concentrated nutrient elements. [30]

Unlike proteins and ash, lipid contents had distinct results. Lentils are low-fat, whether it was before or after germination. Initially, non-germinated seeds (NGS) contained respectively 4.57% to 4.65% of lipid. These statistically different values ($p < 0.05$) confirmed that lentils are naturally a low-fat legume with a range below 5% [41–43]. Conversely, soaking has already initiated the downward trend with significant decreases (3.88% for coral, 3.92 ± 0.02% for green, and 3.95 ± 0.01% for black). These values can be attributed to the leaching phenomenon and the early activation of the lipase enzyme during imbibition [29,44], while it was severed during the germination stage, reaching the lowest levels of 1.82% to 1.88%. It can be due to the conversion of lipid into soluble sugars to support the seed embryo [43,45-47].

In contrast to germination, lipid content was increased for the dried germinated seeds (DGS), with the value 4.09% for the coral, 4.12% for the green, and 4.15 ± 0.001% for the black lentils. After drying, it was higher than during germination and soaking but still below the initial value [48].

Moreover, the results demonstrated that the dietary profile of the lentils was significantly

influenced by the germination stage. Non-germinated seeds were marked by 6.92 ± 0.01 g for the coral variety, 7.12 ± 0.01% for the green, and 7.15 ± 0.01% for the black variety of lentils. These values were statistically significant ($p < 0.05$). They are related to the description of lentils as a source of dietary fiber, confirmed by the research of Anjum et al. (2025) [46–49]. During the soaking stage, fiber contents reached 7.22% to 7.45% for the lentils. This rising variation can be caused by the solubilization of certain starchy components, which increase the proportion of indigestible fibers after the rehydration process. Pursuing the germination stage brought a significant enhancement in fiber content, reaching 7.88% for the coral lentils to 8.03 g for the black. The existence of metabolic activity explains this variation. However, the fiber concentration for dried germinated seeds increased to 8.25% for coral, 8.42% for green, and 8.45% for black lentils. This content increase is highly significant ($p < 0.05$). It can be because of carbohydrate synthesis during germination and the moisture removal during the drying process. This last process enhances the dietary fiber of lentils and gives them the prebiotic potential. [46,50,51]

From the others' nutrient profiles to carbohydrates, non-germinated seed was marked by a high content of carbohydrates (47.84% for the coral, 46.90% for the green, and 46.94% for the black lentils). Chauhan et al. (2025) confirmed that these values are due to the importance of polysaccharides, mainly starch, as an energy reservoir in legumes [52]. Due to high moisture content during the imbibition and germination stage, carbohydrate content decreased to under 10%. This reduction is due to the existence of endogenous enzymes such as α-amylase and β-amylase, which catalyze starch hydrolysis. This hydrolysis consumed ATP during cellular respiration for seedling development [52–55].

In parallel, the energy value followed the macronutrients trend. NGS lentils are, initially have a high-calorie value of around 350 kcal/100 g. This value reached the lowest value, 174 to 182 kcal/100g, during the soaking and germination stage. This reduction results in a germinated product with the reduction of both lipids and carbohydrates. This transition optimized the nutritional quality of the final product, improving its protein and fiber levels. That makes lentils an excellent functional probiotic food after germination.

3.2. Minerals content

Through laboratory experiments, three varieties of lentils contained major minerals (Ca, Mg, K), and oligo-elements (Fe, Na, Zn, Cu). Their change across the germination process is illustrated by the following Figure 3.

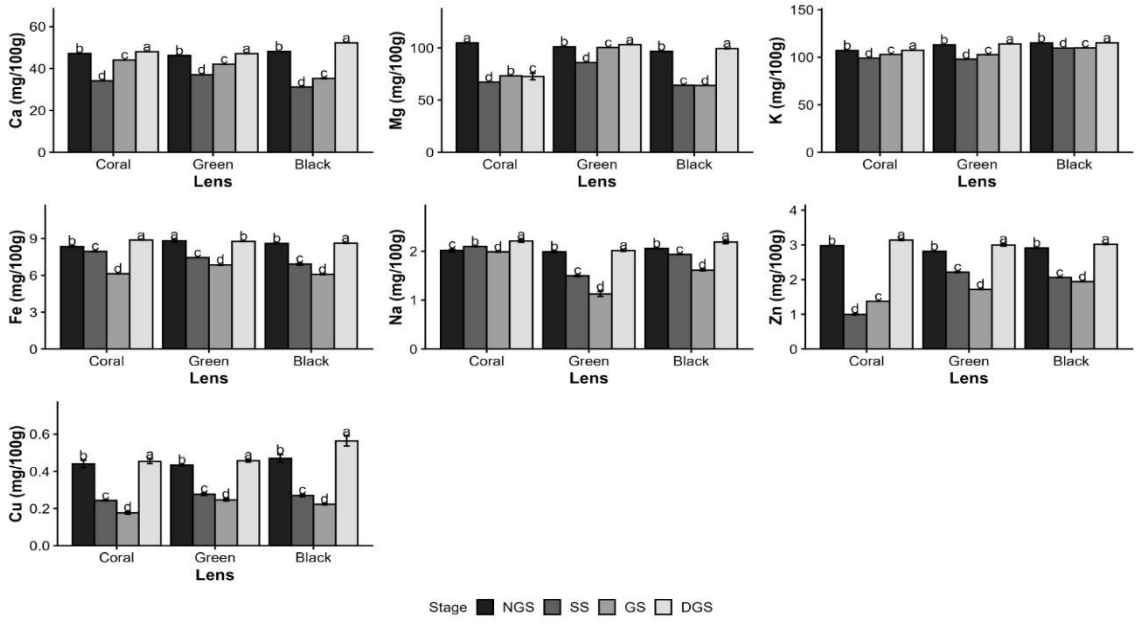

Figure 3. Minerals content on a dry matter basis of three varieties of lentils for each stage of germination with NGS: Non-germinated Seeds, SS: Soaked Seeds, GS: Germinated Seeds, DGS: Dried Germinated Seeds

As shown in Figure 2, the germination process, the mineral profiles of the three varieties of lentils are marked by a similar level of Ca, Mg, K, Fe, Zn, Cu, and Na. This study was already reported by Vargas et al. (2025), Benayad et Aboussaleh (2021), who showed that lentils are a source of nutrients. However, for most major minerals, black lentils generally have the highest amount in 100 g, with 48.12 ± 0.01 mg of Ca, 115.08 ± 0.06 mg of K, and 96.75 ± 0.47 mg of Mg. While it was 47.15 ± 0.14 mg of Ca, 107.20 ± 0.02 mg of K, 104.87 ± 0.06 mg of Mg for the coral varieties, and 46.18 ± 0.01 mg of Ca, 113.14 ± 0.06 mg of K, and 101.19 ± 0.33 mg of Mg for the green seeds. For the oligoelements like Fe, Cu, Zn, Na, they were in noteworthy amounts inside lentils. 8.34 ± 0.11 mg to 8.82 ± 0.18 mg of Iron, 0.43 ± 0.01 mg to 0.47 ± 0.03 mg of Cu, 2.82 ± 0.01 mg to 2.98 ± 0.01 mg of Zn, and 1.99 ± 0.03 mg to 2.06 ± 0.02 mg of Na. These values confirmed that lentils are a relevant source of essential trace minerals for human nutrition [56–58].

Moreover, through experiments, results revealed that mineral content was evaluated across germination. Soaking stage (SS) caused a significant ($p < 0.05$) substantial loss in all major and oligoelements. Calcium and Magnesium dropped, reaching 23 to 35%. Muroki et al. (2023) reported that this reduction can be the effect of dilution after water absorption. Uptake of water leached soluble ions such as K^+, Na^+, Mg^{2+}, Ca^{2+}, Fe^{2+}, and Zn^{2+} [59–62].

In contrast, major minerals are partially recovered during the germination stage, caused by hydrolytic enzyme activation during embryo development, which enhances the potential bioaccessibility of trace minerals [40,63,64]. Whereas, for the major minerals (Ca, Mg, K), dried germinated seeds (DGS) restored or have the highest concentrations, exceeding those of non-germinated seeds. It was with maximum values of Ca (52.25 ± 0.03 mg), K (115.19 ± 0.06 mg), and Cu (0.56 ± 0.05 mg for the black lentils). Statistical analysis confirmed that nutritional density evolution is significant after final drying ($p < 0.05$). This position of dried germinated lentils, especially the black variety, makes these seeds, as a functional ingredient to fight against micronutrient deficiency, mainly Iron and Zinc.

3.3. Phytochemical profile

According to the results provided by Pontoni et al. (2025) determination of the bioactive profile of three varieties of lentils revealed that lentils contained antioxidant, total polyphenol, and tannins, as the most secondary metabolites [46–48]. The following Figure 3 presents the trend of these factors before and the effect of the germination process on them.

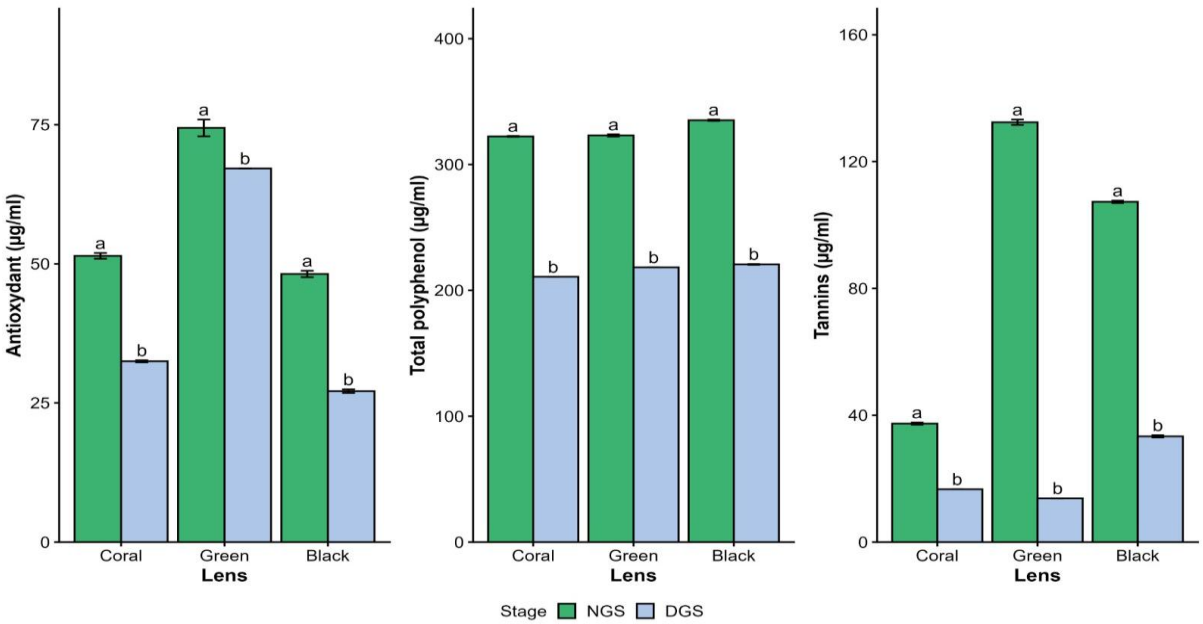

Figure 4. Phytochemical profile of three varieties of lentils before and after germination with NGS: Non-germinated Seeds, DGS: Dried Germinated Seeds

Regarding the total polyphenols and tannins, non-germinated seeds contained high phenolic content, with the black variety having the highest concentration at 335.20 ± 0.70 µg/ml. However, this value decreased due to the germination stage combined with drying. These processes dropped the total polyphenol of black lentils to 220.62 ± 0.58 µg/ml and reached the lowest value of 210.85 ± 0.00 µg/ml for the coral lentils.

Interestingly, germination induced massive degradation of tannins from 107.29 ± 0.64 µg/ml to 33.34 ± 0.58 µg/ml (black lentils). And coral lentils have the lowest content of tannins after germination, with 16.67 µg/ml. Statistical analysis confirmed that these changes are highly significant ($p < 0.05$) for all varieties. Many authors, such as Yilmaz Tuncel et al. (2025), Elliot et al. (2022), and Atudorei et al. (2021), explained this downward trend. It is due to the enzyme activation, such as polyphenol oxidase and peroxidase, during germination. In addition, there was leaching of soluble phenolic fractions during the soaking stage, and it was severe during the drying process. [40,59,63–65]

About antioxidants, it follows the same way as the phenolic activity and tannins. The laboratory experiment results reflected a decrease in the antioxidant capacity of lentils. From Figure 4, the green seed showed the highest oxidant capacity, before germination (74.43 ± 2.59 µg/ml), while the black lentils had the lowest value after germination (27.16 ± 0.58 µg/ml). The observed reduction is correlated with the decrease of total polyphenols and tannins, on the one hand. On the other hand, metabolic degradation occurs during seedling development. This induced a lower antioxidant level for all of the dried germinated lentils [59,63]. In 2022, Elliot et al. and in 2025, Yilmaz et al. reported that compared to the nutritional significance of antinutritional factors, it represents a significant quality improvement in the digestibility and mineral bioavailability of the legumes, such as the lentils [47,63–65]. Tannins are known as inhibitors of digestive enzymes like α-amylase and trypsin [66], and their reduction up to 83% (from 133.02 to 22.25 µg/ml) in green lentils decreases these inhibitory effects.

3.4. Antifungal and antimicrobial activities

Using the Broth microdilution method, as shown in Figure 5, lentil extract exhibited dose-dependent antibacterial activity against six pathogenic microorganisms (*Escherichia coli, Salmonella, Shigella, Staphylococcus aureus, Listeria monocytogenes, and Clostridium perfringens*),

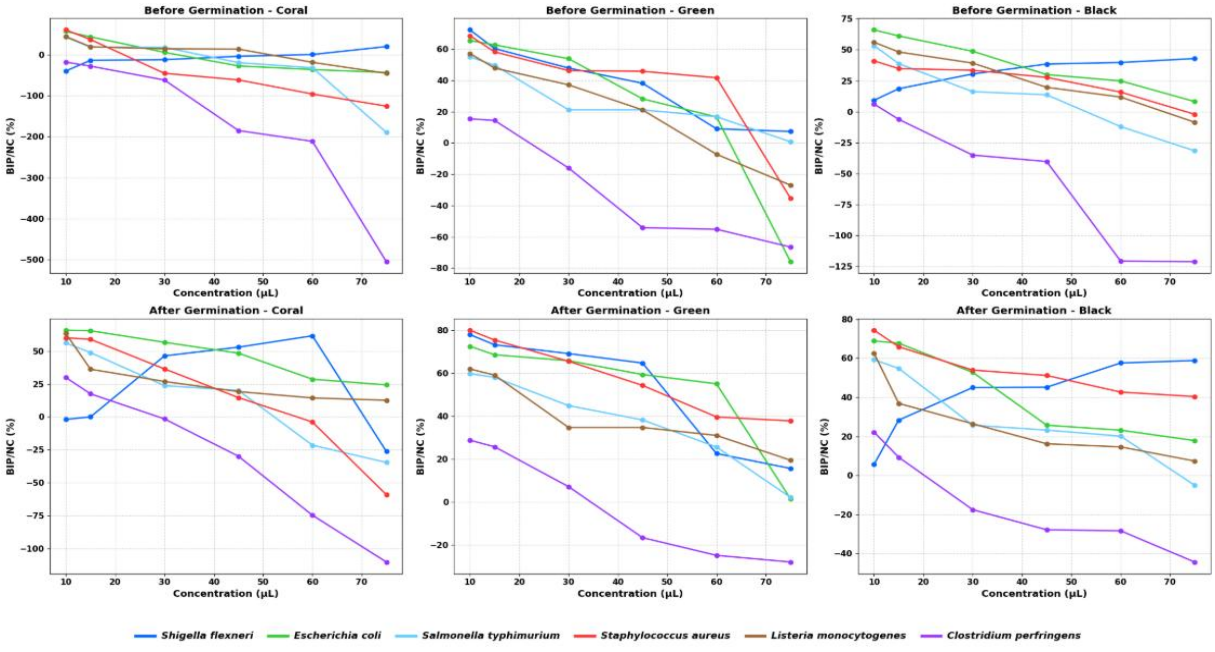

Figure 5. Microbial activity of three varieties of lentils in correlation with BIP%/N: Bacterial Inhibition Percentage on Negative Control

Overall, before and after germination, the lentil extract inhibits the growth of Gram-negative bacteria (*Escherichia coli, Salmonella, and Shigella*) and Gram-positive bacteria (*Staphylococcus aureus, Listeria monocytogenes, and Clostridium perfringens*). That is related to Alexander et al. (2024) results about the efficacy of lentils antimicrobial activity [47]. At high doses of extract, negative BIP% values marked inhibition or low stimulation of bacterial development. Dried germinated extracts (DGS) showed the best efficacy across all strains and varieties, with BIP%/NC values negative at higher concentrations (at 60 to 70 µl). For instance, against *Staphylococcus aureus,* inhibition dropped from -125.46 % (coral NGS at 75 µL) to -59.17 % (DGS), and from -35.32 % (green NGS) to 37.84 % (positive growth in DGS). Similar trends were observed for *Listeria monocytogenes* (from -125.46 % to -40.37 % in black) and *Clostridium perfringens* (from -189.66 % to -34.64 % in coral). These changes were highly significant ($p < 0.05$) and were due to the degradation of antimicrobial compounds during germination and leaching during soaking/drying [54].

However, for several pathogens, germination stabilized or even enhanced inhibition at low-intermediate doses (10 to 45 µl), especially for green and black lentils. For example, green lentils remain high after germination against *Escherichia coli* (from 72.55 to 59.41%). It stays above zero at higher doses. That phenomenon was probably caused by the effect of bacteriostatic persistence despite the reduction in total polyphenolic described previously. The dose-effect relation was not strictly linear because some inhibition was observed at intermediate concentrations, followed by a reduction of negative value at high doses.

In fact, especially for green and black varieties before and after germination, *Escherichia coli* and *Salmonella typhirium* are generally the most sensitive to the extract with BIP% values above 50%. In contrast, Clostridium presented a low sensitivity to lentil extract, with a BIP% negative. That confirmed that anaerobic Gram-positive species are resistant to phenolic vegetal extract [67,68]. Across doses and strains, green and black lentil extracts had higher inhibition percentages than coral. Czerkas et al. (2024) mentioned that the phenomenon is correlated with the high initial contents of polyphenols and tannins, because they are the bioactive serve as key antimicrobials [69]. Enzymatic hydrolysis during germination converted complex phenolics into simpler forms. It reduced antimicrobial potential but enhanced digestibility [70,71].

4. Conclusion

In summary, this study demonstrates that germination significantly enhances the nutritional and bioactive profiles of coral, green, and black lentils. It highlights the critical role of water in seed germination, while Non-germinated seeds contained high macronutrient values (proteins 26–27 g/100 g, fibers 7–8 g/100 g) and micronutrients (K 107–115 mg/100 g, Zn 2.8–3.0 mg/100 g), but germination increased proteins (up to 30 g/100 g in black) and mineral density (Ca up to 52 mg/100 g). Bioactive compounds, including total polyphenols (210–240 µg/ml in DGS), antioxidants (27–40 µg/ml), and tannins (17–33 µg/ml), declined post-germination due to enzymatic degradation and leaching.

Antibacterial activity, dose-dependent against Gram-positive and Gram-negative pathogens, was also reduced in dried germinated extracts. Whereas the green and black varieties retained bacteriostatic effects at intermediate doses, correlating with residual phenolics. The black variety consistently outperformed others in mineral retention and bioactive stability. It makes germinated lentils a superior functional food.

These findings highlight germination as a simple process to valorize lentils.

Future research should investigate in vivo bioavailability and sensory acceptance to facilitate their integration into diverse diets for improved global health and food security.

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Conflicts of interest / Competing interests

All the authors declare that there are no conflicts of interest.

Availability of Data and Materials

All data generated or analyzed during this study are included in this published article.

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