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Enhanced nutritional contents of dried and germinated legumes with perspective of antioxidant activity and phenolic contents**

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Abstract. Beans and lentils are good sources of overall phenolic content and have high levels of free radical scavenging capacity. The goal of the present study was to evaluate the phenolic and antioxidant content of both dried and germinated beans and lentils. In order to do this, total phenolic content, 2-2-diphenyl-1-picrylhydrazine, and 2,2'-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid) antioxidant were measured using the Folin-Ciocalteu method. Seven different varieties of beans and lentils were used to extract total phenolic content using 50% (v/v) aqueous ethanol. In samples of germinated seeds, the legumes showed significantly ($p<0.05\%$) higher total phenolic content, 2-2-diphenyl-1-picrylhydrazine, and antioxidant activity. However, the analysis revealed an increase in the total phenolic content content in sprouted beans and lentils and decreased activity in dried beans. The present study suggests that the content of phenolics and antioxidant activity in legumes are increased during the germination process, but are lower in dried samples. The present work supports the idea that germinated beans are a natural source of antioxidants that can be used commercially.

Keywords: beans, diseases, spectrophotometer, radicals, scavenging activity

1. INTRODUCTION

Legumes are cultivated worldwide and have a significant role in human diets (Oyeyinka *et al*., 2017) due to the presence of bioactive compounds having therapeutic effects that help to change the human metabolic system (Marinangeli and Jones, 2011). Compared to people on other continents, Asians consume more legumes that are high in phenols. Legumes also play a role in bone health, which is specifically important in regions with concerns related to bone health. In addition to promote bone health, legumes also offer low glycaemic index protein and minerals (Fuentes-Zaragoza *et al*., 2010). Legumes are antioxidant-rich, containing derivatives like flavonoids, procyanidins, anthocyanins, phenols, and tannins that fight against breast cancer and cardiovascular diseases and exert hypercholesterolemic effects (Zhang *et al*., 2015). Legumes include polyphenols that are essential for physiological and metabolic processes, which reduce the generation of free radicals (Giusti *et al*., 2017). They inhibit the formation

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of reactive oxygen species (free radicals) produced by break down of larger macromolecules in the human body, *e.g*., lipids, DNA, and proteins (Amarowicz *et al*., 2009). The water-insoluble polyphenols play a significant role in antimicrobial, anti-atherogenic, antimutagenic, and anti-inflammation activities (Balasundram *et al*., 2006).

However, the antioxidants and polyphenols present in legumes receive less attention. Germination is a cheap and cost-effective approach to improve bean quality and its nutritional profile. After germination, the antioxidant activity of legumes increased further (López-Amorós *et al*., 2006). Antioxidant compounds produce changes in the biological processes of respiration and new cell development during the germination stage in legumes. This is an effective stage for increasing nutritional activity (amino acid profile (AA), soluble and insoluble dietary fibers, and total soluble solids) and numerous other active components in legumes and pulses (Paucar-Menacho *et al*., 2010; Sakhi *et al.,* 2025). This activity allows legume products to employ as dietary supplements, medicinal components, and food additives (Alkaltham *et al*., 2022).

During germination, various enzymes, including polyphenol oxidases and peroxidases, become activated, which leads to the breakdown of complex molecules as well as the synthesis of new antioxidant compounds. This process promotes the hydrolysis of glycosidic bonds present in phenolic compounds, which results in the release of aglycones – the more bioactive forms of antioxidants (James *et al*., 2020; Atudorei *et al*., 2021). Germinated legumes also decrease the overall fat content and show higher levels of vitamins (*e.g*., riboflavin) and minerals (*e.g*., sodium, magnesium, iron, and zinc). The availability of essential nutrients increases in germinated legumes due to the mobilization of seed reserves (Kiersnowska and Jakubczyk, 2022).

Germinated legumes can be consumed as food/pulverized and used as a medicinal material in the pharmaceutical or medical industries (Ying *et al*., 2013). The benefits of bean germination and its culinary byproducts are becoming well known, because like well known, because these will be acknowledged and included in future consumer food practices. There is a significant likelihood that goods made from germinated legumes will be commercialized (Chinma *et al*., 2021). However, to ascertain and confirm the trend of increasing or decreasing antioxidants and phenols in legumes, extensive research is still needed (Liu *et al*., 2022).

The current study aimed to evaluate the content of polyphenols and antioxidants 2-2-diphenyl-1-picrylhydrazine (DPPH) and 2,2'-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid (ABTS) of dried and sprouted beans/lentils.

2. MATERIALS AND METHODS

2.1. Collection of seeds

The certified beans were obtained from "Ayub Agricultural Research Institute" in Faisalabad, Punjab, Pakistan, on personal request for research purposes.

Sample preparation: Five different kinds of beans were selected for analysis, including black chickpeas (*Cicer arietinum*), cowpeas (*Vigna unguiculata*), white chickpeas (*Cicer arietinum*), mung beans (*Vigna radiata*), red beans *(Phaseolus vulgaris)*, and two kinds of lentils (*Vigna mungo*) and masoor (*Lens culinaris*) for analysis. Each of the samples was divided into 3 parts, of which 1 was subjected to germination while the other two were analyzed for total phenolic content (TPC) and antioxidant activity (DPPH and ABTS).

2.2. Germination of samples and percent elongation measurement

The 2-3 g samples from each of the 7 varieties of beans or lentils were taken, cleaned, and washed using running water. Later on, they were soaked in water at 28°C for 1 h. Excess water was removed after 1 h and the seeds were placed in a sprouter (60×150 mm) for germination at 28°C in a darker place. This size provided an adequate area that prevented overcrowding where germination rates and elongation may be compromised. The germination period was 120 h, with the seeds moistened after every 24 h interval. The seeds were incubated at 28°C until 98% germination was achieved. At 98% germination, the biochemical characters of seeds are altered in order to increase their nutritional value. A hygrometer was used to ensure that the relative humidity remained between 70 and 80% within the germination chamber, thereby providing optimal germination conditions. The radicle elongation percentage of the germinated lentils/beans was measured using a measuring scale and calculated using the formula:

$$\%EL\ (elongation) = \frac{L_f(when\ finally\ ruptures) - L_o(original\ gauge\ length)}{L_o(original\ gauge\ length)} 100.$$

Extraction of samples: The beans/lentils (100 g) were soaked up in distilled water for 24 h, then sieved and milled with 400 mL of distillate water, sterilized for 1 h in an autoclave and cooled for 24 h. The samples were extracted for 3 h with 70% (v/v) ethanol (700 mL) using a magnetic paddle. This ratio is not as polar as distilled water and it is also less nonpolar than pure ethanol; this shown that the solution is able to extract most bioactive substances, both polar and non-polar metabolites, due to the logical middle-range polarity. This balance enables the solubilization of a range of phytochemicals, including phenolics and flavonoids, which may not be extracted in the same way by pure solvents. This mixture was then centrifuged for 10 min at 4500 rpm at 25ºC in a capped centrifuge tube and poured

into a lab dish. The remaining pellet and residues were extracted again with 70% (v/v) ethanol (300 mL) for 3 h again using a magnetic paddle and then centrifuged for 10 min at 4500 rpm. Both extracts were combined to give approximately 1200 mL and kept in a refrigerator until drying. Before drying, the samples were concentrated to 100 mL by a Büchi rotavapor at 50°C and 5-15 kPa (pressure). This extract was dried on a Büchi Mini Spray Dryer (Flawil, Switzerland) after water dilution. The inlet (120-125°C) and outlet (60-63°C) temperatures were adjusted, and the dried samples were kept in a freezer (-22°C) for further analysis.

Preparation of solutions for analysis:

A) Gallic acid equivalent (GAE mg g^{-1}) standard solution: 0.100 g of gallic acid (GA) and a volume up to 100 mL of distilled water were taken for the preparation of the gallic acid stock solution. Standard solutions of 10, 20, 50, 100, 150, and 200 µL were prepared for 5 mL of gallic acid solution constituents to further create the standard curve of a 2-40 µg mL^{-1} linearity range. B) 2, 2-diphenyl-1-picrylhydrazyl radical (DPPH) solution (0.1 mM), a stable free radical used to measure antioxidant activity. The 39.4 mg of DPPH was weighed, placed in a beaker, and dissolved in 1 L of ethanol to prepare 0.1 mM of a solution for DPPH analysis. C) 2,2'-Azinobis-(3-Ethylbenzothiazoline-6-Sulphonate) (ABTS) solution (0.1 mM). For the preparation of 0.1 mM of an ABTS solution, 0.22 mg of ABTS, another antioxidant assay used to evaluate the scavenging activity of antioxidants, was added in a beaker containing ethanol to the volume.

2.3. Determination of total phenolic content

The Folin-Ciocalteu reagent was the standard method used to measure the total phenolic contents proposed by Xu and Chang (2007). The 50 µL of extract and 250 µL of Folin-Ciocalteu reagent were taken. The 750 µL of Na_2CO_3 (7% w/v) and 3 mL of distilled water were added to the mixture and left for 8 min. Distilled water (950 µL) was added again to the mixture, and allowed to stay for another 2 h at room temperature. The blank was run with distilled water in a UV/visible spectrophotometer (Schimadzu UV 1700) with absorbance at 765 nm. The samples were run in triplicate and the results were taken as gallic acid equivalent (mg GAE g^{-1}) measured by a standard curve of gallic acid. The calibration standard curve of gallic acid has a linearity range of 2 – 40 µg mL^{-1} and $r^2 = 0.9991$ (Fig. 1).

2.4. Determination of antioxidant capacity (AC)

A) DPPH antioxidant activity was determined accordingly Xu and Chang (2007). A DPPH solution (ethanolic) of about 3.8 mL was taken and mixed with 0.2 mL of sample extract. The mixture was vortexed for 1 min and then kept in a dark place for 30 min. The blank was run using ethanol by a spectrophotometer (Schimadzu UV 1700)

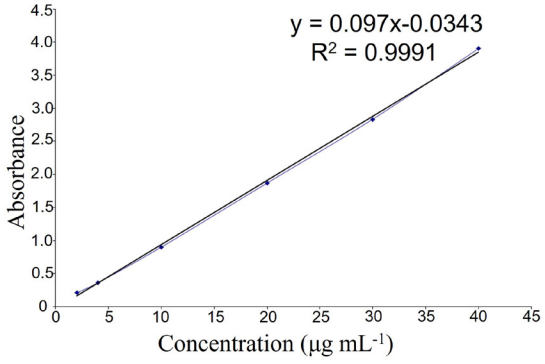

Fig. 1. Calibration curve for gallic acid.

and measured at absorbance level of 517 nm. The following equation was used to calculate the discoloration of the DPPH sample: $[1– (A_{sample}/A_{cont})]$ 100. BHA was used as a standard, and a calibration curve was drawn to determine the AOs (µg BHA 100 g^{-1}) of dried/germinated lentils/beans. B) ABTS: Initial mixing was done by adding 3.0 mL of diluted ABTS solution (0.1 mM) to 0.2 mL of legume extract. Absorbance of the prepared solutions was taken at 734 nm after 10 min. The ABTS activity of the samples was calculated as the difference between $A_{initial}$ and $A_{10\ min}$ after the sample reaction. All samples were run in triplicate, with methanol taken as a blank solution. BHA was used as a standard, and drawn a calibration standard curve to determine the antioxidant activity (µg BHA 100 g^{-1}) of dried/germinated lentils or beans.

2.5. Statistical analysis

Results were collected as mean ± standard deviation. All analyses were performed in triplicate, and significance ($p<0.05\%$) was assessed using ANOVA (Analysis of Variance). SPSS software was used to analyze the data statistically. Principal component analysis (PCA) and correlations (collinearity) were determined using the TIBCO Statistica software (version 12.0, StatSoft Inc., Palo Alto, CA, USA) at a significance level of $\alpha<0.05\%$. Principal component analysis (PCA), analysis of variance, and correlation determination were performed at the significance level of $\alpha = 0.05$. The PCA data matrix for the statistical analysis of the results had 6 columns (compound names) and 7 rows (case type). The Cattel criterion was used as a base to determine the optimal number of PCAs. The input matrix was scaled automatically.

3. RESULTS

3.1. Effects of germination time on radicle elongation

Elongation at a germination period of 120 h showed a quick tendency of germinated lentils/beans. At the germination day 5 (120 h), higher radicle elongation was observed in cowpea (23.3 cm), followed by red beans (21.5 cm)

and masoor lentils (14.5 cm) than the other varieties. The elongation percentage decreased in *Lens culinaris, Phaseolus vulgaris,* and *Vigna unguiculate* at a germination period of 72 h. The observed trends reveal that the red beans and cowpea showed more elongation, possibly due to water absorption during germination and species-specific differences in metabolic activity. The analysis revealed that, with an increase in the germination period, the elongation efficacy decreased in the samples. Thus, a germination period of 1-3 days is suggested to be the most effective (Fig. 2a).

The percentage elongation of 77.33, 87.32, and 72.59% was found in *Phaseolus vulgaris, Lens culinaris,* and *Vigna radiata* sprouts, respectively, and it reached its peak at 72 h, while at days 4 and 5, the *Lens culinaris* percentage elongation dropped to 56 and 25%, respectively. These decreases may indicate a critical point reached by the germination process, where radicle elongation was delayed due to environmental factors or reduced nutrient availability. The percentage elongation in *Phaseolus vulgaris* and *Vigna radiata* at day 4 and 5 was reduced. *Vigna mungo* (25.86%) showed the lowest elongation percentage on day 5 (Fig. 2b).

3.2. Total phenolic content in dried and germinated seeds

The results revealed a significant increase in TPCs in all seven varieties of beans/lentils after germination (Table 1).

Previous studies showed that TPC was affected by legume fractions and the duration of germination. However, the current study revealed a significant ($p<0.05\%$) increase in TPC with an increase in the germination period, compared to original leguminous seeds. The highest level of TPC was found in germinated red beans (*Phaseolus vulgaris*) at 15.40 mg GAE g^{-1}, while the lowest value was found in white chickpeas (*Cicer arietinum*) at 2.52 mg GAE g^{-1}.

In the germinated and dried samples of white lentils, the total phenolic content of 8.93 mg GAE g^{-1} and 6.62 mg GAE g^{-1} were shown in this study, respectively. Among the other samples, *Lens culinaris* had a lower TPC of 1.49 mg GAE g^{-1} (Table 1).

The order of germinated legumes in terms of TPC is as follows:
Red beans > Masoor > Mung > Mash > Cowpea > Black chickpeas > White chickpeas.

The order of dried legumes is as follows:
Mash > Red beans > Mung > Cowpea > White chickpea > Black chickpeas > Masoor, as shown in Table 1.

This antioxidant capacity was influenced by germination time and leguminous fractions. The antioxidant capacity of lentils was provided by low molecular-weight phenolic compounds. The DPPH analysis revealed the antioxidant activity of germinated and dried legumes to be from 0.74 to 14.01 µg BHAE 100 g^{-1} and from 4.63 to 14.06 µg BHAE 100 g^{-1}, respectively. Germinated red beans showed the highest DPPH activity at 18.59 µg 100 g^{-1}, compared to dried beans at 14.06 µg 100 g^{-1}. Moreover,

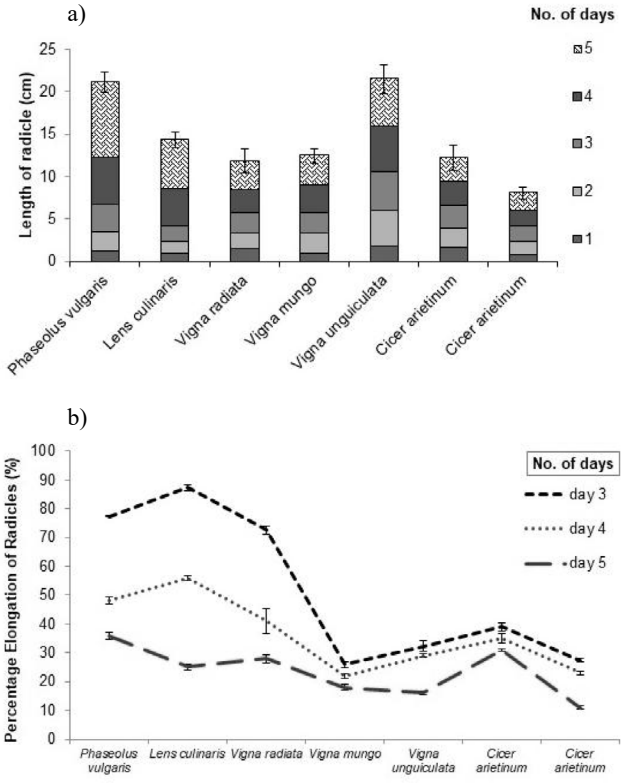

Fig. 2. a) Kinetic changes of radicle length (cm) of beans/lentils with germination time, b) percentage elongation of radicles (beans/lentils) germination with time.

Table 1. Mean values comparison of TPC in dried/germinated beans/lentils (approximately)

Species name	GB/L	DB/L
P. vulgaris (RB)	15 ± 0.01^{a}	4 ± 0.4^{b}
V. radiata (MB)	10 ± 0.08^{c}	3 ± 0.3c
V. unguiculate (CP)	4 ± 0.14^{d}	2.3 ± 0.1^{c}
C. arietinum (BCP)	3 ± 0.06^{e}	2 ± 0.2^{d}
C. arietinum (WCP)	3 ± 0.01^{d}	2 ± 0.6^{c}
L. culinaris (Ms/L)	12 ± 0.16^{b}	2 ± 0.03^{d}
V. mungo (ML)	9 ± 0.05^{b}	7 ± 0.6^{a}

RB – Red Bean, Ms/L – Masoor/Lentil, MB – Mung Bean, ML – Mash Lentil, CP – Cowpea, BCP – Black Chick Pea, WCP – White Chick Pea DB/L: Dried beans/lentils, GB/L – Germinated beans/lentils. Values in the same column marked with different letter differ significantly ($p < 0.05$).

the DPPH activity of germinated white beans was 3.76 µg 100 g^{-1}, compared to dried white beans, which had the lowest value of 0.74 µg 100 g^{-1}. The ABTS activity was found to be better in determining the phenolic contents of dried beans/lentils. Black chickpeas, mash (White lentils), white chickpeas, and cowpea with ABTS showed effective

Table 2. Mean values comparison of DPPH (scavenging/inhibition activity) and ABTS in dried/germinated beans/lentils (approximately)

Species name	% Inhibition (0.1 mM)		Antioxidant capacity (µg equivalent of BHA/100 g^{-1})			
	ABTS	DPPH	GB/L	DB/L	GB/L	DB/L
	(GB/L)		(DPPH)		(ABTS)	
P. Vulgaris (RB)	83 ± 0.07	68 ± 3.4	19 ± 0.01^{a}	14 ± 2.9^{a}	15 ± 0.9^{b}	12 ± 1.7^{a}
V. radiata (MB)	58 ± 0.10	16 ± 0.6	11 ± 0.01^{c}	1.1 ± 0.9^{e}	11 ± 2.2^{d}	10 ± 1.2^{b}
V. unguiculata (CP)	23 ± 0.06	7 ± 2.4	3.8 ± 0.02^{c}	1.0 ± 3.1^{d}	14 ± 1.1^{c}	10 ± 1.8^{b}
C. arietinum (BCP)	15 ± 0.05	6 ± 1.5	1.4 ± 0.04^{d}	4.2 ± 2.1^{c}	22 ± 2.2^{a}	8 ± 3.0^{c}
C. arietinum (WCP)	12 ± 0.06	3.3 ± 0.5	2.3 ± 0.01^{e}	5 ± 1.0^{c}	15 ± 1.7^{c}	10 ± 2.7^{a}
L. culinaris (Ms/L)	67 ± 0.02	5 ± 0.3	14 ± 0.02^{b}	5 ± 0.8^{c}	13 ± 2.7^{c}	8 ± 1.9^{c}
V. mungo (ML)	51 ± 0.08	36 ± 1.6	9.2 ± 0.01^{d}	4.6 ± 2.0^{b}	15 ± 2.5^{b}	12 ± 3.7^{a}

Values in the same column marked with different letters differ significantly ($p < 0.05$).

radicle-scavenging activity, compared to DPPH in germinated beans and lentils. The current study revealed that the antioxidant capacities of germinated lentils were greater at 14.01 µg 100 g^{-1} than dried lentils (Masoor) (Table 2).

3.3. Estimation of radical scavenging activity

ABTS and DPPH are stable and effective sources to estimate the free radical scavenging activity of legumes. The quantity of polyphenols in beans is related to their antioxidant capacity. The observed antioxidant capacities of DPPH and ABTS in germinated beans and lentils were found to have a maximum value in this study (Table 2). The decreasing order of the ABTS inhibition percentage of germinated beans/lentils of is given below:

Phaseolus vulgaris > *Lens culinaris* > *Vigna radiata* > *Vigna mungo* > *Vigna unguiculata* > *Cicer arietinum* (black) > *Cicer arietinum* (white).

The decreasing order of inhibition with respect to DPPH is given below:

Phaseolus vulgaris > *Vigna mungo* > *Vigna radiata* > *Vigna unguiculata* > *Cicer arietinum* (black) > *Lens culinaris* > *Cicer arietinum* (white) (Table 2).

The phenolic content and antioxidant activity of legume extracts were significantly correlated. Overall, the analysis revealed the highest TPC in germinated beans, compared to lentils. In addition to antioxidant activity (ABTS and DPPH), it showed an increasing trend of AO activity in both germinated beans and lentils. In the present study, stronger free radical scavenging activity was exhibited by red beans (*Phaseolus vulgaris*). This might be due to the presence of a high level of phenolics and antioxidant compounds.

3.4. Principal component analysis (PCA)

The matrix of correlation of all the analyzed parameters is presented in Table 3. The correlation between the explained variables was determined by the determinant of the correlation matrix. Correlation close to 0 showed a stronger effect, while correlation closer to range 1 showed a lower degree of collinearity among the variables. PCA

Table 3. Correlation matrix for the tested parameters

r>= -1 -0.80 -0.60 -0.40 -0.20 0 0.20 0.40 0.60 0.80 1

	ABTS (GB/L)	DPPH (GB/L)	GB/L(DPPH)	DB/L(DPPH)	Germinated	Dried
ABTS (GB/L)	1.000	0.697	0.992	0.548	0.997	0.321
DPPH (GB/L)	0.697	1.000	0.714	0.817	0.726	0.590
GB/L(DPPH)	0.992	0.714	1.000	0.612	0.995	0.262
DB/L(DPPH)	0.548	0.817	0.611	1.000	0.601	0.180
Germinated	0.997	0.726	0.995	0.601	1.000	0.312
Dried	0.321	0.590	0.262	0.180	0.312	1.000

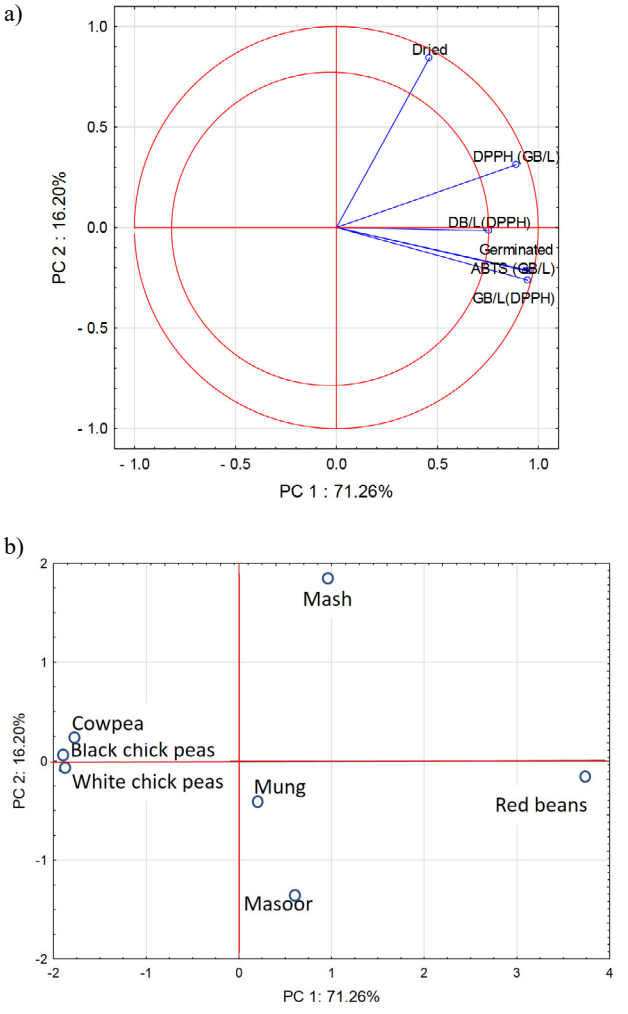

Fig. 3. Projection of: a) variables compounds on the PC1 and PC2 loadings plot, b) cases on the PC1 and PC2 scores plot.

contains six variables representing the variability of components in the system. Figure 3 present variables on two planes: PC1 at 71.26% and PC2 at 16.20%, with a dependence level of 87.46% (Fig. 3a).

The correlation matrix showed strong and positive collinearity among GB/L (DPPH), ABTS (GB/L), DB/L (DPPH). Moreover, a weak positive collinearity was found between the above-mentioned parameters and DPPH (GB/L), and there was no correlation between them. The variability of PCA was strongly affected and influenced by the compounds and components within the two-circular regions (Fig. 3a). Figure 3b indicated the cases. PC1 (positive) and PC2 (negative) showed the case of legumes like Masoor, red beans, and Mung, while +ve PC1 and -ve PC2 values describe the Mash case. In turn, the negative PC1 values describe Cowpea, Black chick peas, and White chick peas.

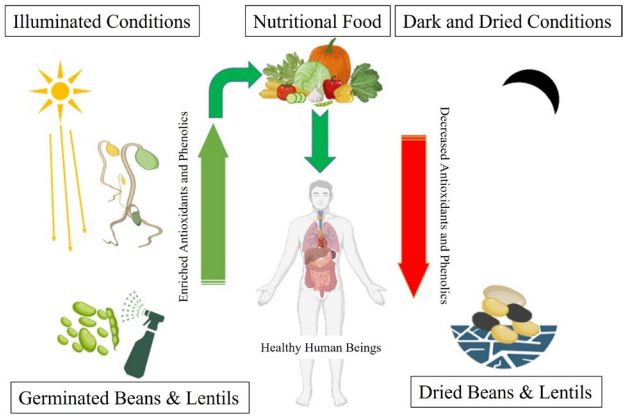

Fig. 4. Health oriented benefits of germinated beans and lentils suppressed under the influence of dark conditions.

4. DISCUSSION

Legumes, not rice, corn, millet, or wheat, are known for their total phenolic chemicals. Due to their antioxidant properties, the major phenolic classes in beans and lentils are becoming popular. The major groups of phenolic chemicals found in beans and lentils are becoming well-known due to their antioxidant effects. The levels of phenolics, tocopherols, and vitamin C, *i.e.* all naturally occurring endogenous antioxidants, change during the germination of legume seeds (Fig. 4). Giusti *et al*. (2017) examined 14 polyphenolic substances, with dehulled red lentils having a polyphenol content of 3 mg kg^{-1} and TPC of 1630.5 mg kg^{-1} in ruviotto beans.

The germination period of bean fractions is influenced by the phenolic compounds present therein. The TPC in the legumes increased after germination. The TPC concentration in cotyledons, lentil seed hulls, and radicles significantly increased ($p<0.05\%$) with an increased germination period (Chávez-Mendoza *et al*., 2019). The findings reported by Aguilera *et al*. (2015) were similar to those obtained by Duenas *et al*. (2009, 2015) for lentils and beans. Lentils greatly outperformed kidney beans in terms of TPCs, which did not change (Ganesan and Xu, 2017). The findings of the current study were slightly different from those shown by Chávez-Mendoza *et al*. (2019) in TPC results, which were significantly ($p<0.05\%$) higher in the current study than those reported in the seed coating of beans (range from 0.69 to 3.32 mg GAE g^{-1}).

TPC was found to be higher in red, black, and brown beans (Ganesan and Xu, 2017). Dried beans (*Phaseolus vulgaris* L.) and adzuki beans were polyphenol-rich (Amarowicz *et al*., 2008), while faba bean extracts contained polyphenols within the range of 40.7 to 66.1 mg g^{-1} (Rybiński *et al*., 2019). Pea seeds (Amarowicz and Troszyńska (2003) showed the lowest TPC as well as broad beans (Amarowicz *et al*., 2008). Fenugreek, dried black

beans, white chickpea, and chickpea exhibited minimum levels of phenolics of 5.79, 5.68, 1.83, and 1.70 (Saleh *et al.,* 2019).

The total phenolic content of *Lens culinaris* (1.49 mg GAE g^{-1}) in the current findings was significantly lower than in the study by Salem *et al*. (2014), who reported TPC of about 60.39 mg GAE g^{-1}, Nair *et al*. (2012), who mentioned 1191 mg kg^{-1}, and Awada *et al*. (2005), who mentioned 4730 mg kg^{-1}. On the other hand, Zhao *et al*. (2014) and Amarowicz *et al*. (2009) reported a high content of phenolics in green/red lentils.

The lower content of phenolics during the period of germination might be due to two reasons. One of the reasons could be reactive oxygen species (ROS), while the other was the decreased anthocyanins and flavan-3-ols during germination. ROS greatly influenced the germination process of seeds, transmitting signals that ultimately reduced the antioxidant capacity of legume extracts (beans/lentils) (Gomes and Garcia, 2013).

Phenolics were reported to be reduced in lentils, soybeans, and peanuts during post-germination (Megat Rusydi and Azrina, 2012), irrespective of this study, as shown in Table 1, while Khang *et al*. (2016) determined a significant increase in phenolics during the sprouting of legumes. Xue *et al*. (2021) found a range of phenolics within 44.87-90.31% in germinated black beans, soybeans, and mung beans at first, which significantly decreased afterwards.

In addition to white lentils in the current study, the phenolic levels were similar to those in lupine seeds (8.56 mg gallic acid/g) and faba beans (7.11 mg gallic acid/g). A study by Padhi *et al*. (2017) determined an antioxidant capacity from 1.16 to 7.45 mg GAE g^{-1} DW in 14 Canadian pulses, which included lentils, beans, and peas. They found maximum antioxidant activity in dark testa than pale samples. The presence of active ingredients in legumes increased their antioxidant capacity (AC). The current study showed higher ACs in germinated samples than in dried ones (Masoor), comparable to the findings reported by Enciso-Roca *et al*. (2021), but different from AC in lentils (Zhao *et al*., 2014). Research performed at these parameters supported the fact that, with an increase in the germination period, the contents of anti-oxidants also increased (Saleh *et al*., 2019), as mentioned in the above studies. However, the AC of black beans was not affected by the germination process and remained the same during the whole experimental study.

Gubanenko *et al*. (2019) reported increased antioxidant activity in seedlings of lentils than in sprouted chickpeas. The AC of common beans compared to cotyledons ranged from 23.86 to 84.10% and from 0.66 to 29.77%, respectively (Chávez-Mendoza *et al*., 2019).

The scavenging activity determined in the present study was similar to the findings of Saleh *et al*. (2019). However, they determined AC in lupine and common beans, which showed the highest activity of 84.5% in common beans, compared to lupine seeds (78.29% AC). The current study determined the maximum scavenging activity of over 38.5% in lentils (Zhao *et al*., 2014).

López-Amorós *et al*. (2006) determined high antioxidant activity in beans and lower activity in lentils related to the germination period. This was comparable to the present study, in which these parameters were dependent on the duration of the germination process. TPC and antioxidant activity were investigated in bay beans, Chinese beans, black beans, and grey beans by Wang *et al*. (2015). TPC and AC were high in red beans, red kidney beans, black beans, soybeans, and mung beans but low in red lentils, yellow lentils (daals), and chickpeas.

Several other studies confirm that germination significantly enhances the antioxidant activity of legumes. This is due to the increased metabolic activity during seed respiration as well as cell development. Ultimately, this leads to higher synthesis of antioxidants and essential nutrients like amino acids and dietary fibers (James *et al*., 2020; Atudorei *et al*., 2021; Kiersnowska and Jakubczyk, 2022).

The nutrient-dense composition of processed beans and lentils has the potential to significantly alter food systems and address global nutrition security and sustainability (Siddiq *et al*., 2022). They also offer benefits related to health and nutrition as well as economic and environmental factors that are essential for sustainable development. It has been demonstrating that beans and lentils are a good source of protein, fiber, carbohydrates, and micronutrients; they are also a significant source of minerals (iron, zinc, folate, and magnesium) and vitamins. These all-nutrient sources are linked to better health and lower the risk of infectious and chronic illnesses (Medendorp *et al*., 2022). The phytochemicals found in pulses possess antioxidants and phenolics, indicating that pulses may have significant anti-cancer effects, improve serum lipid profiles, and prevent several other cardiovascular diseases. Emerging research probing the effects of beans and lentils on HIV and consumption patterns may have further effects on health. Beans and lentils in the diet is a healthy way to meet dietary recommendations and reduce the risk of several chronic diseases.

The beans and lentils used in this study are an inexpensive source of nutrients that can be systematically incorporated into diets for humans of all ages at home. Through social protection measures, *e.g*., school feeding programs, they can reduce poverty and malnutrition. Increasing stability, easy utilization, and affordable legume-based products are a key measure for reducing poverty and alleviating malnutrition in developing and underdeveloped countries (Augustin and Cole, 2022).

The incorporation of legume-based food systems has already begun and is supported by industrial-scale manufacturing of protein concentrates. Although the incorporation of bean- and lentil-derived protein in food systems is unlimited, some applications are more common in plant-based bakery, yogurt, brewages, and meat analogues (Goldstein and Reifen, 2022).

5. CONCLUSIONS

The total phenolic content and antioxidants varied among the cultivars of lentils/beans. The legume extract of both beans and lentils revealed higher phenolic levels in germinated samples than in dried samples, where they decreased significantly. Overall, the study found that sprouting can increase the active ingredients in the legumes, which can be beneficial for human beings, while germinated beans are the most useful sources of antioxidants and phenolics among all.

The present study suggested that phenolics and antioxidant activity in legumes are increased during the germination process, which was lower in dried samples. However, germinated beans exhibited the highest activity; therefore, at the commercial level, germinated beans can be used as a source of natural antioxidants in foods.

The present findings can indicate opportunities for farmers to pay attention to sprouting practices as a value-added process, thereby providing consumers with more nutritious products. Consumers may also benefit from these findings by adding germinated legumes to their diets. This will be a more natural way to enhance antioxidant intake and reduce the risk of chronic diseases.

Conflicts of Interest: The Authors do not declare any conflict of interest.

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