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RESEARCH

Comparative Analysis of Nutritional and Functional Properties of Mung Bean Grains, Sprouts, and Microgreens

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ABSTRACT

Malnutrition remains a major global concern, particularly in developing regions. Increasing awareness of healthy diets has spurred interest in nutrient-dense, ready-to-eat functional foods such as sprouts and microgreens. This study evaluated variations in nutritional and functional properties of mung bean (variety MI 5) at three developmental stages, grain, sprout, and microgreen to identify the stage with superior attributes. Grains were germinated to produce sprouts (4 days) and microgreens (10 days). Samples were analyzed for protein and moisture, macroelements (nitrogen, phosphorus, and potassium), phytochemical constituents (total phenolics, carotenoids, and ascorbic acid), chlorophyll content, and antioxidant capacity. Results revealed a progressive enhancement in nutritional and functional qualities from grain to microgreen stages. Microgreens exhibited significantly higher ($p<0.05$) levels of protein, total phenolics, carotenoids, ascorbic acid, and antioxidant activity, while sprouts showed intermediate values. The grains contained the lowest concentrations of most bioactive compounds. These findings highlight mung bean microgreens as nutrient-dense functional food, with health-promoting properties compared to grains and sprouts. Their short cultivation cycle, low input requirements, and high functional value make them an accessible and sustainable option for nutrient-rich diets and public health nutrition strategies.

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INTRODUCTION

Healthy diets are essential for optimal nutrition and disease prevention, providing adequate nutrients while limiting harmful substances (Micha *et al*., 2020; Neufeld *et al*., 2021). Yet nearly three billion people, primarily in sub-Saharan Africa and South Asia, cannot afford such diets (Herforth *et al*., 2020; FAO, 2021) leading to a triple burden of malnutrition: undernutrition, micronutrient deficiencies, and overnutrition, with diet-related overnutrition on the rise (Ebert, 2021). Malnutrition, in turn, is a major risk factor for non-communicable diseases (NCDs) such as diabetes, cardiovascular disease, hypertension, stroke, cancer, and obesity, which collectively account for approximately 40.5 million deaths annually, or 71% of all global deaths (Bennett *et al*., 2018; WHO, 2021), placing a substantial burden on healthcare systems. In response, the United Nation's Sustainable Development Goals (SDG) target both hunger and NCDs: SDG 2 seeks to eliminate malnutrition by ensuring year-round access to safe, nutritious food, while SDG 3 aims to reduce premature NCD mortality by one-third by 2030. Achieving these objectives depends on the sustainable production and equitable distribution of diverse, nutrient-rich foods, which could not only improve global dietary patterns but also deliver co-benefits for climate mitigation and environmental sustainability (Willett *et al*., 2019; Vermeulen *et al*., 2020).

Despite broad agreement on the importance of fruits and vegetables in a healthy diet, several studies have reported that current and projected production levels are insufficient to meet recommended consumption targets (Siegel *et al*., 2015; Bahadur *et al*., 2018). In 2015, only 40 countries, representing approximately 36% of the global population, had adequate fruit and vegetable availability based on age-specific dietary recommendations (Mason-D'Croz *et al*., 2019). Although vegetable consumption in sub-Saharan Africa has increased markedly over the past three decades, total fruit and vegetable intake remains low, averaging 268 g per person/per day, which is substantially below the World Health Organization's recommended intake of 400 g (Mensah *et al*., 2021). Concurrently, growing societal interest in healthy eating and lifestyles, reflected in movements such as the promotion of novel and "superfoods", has driven increased demand for fresh, ready-to-eat functional foods and nutraceuticals over recent decades (Voinea *et al*., 2019). Within this context, microscale vegetables, including sprouted grains and microgreens, have gained global popularity as convenient, nutrient-rich foods. Owing to their high phytochemical content, these foods offer considerable potential to diversify diets, enhance nutritional quality, and help address micronutrient deficiencies (Benincasa *et al*., 2019; Kyriacou *et al*., 2019; Galieni *et al*., 2020).

Sprouts and microgreens are important categories of functional foods derived from the seeds of a diverse range of plants, including vegetables, herbs, cereals, and legumes. These foods are typically consumed raw and are distinguished by a rich phytochemical composition, including phenolic compounds (such as phenolic acids, anthocyanins, chalcones, flavanones, flavones, and flavonols), carotenoids (carotenes and xanthophylls), betalains (betacyanins and betaxanthins), vitamins (including ascorbic acid, phylloquinone, and tocopherols), glucosinolates, amino acids, and a wide range of macro- and micro-minerals (Kyriacou *et al*., 2016; Aloo *et al*., 2021; Pires *et al*., 2021). Sprouts are essentially germinated grains of cereals, pseudo-cereals, legumes, herbs, oilseeds, and vegetables. They are typically produced under dark conditions without the use of a growing substrate or application of synthetic agrochemicals and fertilizers, as water alone suffices for cultivation. Sprouts have a very short growth cycle, usually ranging from 4 to 10 days, and the entire sprout, including the roots, is consumed as the edible portion (Di Gioia *et al*., 2017). During germination, levels of anti-nutritional compounds such as trypsin inhibitors, phytic acid, pentosans, tannins, and cyanogenic compounds are declined, while palatability, nutrient bioavailability, and the concentration of health-promoting phytochemicals are enhanced (Wanasundara *et al*., 1999; Vidal-Valverde *et al*., 2002).

Microgreens are defined as tender, immature greens that are larger than sprouts but smaller than baby vegetables or leafy greens. Morphologically, they consist of a central stem bearing two fully developed, non-senescent cotyledons and typically one pair of small true leaves, while the roots are excluded for consumption (Lenzi *et al*., 2019; Turner *et al*., 2020). They are commonly used as garnishes in salads, sandwiches, soups, appetizers, desserts, and beverages, and are highly valued for their nutritional benefits (Kyriacou *et al*., 2016, 2019; Benincasa *et al*., 2019; Galieni *et al*., 2020). Leguminous microgreens have emerged as a promising functional food owing to their potential to provide a sustained and concentrated source of protein and essential nutrients. Their high nutrient density, relative to seed weight, makes them particularly attractive for addressing nutritional requirements (Jayasankar *et al*., 2025). Concurrently, there is a growing trend toward the incorporation of legumes into diverse food applications due to their recognized health benefits and functional versatility. Although legume grains are known to contain anti-nutritional factors, early growth stages such as microgreens generally exhibit minimal levels of these compounds, thereby enhancing their suitability for human consumption (Medendorp *et al*., 2022). Recent years have seen a great deal of research on sprouts and microgreens, but there are still a number of undiscovered or understudied elements, particularly functional properties. Limited evidence indicates that young seedlings may possess significantly higher concentrations of vitamins, minerals, and bioactive phytochemicals compared to their mature counterparts (Marottickal *et al*., 2026). In this context, the present study is particularly relevant and provided insights because it aims to comparatively evaluate the nutritional composition and functional properties of mung bean (*Vigna radiata* L.) across three developmental stages: grains, sprouts, and microgreens. Mung bean, a protein- and nutrient-rich legume widely grown in Asian countries, is now expanding to other regions (Silva Volpato *et al*., 2025). Furthermore, mung bean is particularly well suited for sprout and microgreen production due to its rapid germination, high biomass yield, and accumulation of bioavailable nutrients during early growth stages. With rising global demand for nutritious foods and sustainable agricultural practices, mung bean offers a promising opportunity to diversify food systems and enhance dietary quality worldwide.

METHODOLOGY

Experimental location, design and treatment structure

The experiment was conducted at the Department of Crop Science, Faculty of Agriculture, University of Peradeniya, Sri Lanka, from July to September 2025. The experiment was laid out in a completely randomized design with four replicates per treatment. The treatment structure consisted of three developmental stages of mung bean: grain, sprout, and microgreen (Figure 1). Preparation of mung bean sprouts was carried out in the general laboratory, while microgreen cultivation was performed in the plant house of the Department of Crop Science. The plant house was maintained under full natural light, with a relative humidity of 75–85% and day/night temperatures of 30 ± 3°C and 26 ± 3°C, respectively. Coir dust and vermicompost mixture of 1:1 (v/v) was selected for the study. The laboratory analyses of all samples were carried out at the Analytical Laboratory of the Department of Crop Science, Faculty of Agriculture, University of Peradeniya.

Preparation of sprouts and microgreens

Certified mung bean grains (variety MI 5) were obtained from the Field Crops Research and Development Institute, Mahailluppallama, Sri Lanka. For sprout preparation, mung bean grains were surface sterilized by immersion in 0.1% sodium hypochlorite solution for 10 min to eliminate the microbial contaminants, followed by three rinses with distilled water. The sterilized grains were then soaked in distilled water for 4 h at room temperature (25–27 °C) to facilitate imbibition. Seed germination was carried out in the dark using tissue paper spread across plastic trays. Each replicate consisted of a single tray containing 250 germinated grains. Sprouts were harvested 4 days after germination, defined as radicle emergence ≥ 2 mm, and subsequently processed for further analyses. Mung bean microgreens were grown in seedling trays (30 × 45 cm). Trays were filled with a coir dust and vermicompost mixture (1:1, v/v) (Table 1), and five grains were sown per hole, resulting in a total of 250 grains per tray for each replicate. Watering was carried out once daily to maintain adequate moisture in the growth medium. Microgreens were harvested 10 days after sowing, when the first true leaves had fully emerged. Harvested microgreens were gently washed with distilled water, blotted to remove excess surface moisture, weighed, and immediately processed for subsequent analyses. For grain analysis, a sample of 250 grains constituted one replicate.

Sample processing

Antioxidant activity, total phenolic content, chlorophyll, ascorbic acid, and carotenoid concentrations were determined using fresh samples, whereas nitrogen (N), phosphorus (P), and potassium (K) contents were analyzed using dried samples. The fresh weights of grains, sprouts, and microgreens were recorded immediately after harvest. A portion of each sample were then stored in a freezer until further analysis, and the other portion was oven-dried at 60–70 °C until a constant weight was achieved. Dry weight (DW) (g/tray) was recorded, and percent moisture content was calculated on a fresh-weight (FW) basis as (FW – DW) / FW × 100. The dried samples were subsequently ground into a fine powder using a blender and stored in airtight containers until further analysis.

Figure 1: Grains (a), sprouts (b), and microgreens (c) from mung beans that were used in the experiment

Table 1. Properties of the coir dust and vermicompost mixture as the growth medium used for microgreen cultivation

Parameter	Value
pH	6.2 ± 1.2
Electrical conductivity (mS/cm)	1.3 ± 0.2
Nitrogen concentration (mg g^{-1})	9.2 ± 1.1
Phosphorus concentration (mg g^{-1})	1.3 ± 0.2
Potassium concentration (mg g^{-1})	4.4 ± 0.1
Cation exchange capacity (cmol kg-1)	2.5 ± 0.1

Measurements of macronutrients and crude protein content

Nitrogen content of grains, sprouts, and microgreens was determined using the Kjeldahl method (Nelson and Sommers, 1973), which quantifies total N through acid digestion, distillation, and titration. Approximately 0.5–1.0 g of each dried sample was digested in concentrated sulfuric acid with a selenium catalyst. The resulting digest was distilled, and the liberated ammonia was absorbed into a boric acid solution. The trapped ammonia was then titrated with 0.1 M hydrochloric acid, and the N content was calculated from the volume of titrant consumed. Crude protein content was subsequently estimated by multiplying total N by a conversion factor of 6.25, as commonly used for plant materials (Shaheen *et al*., 2014). Phosphorus concentration was determined using the molybdo–vanado–phosphate colorimetric method (Kitson and Mellon, 1944), while K concentration was measured using a flame spectrophotometer. The concentration of each nutrient was multiplied by the total dry weight of the sample per tray to estimate the total nutrient content of grains, sprouts, and microgreens of each replicate.

Determination of other nutritional properties

Antioxidant capacity was determined using the 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical scavenging assay, which measures the ability of sample extracts to reduce the stable free radical (DPPH), resulting in a decrease in absorbance (Tepe *et al*., 2005; Elzaawely *et al*., 2007; Hsieh *et al*., 2023). A DPPH solution was prepared in 80% methanol, and an aliquot of the sample extract was mixed with the DPPH solution. After incubation for 2 h at 60 ^{0}C in the dark, absorbance was measured at 515 nm using a spectrophotometer. Antioxidant activity was expressed as percentage inhibition of the DPPH radical, and antioxidant concentration in the extracts was quantified using a calibration curve prepared with appropriate standard solutions.

Total phenolic content was determined using the Folin–Ciocalteu method (Hsieh *et al*., 2023). An aliquot of the sample extract (equivalent to 3 g fresh weight), prepared through homogenizing with 25 mL of 80% methanol, was reacted with Folin–Ciocalteu reagent, and the resulting blue coloration was measured spectrophotometrically at 725 nm (Hsieh *et al*., 2023). The total phenolic content was then calculated from a gallic acid standard calibration curve and expressed as mg gallic acid equivalents (GAE) per gram of sample. Ascorbic acid (Vitamin C) content was estimated using the 2,6-dichlorophenolindophenol (DCPIP) titration method (Singleton *et al*., 1999). Fresh samples (10 g) were homogenized with 3% metaphosphoric acid, and the volume was adjusted to 100 mL using the same solution. The extract was titrated against DCPIP dye, and ascorbic acid concentration was calculated based on the volume of titrant consumed. Total chlorophyll and carotenoid contents were determined using fresh samples according to the method of Lichtenthaler and Wellburn (1983). One gram of fresh sample was ground with 80% acetone using a mortar and pestle, filtered, and the volume was adjusted to 100 mL with 80% acetone. Absorbance of the extract was measured at 663 nm for chlorophyll and 470 nm for carotenoids using a spectrophotometer. Pigment concentrations were calculated by substituting the absorbance values at specific wavelengths into the equations of Lichtenthaler and Wellburn (1983) to obtain chlorophyll and carotenoid concentrations (mg L^{-1}), which were then converted to mg g^{-1} fresh weight based on the extract volume and sample weight.

Statistical analysis

All statistical analyses were carried out using SAS statistical software, University Edition, and statistical significance was considered at $p<0.05$. Prior to analysis, the data were checked for normal distribution. Analysis of variance (ANOVA) was performed to compare the effects of the three developmental stages (grains, sprouts, and microgreens) on measured parameters at a 5% significance level. If ANOVA indicates significant difference, mean comparisons among treatments were conducted using the Least Significant Difference (LSD) test, and the standard error was calculated.

RESULTS

Moisture content

To enhance clarity of the results, percentage changes for selected parameters across treatments were calculated from mean values, and only statistically significant differences are presented. The moisture content differed significantly across the three developmental stages (Figure 2). Sprouts and microgreens exhibited substantially higher moisture levels compared to grains, which showed the lowest moisture content. A substantial increase in moisture content was observed during development, rising from 9.71±0.51% in grains to 87.03±0.82% in sprouts and nearly unchanged in microgreens (86.58±0.55%).

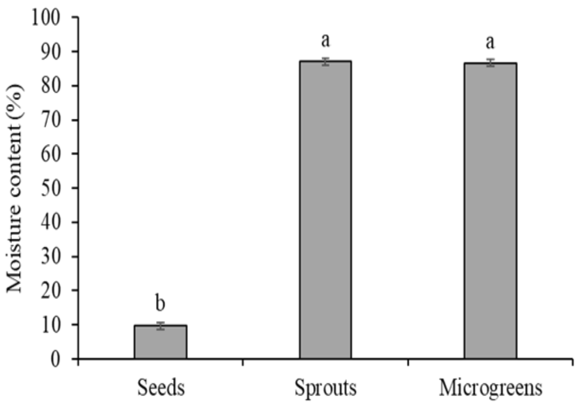

Figure 2: Changes in moisture content (%) across three developmental stages of mung bean: grains, sprouts, and microgreens. Means followed by the same letters are not significantly different at p≤0.05 (LSD test). Error bars represent the standard error (S.E.; n= 4).

Accumulation of macro elements and crude protein

The crude protein content of mung bean differed significantly among developmental stages ($p<0.05$), with a clear increase from grains to sprouts and microgreens (Figure 3A). On a dry weight basis, crude protein content increased progressively from grains (approximately 26%) to sprouts (32%) and was highest in microgreens (45%). This progressive increase indicates that germination and early seedling development substantially enhance protein concentration. Nitrogen concentration increased steadily from grains (40.2±4.8 mg g^{-1}) to sprouts (48.8±1.7 mg g^{-1}) and reaching the highest level in microgreens (67.7±1.5 mg g^{-1}) (Figure 3B). Phosphorus content also increased significantly ($p<0.05$) during germination and early growth, with mean concentrations following the order grains < sprouts <microgreens (Figure 3C). In contrast to the accumulation patterns observed for N and P, K showed a different trend across developmental stages (Figure 3D). Potassium concentrations were comparable between grains and sprouts but were significantly lower ($p<0.05$) than those reported for microgreens. On average, microgreens contained approximately 3.5-fold higher K levels compared to grains and sprouts, highlighting enhanced K accumulation during early vegetative growth (Figure 3D).

Phytochemical properties across three developmental stages

The chlorophyll pigment content of mung bean varied significantly ($p<0.05$) among the grains, sprout, and microgreen stages, reflecting the transition during germination and seedling establishment (Figure 4A). Total chlorophyll content increased significantly from 0.05±0.05 mg g^{-1} FW in grains to 0.065 ±0.03 mg g^{-1} FW in sprouts and reached 0.503±0.13 mg g^{-1} FW in microgreens. The total phenolic content of mung bean exhibited a significant variation among the stages ($p<0.05$), indicating that germination and greening markedly influence the biosynthesis of bioactive compounds (Figure 4B).

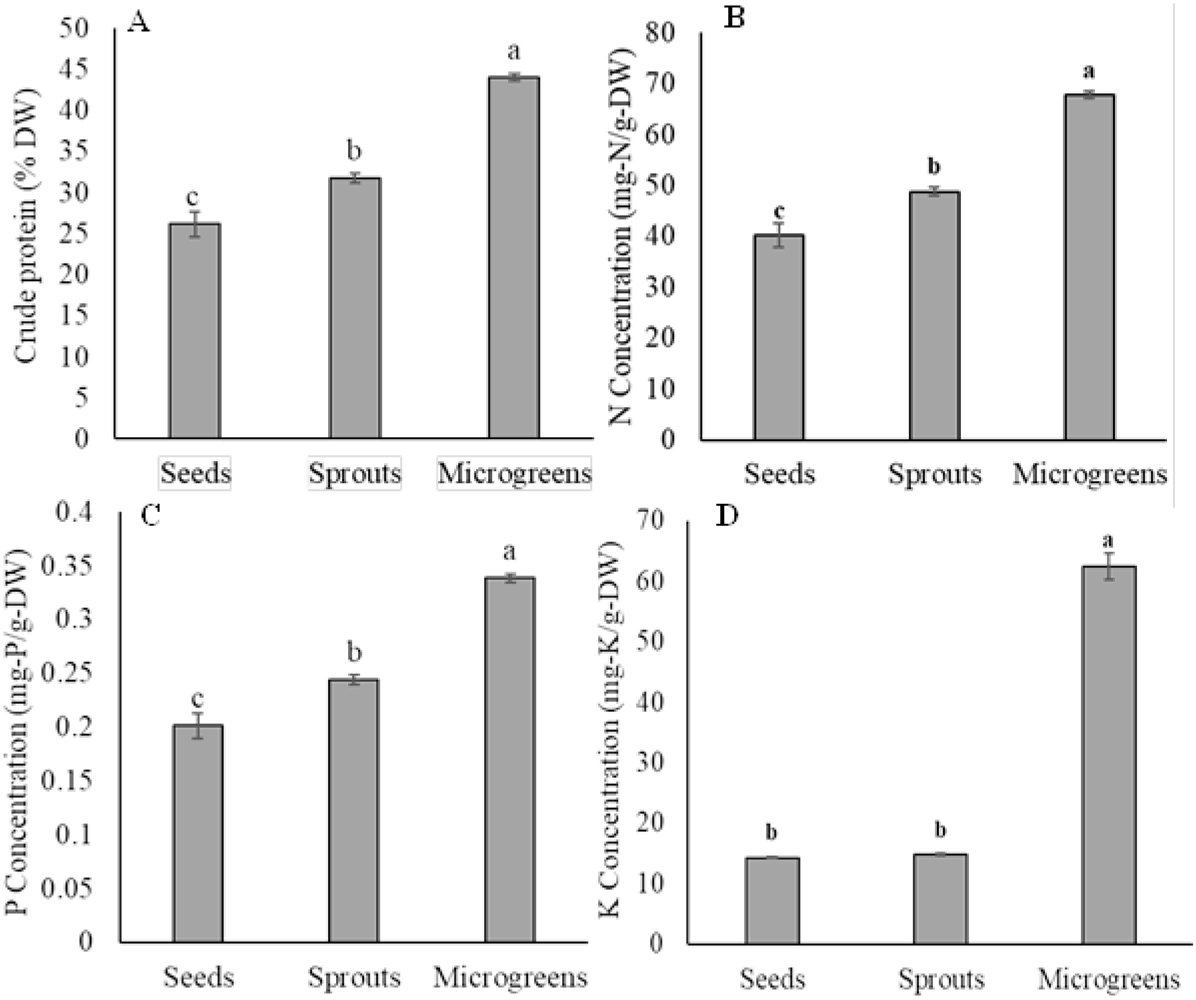

Figure 3. Changes in crude protein content (A), N concentration (B), P concentration (C), and K concentration (D) across three developmental stages of mung beans: grains, sprouts, and microgreens. Means followed by the same letters are not significantly different at p≤0.05 (LSD test). Error bars represent the standard error (S.E.; n= 4)

The total phenolic content increased progressively from 1047±27.2 mg g^{-1} FW in grains to 1244±16.3 µg g^{-1} FW in sprouts and reached 1332±34.8 µg g^{-1} FW in microgreens. Similarly, the carotenoid content of mung beans increased markedly during the transition from seed to sprout and microgreen stages (Figure 4C). The mean carotenoid concentration rose from 0.134±0.085 mg g^{-1} FW in grains to 0.158±0.065 mg g^{-1} FW in sprouts, achieving the highest level of 1.121±0.56 mg g^{-1} FW in microgreens. This progressive enhancement indicates that carotenoid biosynthesis intensifies during germination and early seedling development in mung bean.

The ascorbic acid content of mung bean showed a significant (p<0.05) variation across the three developmental stages, exhibiting a pronounced increase from 4.5±0.72 mg $100g^{-1}$ FW in grains and 5.5±0.72 mg $100g^{-1}$ FW in sprouts, to a value of 25±2.50 mg 100 g^{-1} FW in microgreens (Figure 4D). No significant difference in ascorbic acid content was observed between seeds and sprouts. However, among the three development stages, the microgreen stage showed the highest ascorbic acid content, approximately five times higher than the average values observed in seeds and sprouts (Figure 4D).

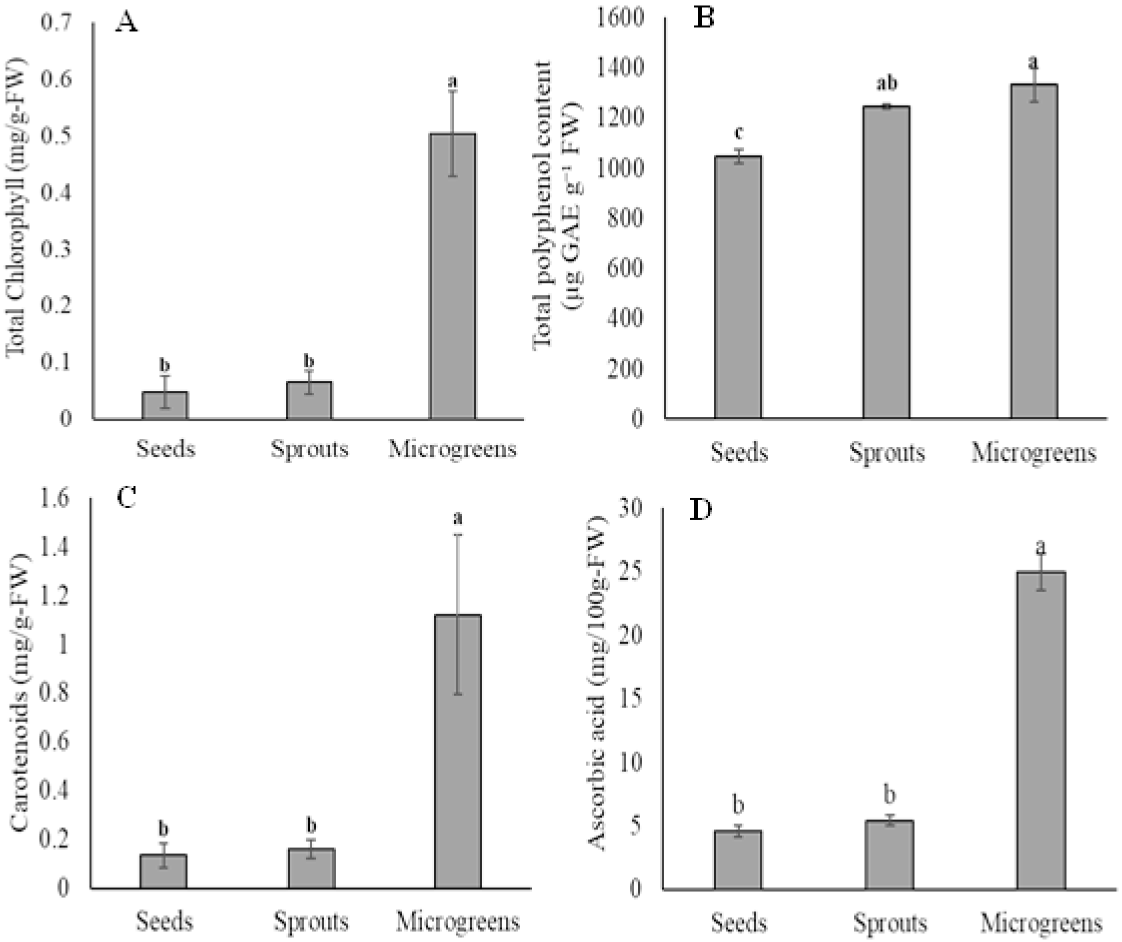

Figure 4. Changes in total chlorophyll (A), phenol content (B), carotenoids (C), and ascorbic acid (D) across three developmental stages of mung bean: grains, sprouts, and microgreens. Means followed by the same letters are not significantly different at p≤0.05 (LSD test). Error bars represent the standard error (S.E.; n= 4)

The antioxidant activity of mung bean exhibited a progressive increase from the seed (34±4.2 µmol TE g^{-1} FW) to the sprout (110±8.5 µmol TE g^{-1} FW) and reached the highest level in the microgreen stage (156±10.7 µmol TE g^{-1} FW) (Figure 5). This increase represents an overall enhancement of antioxidant activity from the dry seed to the microgreen phase, indicating that germination and early seedling development markedly promote antioxidant potential. For example, microgreens exhibited antioxidant levels that were approximately 358% higher than those of grains and 41% higher than those of sprouts. Further, sprouts recorded 223% greater antioxidant activity compared to that of grains (Figure 5).

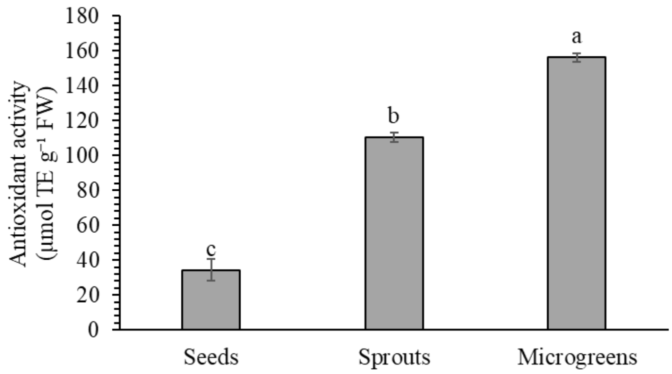

Figure 5. Changes in antioxidant activity across three developmental stages of mung bean: grains, sprouts, and microgreens. Means followed by the same letters are not significantly different at p≤0.05 (LSD test). Error bars represent the standard error (S.E.; n= 4)

DISCUSSION

With increasing societal awareness of healthy dietary practices, global demand for fresh, ready-to-eat functional foods, particularly microscale vegetables such as sprouted grains and microgreens, has risen substantially in recent years (Rouphael *et al*., 2021; Ebert, 2022). In this context, the present study evaluated the nutritional and functional properties of mung beans representing three developmental stages: grains, sprouts, and microgreens. Moisture content showed a clear and progressive increase from grains to sprouts and microgreens with sprouts and microgreens exhibiting comparable moisture levels. On average, moisture content in sprouts and microgreens was approximately 7.5-fold higher than in grains. This magnitude of increase is consistent with previous findings in germinated legumes, where El-Adawy *et al*. (2003) and Guo *et al*. (2012) reported substantial increases in moisture content during sprouting, due to rapid water uptake and activation of metabolic processes. The high moisture content observed in sprouts and microgreens has important nutritional and post-harvest implications, as it facilitates enzymatic activity and improves nutrient bioavailability, while simultaneously increasing susceptibility to spoilage and necessitating careful storage and handling. Overall, these findings underscore that the sprouting and microgreen stages represent highly metabolically active phases characterized by substantial water accumulation, which is essential for rapid tissue growth and nutrient transformation.

The present study demonstrated a clear increase in protein content from grains to sprouts and further to microgreens, with microgreens exhibiting the highest values among the three developmental stages. This progressive enhancement highlights the nutritional advantage of the microgreen stage and is consistent with previous reports by Randhir *et al*. (2004) and Guo *et al*. (2012), who also observed significant increases in crude protein content in germinated mung bean and soybean. The observed increase in protein content may be associated with metabolic reactivation following water imbibition, including the mobilization of storage proteins and the synthesis of new structural and functional proteins during early growth (El-Adawy *et al*., 2003; Mubarak, 2005). Additionally, processes such as the development of photosynthetic machinery and N assimilation could contribute to these changes; however, these mechanisms were not directly investigated in the present study. From a nutritional perspective, the higher protein content of mung bean microgreens underscores their potential as a valuable component of functional foods. As plant-based diets gain increasing global acceptance, microgreens represent a concentrated, digestible, and sustainable source of essential amino acids, making them particularly suitable for vegetarian and vegan populations (Puccinelli *et al*., 2024; Seth *et al*., 2025).

The enhanced protein profile of mung bean microgreens may contribute to their higher antioxidant potential, as amino acids such as cysteine and tyrosine serve as precursors for antioxidant peptides and glutathione biosynthesis (Gu *et al*., 2012). This likely underlies the greater antioxidant activity observed in microgreens compared with sprouts and grains. The concurrently elevated total phenolic content further reinforces their antioxidant capacity and nutraceutical value, given the radical-scavenging, anti-inflammatory, and anticarcinogenic properties of these compounds (Marta *et al*., 2024). Overall, these results offer new comparative evidence that mung bean microgreens are the richest developmental stage in protein and antioxidants, emphasizing their promise as a functional food for enhancing nutrition and supporting health. Further studies are needed to characterize individual antioxidant compounds, assess bioavailability, and evaluate post-harvest stability.

Carotenoid extracts are widely used as therapeutic agents in the prevention and management of ocular and cardiovascular diseases, as well as in cancer treatment (Eggersdorfer and Wyss, 2018; Jambor *et al*., 2022). The relatively low carotenoid concentration in grains can be attributed to their metabolically quiescent state, whereas the increase observed during sprouting reflects the activation of key enzymatic pathways involved in photosynthetic pigment biosynthesis (Maoka, 2020). The consistent trend reported across previous studies, including the present investigation indicates that microgreen development represents a critical phase for carotenoid biosynthesis and accumulation. Consequently, the substantial elevation of carotenoid content in mung bean microgreens markedly enhances their nutritional and functional value. These results suggest that mung bean microgreens are a richer dietary source of carotenoids than grains or sprouts. This observation supports the growing recognition of microgreens as a functional food with promising applications in health-promoting diets and nutraceutical formulations (Sehrish *et al*., 2023; Gunathilake *et al*., 2025). Furthermore, the findings have practical implications for the food industry, where carotenoid-rich microgreens may be utilized as natural colorants and bioactive ingredients in the development of value-added food products (Puccinelli *et al*., 2024; Seth *et al*., 2025).

In addition to carotenoids, the present study observed concurrent increases in chlorophyll and ascorbic acid content across developmental stages, with microgreens exhibiting the highest concentrations (Ebert, 2022; Partap *et al*., 2023). The parallel increase in carotenoids and vitamin C is consistent with previously reported trends in mung bean germination, where several-fold increases in ascorbic acid have been documented (Guo *et al*., 2012; Tang *et al*., 2014), suggesting coordinated enhancement of antioxidant compounds during early plant development. From a nutritional perspective, the elevated vitamin C content in microgreens is particularly important due to its role in immune function, collagen synthesis, and improved iron absorption (Chisnall *et al*., 2017; Nowak, 2021; Alberts *et al*., 2025). Furthermore, the consumption of microgreens in fresh, uncooked form helps preserve thermolabile nutrients, thereby enhancing their dietary value (Ebert, 2022). Collectively, these results demonstrate that mung bean microgreens are a nutritionally enriched stage with significantly enhanced antioxidant composition, highlighting their potential to improve dietary antioxidant intake and contribute to the alleviation of micronutrient deficiencies.

This study provides important insights into the nutritional and functional enhancement of mung bean across developmental stages; however, its findings are limited by the use of a single genotype (MI 5) under controlled conditions and the lack of *in vivo* validation of bioavailability and health effects. Additionally, detailed characterization of individual bioactive compounds and the impact of post-harvest handling on nutrient stability were not addressed. Future research should therefore focus on comprehensive metabolomic profiling, bioavailability, post-harvest management, scalable production strategies, and potential consumer acceptance or market viability to support the effective utilization and commercialization of mung bean microgreens as a functional food.

CONCLUSIONS

The comparative analysis of mung bean across its developmental stages; grains, sprouts, and microgreens, revealed significant and progressive biochemical transformations that markedly enhanced nutritional and functional quality. Among the three stages, microgreens consistently exhibited the highest levels of protein, N, P, and K, as well as elevated concentrations of phenols, carotenoids, ascorbic acid, and overall antioxidant activity, establishing them as the nutritionally and functionally superior form. Sprouts represented an intermediate developmental stage, characterized by balanced mineral composition and moderate antioxidant capacity, whereas grains primarily functioned as storage tissues with limited metabolic activity. These results highlight the potential of mung bean sprouts and microgreens as valuable functional foods that could address protein and micronutrient deficiencies in plant-based diets. Moreover, their rich antioxidant and vitamin profiles position them as promising ingredients for health-oriented food products and nutraceutical applications. Collectively, these findings enhance understanding of nutrient dynamics during early plant growth and underscore the potential of mung bean microgreens as a sustainable functional food to improve dietary quality and promote human health.

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COMPETING INTERESTS

No potential conflict of interest was reported by the authors.

REFERENCES

Alberts, A., Moldoveanu, E. T., Niculescu, A. G., and Grumezescu, A. M. (2025). Vitamin C: A comprehensive review of its role in health, disease prevention, and therapeutic potential. *Molecules* 30:748. https://doi.org/10.3390/molecules30030748

Aloo, S. O., Ofosu, F. K., Kilonzi, S. M., Shabbir, U., and Oh, D. H. (2021). Edible plant sprouts: health benefits, trends, and opportunities for novel exploration. *Nutrients*13(8):2882. https://doi.org/10.3390/nu13082882

Bahadur, K. K. C., Dias, G. M., Veeramani, A., Swanton, C. J., Fraser, D., Steinke, D., Lee, E., Wittman, H., Farber, J. M., Dunfield, K., *et al*. (2018). When too much isn't enough: Does current food production meet global nutritional needs? *PLoS ONE* 13 (10): e0205683. https://doi.org/10.1371/journal.pone.0205683

Benincasa, P., Falcinelli, B., Lutts, S., Stagnari, F., and Galieni, A. (2019). Sprouted grains: a comprehensive review. *Nutrients*11(2):421. https://doi.org/10.3390/nu11020421

Bennett, J. E., Stevens, G. A., Mathers, C. D., Bonita, R., Rehm, J., Kruk, M. E., Riley, L. M., Dain, K., Kengne, A. P., Chalkidou, K., *et al*. (2018). NCD Countdown 2030: Worldwide trends in non-communicable disease mortality and progress towards Sustainable Development Goal target 3.4. *The Lancet* 392 (10152): 1072-1088. https://doi.org/10.1016/s0140-6736(18)31992-5

Di Gioia, F., Renna, M., and Santamaria, P. (2017). Sprouts, microgreens and baby leaf vegetables. *Food Engineering Series* 403-432. https://doi.org/10.1007/978-1-4939-7018-6_11

Ebert, A. W. (2022). Sprouts and microgreens—novel food sources for healthy diets. *Plants* 11: 571. https://doi.org/10.3390/plants11040571.

Eggersdorfer, M., and Wyss, A. (2018). Carotenoids in human nutrition and health. *Archives of Biochemistry and Biophysics* 652: 18–26 https://doi.org/10.1016/j.abb.2018.06.001.

El-Adawy, T., Rahma, E., El-Bedawey, A., *et al*. (2003). Nutritional potential and functional properties of germinated mung bean, pea and lentil seeds. *Plant Foods for Human Nutrition* 58: 1-13. https://doi.org/10.1023/B:QUAL.0000040339.48521.75

Elzaawely, A. A., Xuan, T. D., and Tawata, S. (2007). Essential oils, kava pyrones and phenolic compounds from leaves and rhizomes of *Alpinia zerumbet* (Pers.) B.L. Burtt. & R.M. Sm. and their antioxidant activity. *Food Chemistry* 103(2):486-494. https://doi.org/10.1016/j.foodchem.2006.08.025

FAO, IFAD, UNICEF, WFP, and WHO. (2021). The State of Food Security and

Nutrition in the World 2021. Transforming food systems for food security, improved nutrition and affordable healthy diets for all. Rome, Italy. https://doi.org/10.4060/cb4474en

Galieni, A., Falcinelli, B., Stagnari, F., Datti, A., and Benincasa, P. (2020). Sprouts and microgreens: trends, opportunities, and horizons for novel research. *Agronomy* 10 (9): 1424. https://doi.org/10.3390/agronomy10091424

Gunathilake, S., Aluthge, S., Farahnaky, A., Jafarzadeh, S., and Majzoobi, M. (2025). Cereal and pseudocereal microgreens: Emerging functional foods for human health and sustainability. *Journal of Cereal Science* 125: 104259. https://doi.org/10.1016/j.jcs.2025.104259

Gu, L., Zhao, M., Li, W., You, L., Wang, J., Wang, H., and Ren, J. (2012). Chemical and cellular antioxidant activity of two novel peptides designed based on glutathione structure. *Food and Chemical Toxicology* 50(11): 4085–4091. https://doi.org/10.1016/j.fct.2012.08.028

Guo, X. T. Li., Tang, K., and Liu, R. H. (2012). Effect of germination on phytochemical profiles and antioxidant activity of mung bean sprouts (*Vigna radiata*). *Journal of Agricultural and Food Chemistry* 60 (44): 11050-5. https://doi.org/10.1021/jf304443u

Herforth, A., Bai, Y., Venkat, A., Mahrt, K., Ebel, A., and Masters, W. A. (2020). Cost and affordability of healthy diets across and within countries. Background paper for the State of Food Security and Nutrition in the World *2020.* FAO. https://doi.org/10.4060/cb2431en

Hossain, M., Munné-Bosch, S., Burritt, D., Diaz-Vivancos, P., Fujita, M., and Lorence, A. (2017). Ascorbic acid in plant growth, development and stress tolerance. In *Importance of Vitamin C in Human Health and Disease*, by M., and R. Macknight Chisnall. Springer, Cham. https://doi.org/10.1007/978-3-319-74057-7_19

Hsieh, C. Y., Tsai, J. R., Lee, C. J., Ciou, Y. R., Li, J. S., Tayo, L. L., and Tsai, P. W. (2023). Biological properties and phytonutrient profile of beans: *Vigna angularis*, *Vigna radiata*, and *Glycine max*. *Biointerface Research in Applied Chemistry*13(1):53. https://doi.org/10.33263/BRIAC131.053

Jambor, T., Knizatova, N., Valkova, V., Tirpak, F., Greifova, H., Kovacik, A., and Lukac, N. (2022). Microgreens as a functional component of the human diet: A review. *Journal of Microbiology, Biotechnology and Food Sciences* 12: e5870. https://doi.org/10.55251/jmbfs.5870

Jayasankar, R. R., Mirle, R., Aranganathan, V., Giresha, A.S. (2025). Nutritional composition of leguminous microgreens. In: Mathur, P., Gupta, A. (eds) Recent Trends and Applications of Leguminous Microgreens as Functional Foods. Springer, Cham. https://doi.org/10.1007/978-3-031-75678-8_4

Kitson, R. E., and Mellon, M. G. (1944). Colorimetric determination of phosphorus as molybdovanado phosphoric acid. *Industrial & Engineering Chemistry Analytical*

Edition 16 (6): 379–83. https://doi.org/10.1021/i560130a017

Kyriacou, M. C., El-Nakhel, C., Graziani, G., Pannico, A., Soteriou, G. A., Giordano, M., Ritieni, A., De Pascale, S., and Rouphael, Y. (2019). Functional quality in novel food sources: Genotypic variation in the nutritive and phytochemical composition of thirteen microgreens species. *Food Chemistry* 277: 107-118. https://doi.org/10.1016/j.foodchem.2018.10.098

Kyriacou, M. C., Rouphael, Y., Di Gioia, F., Kyratzis, A., Serio, F., Renna, M., De Pascale, S., and Santamaria, P. (2016). Micro-scale vegetable production and the rise of microgreens. *Trends in Food Science & Technology.* 57: 103–115. https://doi.org/10.1016/j.tifs.2016.09.005

Lenzi, A., Orlandini, A., Bulgari, R., Ferrante, A., and Bruschi, P. (2019). Antioxidant and mineral composition of three wild leafy species: A comparison between microgreens and baby greens. *Foods* 8: 487. https://doi.org/10.3390/foods8100487

Lichtenthaler, H. K., and Wellburn, A. R. (1983). Determination of total carotenoids and chlorophylls. *Biochemical Society Transactions* 11 (5): 591–592.

Maoka, T. (2020). Carotenoids as natural functional pigments. *Journal of Natural Medicines* 74 (1): 1-16. https://doi.org/10.1007/s11418-019-01364-x

Marottickal, S. S., Saji, N., Valattil, N., Sajeev, S, Surendran, T., Kuriakose, R., Syamala, A., Ivanišová, E, Nowicki, M., and Kowalczewski, P. Ł. (2026). Enhanced nutritional value of mung bean microgreens compared to sprouts: a quantitative study" *Open Life Sciences* 21(1): 20251278. https://doi.org/10.1515/biol-2025-1278

Marta, A. E., Stoica, F., Ostaci, S., and Jităreanu, C. D. (2024). The antioxidant profile of some species of microgreens cultivated on hemp and coconut substrate under the action of a biostimulator based on humic acids. *Horticulturae* 10: 1238. https://doi.org/10.3390/horticulturae10121238

Mason-D'Croz, D., Sulser, T. B., Wiebe, K., Rosegrant, M. W., Lowder, S. K., Nin-Pratt, A., Willenbockel, D., Robinson, S., Zhu, T., and Cenacchi, N., *et al*. (2019). Agricultural investments and hunger in Africa modeling potential contributions to SDG2 – Zero Hunger. *World Development* 116: 38-53. https://doi.org/10.1016/j.worlddev.2018.12.006

Medendorp, J., DeYoung, D., Thiagarajan, D.G., Duckworth, R. and Pittendrigh, B. (2022). A systems perspective of the role of dry beans and pulses in the future of global food security. In Dry Beans and Pulses (eds M. Siddiq and M.A. Uebersax). https://doi.org/10.1002/ 9781119776802.ch21

Mensah, D. O., Nunes, A. R., Bockarie, T., Lillywhite, R., and Oyebode, O. (2021). Meat, fruit, and vegetable consumption in sub-Saharan Africa: A systematic review and meta-regression analysis. *Nutrition Reviews* 79: 651-692. https://doi.org/10.1093/ nutrit/ nuaa032

Micha, R., Mannar, V., Afshin, A., Allemandi, L., Baker, P., Battersby, J., Bhutta, Z.,Chen, K., Corvalan, C., Di Cesare, M., *et al*. (2020). *Global Nutrition Report: Action on Equity to End Malnutrition.* Bristol, UK: Development Initiatives Poverty Research Ltd. https://globalnutritionreport.org/reports/2020-global-nutrition-report/

Mubarak, A. E. (2005). Nutritional composition and antinutritional factors of mung bean seeds (*Phaseolus aureus)* as affected by some home traditional processes. *Food Chemistry* 89 (4): 489-495. https://doi.org/10.1016/j.foodchem. 2004.01.007

Nelson, D. W., and Sommers, L. E. (1973). Determination of total nitrogen in plant material. *Agronomy Journal* 65 (1): 109-12. https://doi.org/10.2134 /agronj1973. 0002196200 65 00010033x

Neufeld, L. M., Hendriks, S., and Hugas, M. (2021). *Healthy Diet: A Definition for the United Nations Food Systems Summit 2021.* A Paper from the Scientific Group of the UN Food Systems Summit. 2021. https://www.un.org/sites/un2.un.org /files/healthy_diet_ scientific_group_march-2021.pdf

Nowak, D. (2021) . Vitamin C in human health and disease. *Nutrients* 13 (5): 1595. https://doi.org/10.3390/nu13051595

Partap, M., Sharman, D., Deekshith, H. N., Thakur, M., Verma, V., Ujala, and Bhargava, B. (2023). Microgreen: A tiny plant with superfood potential. *Journal of Functional Food* 107: 105697. https://doi.org/10.1016/j.jff.2023.105697

Pires, D. O. E., Di Gioia, F., Rouphael, Y., Ferreira, I. C. F. R., Caleja, C., Barros, L., and Petropoulos, S. A. (2021). The compositional aspects of edible flowers as an emerging horticultural product. *Molecules* 26: 6940. https://doi.org/10.3390/molecules26226940

Puccinelli, M., Malorgio, F., and D'Imperio, M. (2024). Editorial: Micro-scale vegetable production: sprouts and microgreens as innovative functional foods. *Frontiers in Plant Science* 15: 1395888. https://doi.org/10.3389/fpls.2024.1395888

Reena, R., Yuan-Tong, L., and Kalidas, S. (2004). Stimulation of phenolics, antioxidant and antimicrobial activities in dark germinated mung bean sprouts in response to peptide and phytochemical elicitors. *Process Biochemistry* 39 (5): 637-646. https://doi.org/10.1016/S0032-9592(03)00197-3

Rouphael, Y., Colla, G., and De Pascale, S. (2021). Sprouts, microgreens and edible flowers as novel functional foods. *Agronomy* 11: 2568. https://doi.org/10.3390/ agronomy 11122568

Sehrish, A., Majeed, I., Zongo, E., Ayub, H., Rasul, H., Rahim, M. A., and AL-Asmari, F. (2023). A review on various extraction and detection methods of bio-functional components from microgreens: food applications and health properties. *International Journal of Food Properties* 26 (2): 3082–3105. https://doi.org/10.1080/ 10942912.2023. 2272564

Seth, T., Mishra, G. P., Chattopadhyay, A., Deb Roy, P., Devi, M., Sahu, A., Sarangi, S. K., Mhatre, C. S., Lyngdoh, Y. A., Chandra, V., *et al*. (2025). Microgreens: Functional Food for nutrition and dietary diversification. *Plants* 14: 526. https://doi.org/10.3390/ plants 14040526

Shaheen, S., Harun, N., Khan, F., Hussain, R., Ramzan, S., Rani, S., Khalid, Z., Ahmad, M., and Zafar, M. (2014). Comparative nutritional analysis between *Vigna radiata* and *Vigna mungo* of Pakistan. *African Journal of Biotechnology* 11 (25): 6694–6702. https://doi.org/10.4314/ajb.v11i25

Siegel, K. R., Ali, M. K., Srinivasiah, A., Nugent, R. A., and Narayan, K. V. (2014). Do we produce enough fruits and vegetables to meet global health need? *PLoS One* 9(8): e104059. https://doi.org/10.1371/journal.pone.0104059

Silva Volpato, N. d., Gomez, F. M., Giménez, V. D., and Ciampitti I. A. (2025). Global dataset on mung bean for managing seed yield and quality. *Scientific Data* 12: 658. https://doi.org/10.1038/s41597-025-05016-6

Tang, D., Dong, Y., Ren, H., Li, L., and He, C. (2014). A review of phytochemistry, metabolite changes, and medicinal uses of the common food mung bean and its sprouts (*Vigna radiata*). *Chemistry Central Journal* 8 (1): 4. https://doi.org/10.1186/1752-153X-8-4

Tepe, B., Sokmen, M., Akpulat, H. A., and Sokmen, A. (2005). In vitro antioxidant activities of the methanol extracts of four Helichrysum species from Turkey. *Food Chemistry* 90 (4): 685-689. https://doi.org/10.1016/j.foodchem.2004.04.030

Turner, E. R., Luo, Y., and Buchanan, R. L. (2020). Microgreen nutrition, food safety, and shelf life: A review. *Journal of Food Science* 85: 870–882. https://doi.org/10.1111/1750-3841.15049

Vermeulen, S. J., Park, T., Khoury, C. K., and Béné, C. (2020). Changing diets and the transformation of the global food system. *Annals of the New York Academy of Sciences* 1478 (1): 3-17. https://doi.org/10.1111/nyas.14446

Vidal-Valverde, C., Frias, J., Sierra, I., Blazquez, I., Lambein, F., and Kuo, Y. H. (2002). New functional legume foods by germination: Effect on the nutritive value of beans, lentils and peas. *European Food Research and Technology* 215: 472–477. https://doi.org/10.1007/s00217-002-0602-2

Voinea, L., Vrânceanu, D. M., Filip, A., Popescu, D. V., Negrea, T. M., and Dina, R. (2019). Research on food behavior in Romania from the perspective of supporting healthy eating habits. *Sustainability* 11: 5255. https://doi.org/10.3390/su11195255

Wanasundara, P., Shahidi, F., and Brosnan, M. E. (1999). Changes in flax (*Linum usitatissimum)* seed nitrogenous compounds during germination. *Food Chemistry* 65: 289–295. https://doi.org/10.1016/S0308-8146(98)00176-9

WHO. (2021). Noncommunicable diseases. World Health Organization. (https://www.who.int/news-room/factsheets/detail/noncommunicable-diseases)

Willett, W., Rockström, J., Loken, B., Springmann, M., Lang, T., Vermeulen, S., Garnett, T., Tilman, D., DeClerck, F., Wood, A., *et al*. (2019). Food in the anthropocene: the EAT–Lancet Commission on healthy diets from sustainable food systems. *The Lancet* 393 (10170): 447-492. https://doi.org/10.1016/S0140-6736(18)31788-4