CHAPTER V
Morphological Variation and Nutritional Analysis of New Mungbean (*Vigna radiata* (L.) Wilczek) Lines for Microgreen Production

5.1 Abstract

This study aims to identifying mungbean genotypes suitable for high-efficiency and nutritionally rich microgreen production. The evaluation including morphological and nutritional composition of microgreens, nine mungbean genotypes were examined, including two certified varieties (CN3 and CN84-1) and seven new lines (SUPER5, P08, P12, P22, W5, and D5). Morphological assessment revealed no significant variation in hypocotyl length across genotypes, with an average of 13.46 cm. However, significant genotypic differences were observed in leaf morphology (length and width) and output ratio. Line SUPER5 exhibited the highest output ratio (4.63), indicating superior microgreen production efficiency. Additionally, SUPER5 combined high protein content (46.55%) with high productivity, making it a promising candidate for microgreen cultivation. Line D5 had the highest carbohydrate content (33.51%), while CN3 and SUPER5 displayed lower carbohydrate levels. CN84-1 showed the highest fiber content (13.37%), and CN3 had the highest ash content (11.49%). Fat content exhibited only slight variation, and moisture content remained relatively stable among genotypes. These findings highlight substantial genetic diversity in both morphological and nutritional traits, supporting the potential for targeted mungbean breeding to enhance microgreen yield and nutritional quality.

5.2 Introduction

Microgreens is the young seedlings of vegetables and herbs harvested shortly after germination, have gained considerable attention as functional foods due to their dense nutritional profiles and bioactive compounds (Xiao et al., 2012). Many research studies have indicated that microgreens contain higher nutritional value compared to their mature counterparts (Morris, 2003; Xiao et al., 2012; El-Nakhel et al., 2020; Singh et al., 2023). These nutrient-rich microgreens offer higher concentrations of vitamins, minerals, antioxidants, and proteins compared to their mature counterparts, making them attractive for health-conscious consumers and urban agriculture (Seth et al., 2025). Their short growth cycle and adaptability to controlled environments further enhance their commercial potential.

Among various crops used for microgreen production, legumes such as mungbean [*Vigna radiata* (L.) Wilczek] present promising opportunities due to their inherent high protein content and beneficial phytochemicals (Dhoot et al., 2017). Mungbean is a widely cultivated pulse crop in Asia, valued for its nutritional quality and agronomic adaptability (Habibullah & Shah, 2007). While mungbean sprouts are commonly consumed, the potential of mungbean microgreens is still unexplored, particularly regarding genetic variation in morphological traits and nutritional composition that could influence yield and quality. Previous studies have demonstrated significant genotypic variation in legume microgreens affecting biomass accumulation, leaf morphology, and nutrient density (Zhao et al., 2022; Barlongo & Mercado, 2024). Understanding such variation is essential for breeding programs aimed at improving microgreen yield and nutritional value. Moreover, nutritional analyses indicate that microgreens often surpass mature seeds in protein and micronutrient content due to accelerated metabolic activity during early growth (Xiao et al., 2012; Ebert, 2022).

Despite these insights, there is limited information on the morphological and nutritional diversity among new mungbean lines specifically cultivated for microgreen production. This study aims to evaluate morphological variation and nutritional profiles across different mungbean genotypes to identify superior lines for microgreen cultivation, thereby supporting targeted breeding and commercial production of nutrient-dense mungbean microgreens.

5.3 Materials and methods

5.3.1 Plant materials

In this study, a total of nine mungbean genotypes (CN3, CN84-1, SUPER5, P08, P12, P22, P24, W5, and D5) were used, and their special features and origins were provided in Table 5.1, including Thai certified varieties (CN3 and CN84-1) and newly developed mungbean lines (SUPER5, P08, P12, P22, P24, W5, and D5).

5.3.2 Samples preparation

Seed samples were prepared by removing impurities, drying them at 45°C for 24 hrs, and then grinding them into a fine powder. The powdered samples were subsequently stored at -20°C to preserve their integrity for nutritional analysis. Sprout samples were prepared using a modified method based on (Wang et al., 2021). Mungbean seeds were washed with sterile distilled water and soaked in warm water at 40°C for 30 min. After soaking, the seeds were kept in dark conditions at room temperature for 8 hrs. Following the soaking period, the seeds were rinsed with sterile distilled water and germinated using coconut coir and peat moss mixed in a 1:1 volume ratio. The mixture was then placed into microgreen growing trays and leveled to a depth of approximately 1 inch. Pre-soaked mungbean seeds were evenly spread across the surface of the growing medium and lightly covered with a thin layer of the same medium. The trays were placed in the growth chamber environments controlled maintained at 25°C and kept moist by regular watering. They were stored in darkness for 3 days, followed by exposure to artificial light with a photosynthetic photon flux density (PPFD) of 20.19 $\mu mol/m^2{\cdot}s$ at wavelengths of 400–700 nm and a photon flux density (PFD) of 21.46 $\mu mol/m^2{\cdot}s$ at 380–780 nm for 4 days, making a total growing period of 7 days.

Table 5.1 Pedigree and special features of nine mungbean genotypes from used in this study.

Genotypes	Pedigree	Special features	Descriptions
CN3	Selection from mutated CN36	Large seed, high yield, uniform maturity	Thai certified varieties developed at Chai Nat Field Crops Research Center, Thailand
CN84-1	Selection from mutated CN36	Large seed, high yield, high percentage of carbohydrate	
SUPER5	Development from double cross lines [(CN72×V4758) × (CN72×V4718)] × [(CN72×V4718) × (CN72×V4785)] (V4718, V4758, and V4785 were originated from India)	High resistance to PM[1/] and CLS[2/]	The mungbean resistant lines developed by Pookhamsak et al. (unpublished data)
P08	Selected from backcrossing between CN84-1 and double cross lines [(CN72×V4758) × (CN72×V4718)] × [(CN72×V4718) × (CN72×V4785)]	Large seed, uniform maturity, moderate resistance to PM and CLS	New resistant lines
P12		High yield, rather drought resistance, high resistance to PM, moderate resistance to CLS	
P22		High yield, uniform maturity, abundant pods, moderate resistance to PM and CLS	
P24		Large seed, uniform maturity, moderate resistance to PM and CLS	
W5	Selected from backcrossing between CN72 and double cross lines [(CN72×V4758) × (CN72×V4718)] × [(CN72×V4718) × (CN72×V4785)]	High yield, abundant pods, pods born above the canopy, high resistance to PM and CLS	
D5	Selected from backcrossing between SUT1 and double cross lines [(CN72×V4758) × (CN72×V4718)] × [(CN72×V4718) × (CN72×V4785)]	Uniform maturity, moderate resistance to PM, abundant pods, pods borne above the canopy, and trichomeless	

[1/] powdery midew, [2/] Cercospora leaf spot

5.3.3 Proximate analysis

The contents of crude protein, crude fat, crude fiber, and total ash were analyzed following the procedures outlined by the Association of Official Analytical Chemists (AOAC, 2019). The total carbohydrate content was calculated by deducting the sum of these proximate components from the total. The parameter was measured in triplicates.

5.3.3.1 Moisture content

The measurement of moisture content, petri dish was placed in a hot air oven at 105°C for 2 hrs. Then, it was placed in a desiccator for 30 min until the temperature of the petri dishes equaled room temperature. Next, the petri dish was weighed using an analytical balance to four decimal places, 2-3 g of sample was placed into the petri dish with the cover slightly ajar and returned to the hot air oven at 105°C for 2 hrs or until dried. After drying, the petri dish containing the sample was allowed to cool in the desiccator for 30 min until the temperature of the petri dishes equaled room temperature. Then, the petri dish with the dried sample was weighed using the analytical balance to four decimal places. The drying process at 105°C was repeated for 1 hr or until the weight difference between two consecutive weighing was no different than 3 mg. The moisture content was calculated using the following equation:

$$\text{Moisture Content (\%FW)} = \frac{(W2 - W3)}{(W2 - W1)} \text{x } 100$$

When: W1 = Weight of the empty petri dish (g)
W2 = Weight of the petri dish with sample before drying (g)
W3 = Weight of the petri dish with the dried sample (g)

5.3.3.2 Crude protein content

The total protein content was determined using the Kjeldahl method. Approximately 0.5-1.0 g of sample was placed into a digestion tube, followed by the addition of 3 g of accelerating agent (a mixture of copper sulfate and potassium sulfate in a 1:10 ratio) and 20 mL of concentrated H_2SO_4. A blank sample was prepared by omitting the sample. Digestion was carried out in a Digestion System at 380 °C for 100 min until a clear blue solution was obtained. After digestion, the tubes were removed and cooled for about 20 min before proceeding to protein distillation using a UDK 149 Automatic Kjeldahl Distillation Unit (VELP Scientifica, Italy). For distillation, 20 mL of 4% boric acid (H_3BO_3) solution mixed with 2–3 drops of mixed indicator (methyl red and bromocresol green at a 1:1 ratio) was prepared in an Erlenmeyer flask for each sample. The distillation was performed with the following program: 45 mL H_2O, 60 mL of 40% NaOH, and a distillation time of 4 min. During distillation, ammonia gas (NH_3) released from the sample reacted with NaOH and condensed into the boric acid solution, causing a color change from pink to green. The resulting solution was then titrated with 0.1 N HCl until the endpoint, indicated by a color change back to pink, was reached. The volume of HCl used was recorded.

$$\text{Crude protein content (\%DB)} = \frac{(\text{A} - \text{B}) \text{ x N x } 1.4007 \text{ x F}}{\text{W}_\text{t}}$$

When: A = Volume of HCl used for sample titration (ml).
B = Volume of HCl used for blank titration (ml).
W_t = Weight of the sample (g).
N = Concentration of the HCl (N).
F = Factor (specific to mungbean, which is 6.25).

5.3.3.3 Crude fiber content

Crude fiber analysis was performed using the Fibertec 2010 automatic analyzer (Foss Tecator, Denmark). Approximately 0.5-1.0 g of sample was placed into a filtered crucible. Then, 150 mL of 1.25% hot H_2SO_4 was added to each tube, along with 3 drops of n-octanol antifoaming agent to minimize foaming. The sample was boiled for 45 min. After boiling, the mixture was filtered until dry by activating air suction, followed by releasing the acid from the sample through valve opening. The samples were washed three times with hot H_2O and filtered to dryness. Next, 150 mL of 1.25% NaOH solution was added, again with 3 drops of n-octanol antifoam, and the sample was boiled for 45 min. After boiling, the sample was filtered and washed three times with hot H_2O. Subsequently, the sample was rinsed with acetone (C_3H_6O) 3 times, each with 25 mL. The filtered crucible containing the residue was removed from the extractor and dried in an oven at 105 °C for 2 hrs, then cooled in a desiccator for 30 min. Following drying, the crucible was incinerated in a muffle furnace at 500 °C for 2 hrs. The furnace was allowed to cool until the temperature fell below 250 °C before opening; the furnace must remain closed for at least 3 hrs prior to sample removal or until the temperature is below 200 °C. Finally, the crucible was cooled again in a desiccator for 30 min before further analysis.

$$\text{Crude fiber content (\%DB)} = \frac{W_2 - W_3}{W_1} \text{ x } 100$$

When: W_1 = Weight of sample (g).
W_2 = Weight of sample + crucible after oven dry (g).
W_3 = Weight of sample + crucible after burn in furnace (g).

5.3.3.4 Ash content

Analysis of ash content started with weighing the constant weight in hot air oven at 105°C for 2 hrs, 2-3 g of the dried sample put into a crucible. The samples were incinerated on a hot plate until smokeless to form a lump. Subsequently, incinerate in a furnace at 500°C for 3 hrs or until a light gray or uniform white ash is obtained. After removal from the furnace, it is allowed to cool to room temperature in a desiccator for 30 min. The weight was recorded, and the ash content calculated according to the following formula:

$$\text{Ash content (\%DB)} = \frac{W_2 - W_1}{S} \text{ x } 100$$

When: W_1 = Weight of the crucible.
W_2 = Weight of the crucible and sample after incineration.
S = Weight of the sample.

5.3.3.5 Fat content

The analysis of fat content was conducted following the Soxhlet extraction method using the Soxtec™ 2050 Auto Fat Extraction System. Initially, the extraction beaker was weighed and dried at 105°C for 1 hr to achieve a constant weight, then cooled in a desiccator. Approximately 1-1.5 g of the sample was weighed and put into the filter paper, then folded and inserted into a cellulose thimble. The cellulose thimble was positioned for extraction and insertion of the extract. Subsequently, 80 mL of petroleum was added to the extraction beaker and put it into the positioned for extraction. The heating program was set with the following parameters: extraction temperature at 180°C, extraction phase: 60 min, rinsing phase of 90 min, and drying phase for 15 min. Upon completion of the program, the extraction beaker containing the extracted fat was removed and dried in a hot air oven at 105°C for 2 hrs. After drying, the beaker was cooled to room temperature in a desiccator for 30 min. Finally, the extraction beaker with the extracted fat was weighed to determine the fat content.

$$\text{Crude fat content (\%DB)} = \frac{\text{B} - \text{A}}{\text{W}} \text{ x } 100$$

When: W = Weight of the sample.
A = Constant weight of extraction beaker.
B = Weight of extraction beaker and extracted fat.

5.3.3.6 Carbohydrate Content

To analyze the carbohydrate content, using the following method outlined by Hailu (2018). Carbohydrate content calculated by subtracting the percentages of moisture, protein, fat, fiber, and ash according to the following formula:

$$\text{Carbohydrate content (\%DB)} = 100 - \text{Moisture} + \text{ Protein } + \text{Fiber } + \text{Fat } + \text{Ash}$$

5.3.4 Morphological data of microgreens

Data collection for the morphological traits including hypocotyl length, leaf length, and leaf width involved measuring twenty sprouts per genotype per replication, with six replications in total (n = 180). Measurements were taken using both a ruler and vernier caliper. The hypocotyl length of microgreens was measured from the base hypocotyl to the shoot tip. Leaf length was determined from the leaf base to the tip, while leaf width was measured at the widest part of the leaf, typically at the midpoint. Output ratio: calculated based on data collected from six replicates for each genotype follow by modified method from (Wang et al., 2021), computed as output ratio = fresh weight of microgreens (g) / weight of mungbean seeds (g)

5.3.5 Data analysis

A completely randomized design (CRD) was utilized for experimental arrangement. The data were subjected to analysis of variance (ANOVA), followed by mean comparisons using Duncan's New Multiple Range Test (DMRT) to evaluate differences in nutrient composition among mungbean genotypes as well as the morphological traits of mungbean microgreens. All statistical analyses were performed with SPSS software version 16.0 (Levesque, 2007).

5.4 Results

5.4.1 The morphological traits and output ratio of microgreen from various genotypes

The evaluated from nine mungbean genotypes were morphological traits and output ratio of microgreens summarized in Table 5.2. The average hypocotyl length was 13.46 cm, ranging from 12.70 cm in line P08 to 14.07 cm in variety CN84-1, with non-statistically significant differences observed among genotypes. The average leaf length was 3.43 cm and differed significantly, with line P08 exhibiting the longest leaf length (3.66 cm), followed by lines P22 and W5, respectively, while line P24 recorded the shortest (3.27 cm), however, it was not significantly different from all other genotypes except P08. Leaf width also showed highly significant differences, with an average of 1.29 cm. Line SUPER5 had the narrowest leaves (0.89 cm), which were significantly smaller than those of the other genotypes, while variety CN3 had the widest leaves (1.43 cm), although the differences were not statistically significant compared to CN84-1, P08, P22, and P24.

The output ratio, an important indicator of microgreen production efficiency, also varied significantly among genotypes. Line SUPER5 demonstrated the highest output ratio (4.63), significantly outperforming P12, P22, and P24. However, its output ratio was not significantly different from the remaining genotypes. Most of the newly developed lines except P12 had an output ratio compared to the recurrent parent CN84-1.

Table 5.2 Morphological traits and output ratio of microgreen from nine mungbean genotypes.

Genotypes	Hypocotyl length (cm)	Leaf length (cm)	Leaf width (cm)	Output ratio
CN3	14.02 ± 0.44[1/]	3.32 ± 0.07 b	1.43 ± 0.04 a	3.70 ± 0.71 ab
CN84-1	14.07 ± 0.47	3.45 ± 0.06 ab	1.38 ± 0.03 a	3.91 ± 0.30 ab
SUPER5	13.71 ± 0.30	3.32 ± 0.06 b	0.89 ± 0.02 c	4.63 ± 0.38 a
P08	12.70 ± 0.72	3.66 ± 0.13 a	1.39 ± 0.02 a	3.51 ± 0.29 ab
P12	13.63 ± 0.26	3.31 ± 0.07 b	1.27 ± 0.03 b	2.20 ± 0.03 c
P22	12.83 ± 0.79	3.54 ± 0.09 ab	1.42 ± 0.03 a	3.17 ± 0.29 bc
P24	13.84 ± 0.29	3.27 ± 0.08 b	1.39 ± 0.05 a	2.97 ± 0.21 bc
W5	13.24 ± 0.15	3.53 ± 0.11 ab	1.26 ± 0.03 b	3.48 ± 0.20 ab
D5	13.04 ± 0.40	3.51 ± 0.07 ab	1.20 ± 0.01 b	3.54 ± 0.42 ab
Mean	13.46	3.43	1.29	3.46
F-test	ns[2/]	*	**	*
C.V. (%)	8.72	5.97	5.99	3.77

[1/] Data showing means ± standard error (S.E.) different letters in column indicate statistically significant differences at 95% confidence level by comparing means using Duncan's New Multiple Range Test (DMRT). [2/] ns = not significant, * = significant at $P \leq 0.05$; ** = highly significant at $P \leq 0.01$, and ns=non-significant at $P > 0.05$.

5.4.2 Nutritional compositions of mungbean genotypes

The proximate nutritional composition of microgreens from nine mungbean genotypes is presented in Table 5.3. Moisture content showed non-statistically significant differences among genotypes, with an average value of 92.41%. In contrast, crude protein, total ash, crude fiber, and carbohydrate content exhibited highly significant differences, while crude fat showed significant differences. Moisture content ranged from 91.80% in P24 to 92.97% in SUPER5, with similar values observed across genotypes. Crude protein content varied significantly, with line SUPER5 exhibiting the highest value (46.55%), followed closely by line P22 (46.14%). Lines P22 and P24 had significantly higher protein contents than the recurrent parent CN84-1, with increases ranging from 1.08- to 1.03- fold, respectively, while line D5 showed the lowest protein content (41.78 %). Crude fat content also showed significant differences, ranging from 1.16% in SUPER5 to 1.93 % in D5. Line P24 (1.83%) had significantly higher fat content than the recurrent parent CN84-1 (1.31%). Line D5 had significantly higher fat content compared to CN3, CN84-1, SUPER5, and W5. Total ash content was the highest in CN3 (11.49%), significantly exceeding that of most new mungbean lines, except for P08 and P12. The lowest total ash contents were recorded in lines P22, P24, and W5 (9.11, 9.08, and 9.41%, respectively), which differed significantly from the other genotypes. Crude fiber content ranged from 11.33% in P22 to 13.37% in CN84-1. Variety CN84-1 exhibited the highest crude fiber content, outperforming the lines SUPER5, P12, P22, and W5. The lowest crude fiber content was observed in line P22 (11.33%), which was significantly lower than other genotypes. Regarding carbohydrate content, line D5 showed the highest value (33.51%), though it was not significantly different from lines P12, P24, and W5. The lowest carbohydrate contents were found in CN3 and SUPER5, with values of 29.51 and 28.91%, respectively, showing statistically significant differences. These results indicate that mungbean microgreens exhibit considerable genotypic variation in protein, fat, ash, fiber, and carbohydrate contents, while moisture content remains relatively stable across genotypes.

Table 5.3 Proximate composition of microgreen from nine mungbean genotypes (%DB[1/]).

Genotypes	Moisture	Crude protein	Crude fat	Total ash	Crude fiber	Carbohydrates
CN3	92.67 ± 0.33[2/]	44.51 ± 0.23 b	1.34 ± 0.15 bcd	11.49 ± 0.06 a	13.15 ± 0.16 ab	29.51 ± 0.29 c
CN84-1	92.34 ± 0.39	42.62 ± 0.12 d	1.31 ± 0.11 cd	10.94 ± 0.02 ab	13.37 ± 0.17 a	31.76 ± 0.15 b
SUPER5	92.97 ± 0.33	46.55 ± 0.11 a	1.16 ± 0.19 d	10.96 ± 0.04 ab	12.42 ± 0.10 b	28.91 ± 0.26 c
P08	92.35 ± 0.07	42.65 ± 0.15 d	1.72 ± 0.01 abc	11.02 ± 0.14 ab	12.90 ± 0.07 ab	31.70 ± 0.06 b
P12	92.81 ± 0.88	42.56 ± 0.33 d	1.76 ± 0.03 abc	10.99 ± 0.13 ab	12.43 ± 0.29 b	32.27 ± 0.29 ab
P22	92.93 ± 0.23	46.14 ± 0.26 a	1.64 ± 0.28 abcd	9.11 ± 0.48 c	11.33 ± 0.46 c	31.78 ± 0.57 b
P24	91.80 ± 0.48	43.73 ± 0.16 c	1.83 ± 0.07 ab	9.08 ± 0.43 c	12.87 ± 0.21 ab	32.50 ± 0.26 ab
W5	92.38 ± 0.12	44.50 ± 0.26 b	1.38 ± 0.19 bcd	9.41 ± 0.12 c	12.37 ± 0.28 b	32.33 ± 0.45 ab
D5	92.22 ± 0.41	41.78 ± 0.08 e	1.93 ± 0.08 a	10.21 ± 0.38 b	12.58 ± 0.39 ab	33.51 ± 0.91 a
Mean	92.50	43.89	1.56	10.36	12.60	31.58
F-Test	ns[2/]	**	*	**	**	**
C.V. (%)	0.79	0.81	16.69	4.37	3.66	2.37

[1/] DM = dry basis. [2/] Data showing means ± standard error (SE) different letters in column indicate statistically significant differences at 95% confidence level by comparing means using Duncan's New Multiple Range Test (DMRT). [3/] * = significant at $P \leq 0.05$; ** = highly significant at $P \leq 0.01$, and ns=non-significant at $P > 0.05$, Moisture reported as fresh weight.

Figure 5.1 Morphological appearance of nine mungbean (*Vigna radiata*) genotypes grown as microgreens.

5.5 Discussion

Microgreens are a new type of crop gaining popularity as they are tender young seedlings harvested at the stage when the first true leaves appear (Treadwell et al., 2020). In contrast, sprouts are germinated seeds that are the smallest and youngest form of plants (Dubey et al., 2024). The primary difference among sprouts, microgreens, and baby greens (which represent a later stage of microgreens) lies in their plant size and cultivation duration (Treadwell et al., 2020). Microgreens are collected later than sprouts but earlier than baby greens (Verlinden, 2020). Microgreens can be regarded as superior substitutes for sprouts owing to their higher nutritional content and more pronounced flavor and taste (Puccinelli et al., 2019). Specifically, microgreens are harvested immediately after their newest leaves develop, whereas baby greens are typically harvested when they reach a height of 5 to 10 cm or after 15 to 40 days from seed germination (Dubey et al., 2024). In this study, nine mungbean genotypes were evaluated which revealed significant genotypic variation in both morphological traits and nutritional composition of microgreens, highlighting the potential for targeted breeding programs. The absence of significant differences in hypocotyl length across genotypes suggests this trait is less influenced by genetic factors in microgreen production, consistent with studies emphasizing stability in certain morphological traits under controlled conditions (Kessy et al., 2024). However, leaf morphology (length and width) and output ratio exhibited marked genotypic differences, with SUPER5 demonstrating superior yield efficiency. These findings align with reports that genetic background strongly influences biomass accumulation and harvest efficiency in legume microgreens (Zhao et al., 2022; Rani et al., 2025).

Nutritional analysis further underscored genotype-specific profiles. Microgreens and sprouts also differ in their chemical composition (Choe et al., 2018). The nutrient content on a dry weight basis, compared between microgreen and mungbean seeds, showed variation. According to a review of over thirty studies on seed nutrition conducted by (Dahiya et al., 2015), the average values for moisture, crude protein, crude lipid, crude fiber, ash, and carbohydrate content in mungbean seeds were 9.80, 23.80, 1.22, 4.57, 3.51, and 61.00%, respectively. Compared to studies on microgreens, most nutrient components show higher quantities in microgreen nutritional except for carbohydrate content, which decreases by up to 30% when seeds are grown into microgreens. Meanwhile, moisture content increases by more than eight times. This increase in moisture influences the practical use of microgreens for consumption. Due to the lower carbohydrate content, microgreens are particularly suitable for health-conscious diets (Zhang et al., 2021). Moreover, microgreens often contain greater concentrations of phytochemicals, minerals, and vitamins compared to their fully matured counterparts (Xiao et al., 2012; Yadav et al., 2019). Additionally, protein content in microgreen lines SUPER5 (46.55%) and P22 (46.14%) exceeds that typically found in mature mungbean seeds (Habibullah & Shah, 2007), highlighting the enhanced nutritional values of microgreens accelerated metabolic activity during early growth stages. Conversely, the lower protein content observed in line D5 (41.78%) suggests a trade-off between carbohydrate and protein accumulation, as evidenced by its highest carbohydrate level (33.51%). Such inverse relationships between macronutrients have been documented in legume microgreens, where genetic variability influences resource allocation (Barlongo & Mercado, 2024).

Moisture content remains relatively stable, averaging 92.5% across genotypes, in contrast to significant variation observed in other traits. Variety CN3 exhibited elevated higher ash levels (11.49%), indicating distinct metabolic priorities among genotypes, potentially associated with environmental adaptation mechanisms (Kessy et al., 2024). Ash primarily consists of mineral salts such as calcium, potassium, and sodium, which reflect the overall mineral composition of the microgreen (Shokunbi et al., 2023). Although high ash content is nutritionally advantageous, excessively elevated ash may indicate contamination from external sources like soil particles, metal residues, cleaning agents, chalk, or sand (Marshall, 2010). These findings align with broader legume research, where variability in ash content reflects differences in mineral uptake and partitioning among genotypes (Habibullah & Shah, 2007). Crude fiber refers to the portion of plant material composed mainly of cellulose, hemicellulose, and lignin that is indigestible by human enzymes (behrLabor-Technik, 2023; Kuzio & Zibula, 2023). It is traditionally measured by acid and alkaline digestion methods, which capture the insoluble fiber fraction but do not account for all dietary fiber components, especially soluble fibers (Trowell, 1976; Mutter, n.d.). Crude fiber analysis is commonly used in animal nutrition and food quality assessments but is considered a limited measure of total dietary fiber (Trowell, 1976; Muinos, 2022). Crude fiber is a subset of dietary fiber, primarily comprising insoluble fiber components. It functions by increasing fecal bulk through water absorption and swelling within the gastrointestinal tract (Barber et al., 2020; He et al., 2022; Alahmari, 2024), which aids in preventing constipation, reducing intestinal transit time, and lowering the risk of colorectal diseases, including cancer. Microgreens exhibiting high crude fiber content, such as line CN84-1 with 13.37%, are likely to confer superior health benefits compared to other genotypes, potentially enhancing overall digestive health and disease prevention.

The observed diversity in output ratio and nutritional traits aligns with the high genetic variability reported in mungbean agronomic traits (Zhao et al., 2022). For instance, line SUPER5 has a combination of high protein and yield efficiency positions as a prime candidate for microgreen focused breeding, while P12 exhibited a low output ratio and may limit its commercial viability. These insights support the prioritization of traits like synchronized maturity and nutrient density in breeding programs, as emphasized in recent studies on value-added legume products (Barlongo & Mercado, 2024).

Overall, based on the morphological and nutritional characteristics, SUPER5 emerged as the most suitable candidate for microgreen production with high protein content and output ratio prioritized, making it ideal for health-focused and protein-enriched products. For applications focusing fiber, CN84-1 is preferable due to their superior values. Conversely, if the goal is to enhance carbohydrate content and texture, D5 is recommended, as they exhibited the highest carbohydrate level.

5.6 Conclusion

This study highlights the significant genotypic variation observed among mungbean genotypes, both in terms of morphological traits and nutritional composition of microgreens. The results indicate that hypocotyl length remained consistent across the genotypes. In contrast, leaf morphology (length and width) and output ratios showed substantial variation. Among the genotypes, SUPER5 emerged as the most suitable for microgreen production, excelling in protein content and output efficiency along with P22 also exhibited high in protein content. D5 displayed the highest carbohydrate level, whereas CN3 and SUPER5 exhibited lower carbohydrate content. The superior fiber content was higher in CN84-1, while CN3 had the highest ash content. Fat content showed only slight differences across the genotypes. The moisture content remained consistently high across all genotypes. Overall, the considerable diversity in both morphological and nutritional characteristics among mungbean microgreen genotypes provides valuable insights for breeding programs aimed at developing superior microgreen varieties with enhanced agronomic performance and nutritional quality.

5.7 References

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