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Research Article

Influence of Cultivar and Harvest Stage on Growth and Phytochemical Composition of Amaranth Microgreens

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Abstract

Background and Objective: Amaranth microgreens are increasingly recognized as valuable functional foods due to their rapid growth, short cultivation cycle, high nutritional density and rich phytochemical content. This study investigated how cultivar and harvest stage affect growth performance and the accumulation of key phytochemical compounds in amaranth microgreens grown under greenhouse conditions. **Materials and Methods:** Two amaranth cultivars, red amaranth and small red-centered amaranth, were grown under greenhouse conditions and harvested at 7, 10 and 14 days after sowing. Growth parameters, including plant height, fresh weight and dry weight, were measured. Chlorophyll content, dietary fiber, vitamin C, total phenolic content and antioxidant activity were also determined. Data was analyzed using analysis of variance and treatment means were compared at $p<0.05$. **Results:** Harvest stage significantly affected most growth and biochemical traits. In both cultivars, plant height, dry weight, chlorophyll content, total phenolic content and antioxidant activity increased with plant age. At 14 days after sowing, red amaranth showed the highest chlorophyll content (0.49 mg/g fresh weight), total phenolic content (4.51 mg GAE/g fresh weight) and antioxidant activity (52.27%). Small red-centered amaranth showed slightly higher dietary fiber (3.18%) and vitamin C content (94.44 mg/g fresh weight) at the same harvest stage. **Conclusion:** Both cultivar and harvest stage influenced the nutritional and phytochemical quality of amaranth microgreens. Harvesting at 14 days after sowing provided the most favorable balance between growth and bioactive compound accumulation, with red amaranth showing superior overall phytochemical performance.

Key words: Amaranth microgreens, antioxidant activity, harvest stage, phytochemicals, vitamin C

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Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Microgreens, the young seedlings of edible vegetables and herbs, have gained increasing attention because of their high nutritional density and potential health-promoting properties[1]. They are typically harvested when the cotyledons are fully expanded and before or at the emergence of the first true leaves, a stage at which they often contain higher concentrations of vitamins, minerals and antioxidant compounds than mature plants[2]. However, the optimal harvest stage for maximizing nutritional quality remains uncertain because phytochemical accumulation can change rapidly during early seedling development[3]. Owing to their short growth cycle and high concentration of bioactive compounds, microgreens are increasingly regarded as functional foods with considerable potential to improve diet quality[4].

Among microgreen species, amaranth is particularly attractive because of its rapid germination, intense pigmentation and desirable nutritional composition. Amaranth microgreens are rich in carotenoids, anthocyanins, phenolic compounds and vitamins, which contribute to their reported antioxidant, anti-inflammatory and hypoglycemic properties[5]. In addition to their nutritional importance, these compounds also enhance sensory quality and market value, making amaranth a promising crop for the production of high-value functional foods[6]. Previous studies have shown that phytochemical accumulation in amaranth and other microgreens is influenced by several preharvest factors, including genotype, substrate, light environment and harvest timing[7,8].

Light quality has received particular attention because of its role in regulating plant metabolism and secondary metabolite biosynthesis. Red and blue light combinations have been shown to improve biomass production, vitamin C concentration, photosynthetic pigments, anthocyanin accumulation and antioxidant capacity in amaranth microgreens[2,9]. Similarly, genotype-dependent differences in phytochemical composition and antioxidant activity have been reported in several microgreen species, indicating that cultivar selection is also critical when targeting specific nutritional traits[10,11]. Although these studies highlight the importance of environmental and genetic factors, most have focused on light manipulation or broad species comparisons rather than on the interaction between cultivar and harvest stage within amaranth microgreens.

Thus, information remains limited on how cultivar choice and harvest timing jointly affect the growth, nutritional composition and antioxidant-related traits of amaranth microgreens under practical greenhouse conditions. This gap restricts the development of evidence-based recommendations for optimizing both yield and functional quality. Therefore, the objective of this study was to evaluate the effects of cultivar and harvest stage on the growth performance and phytochemical composition of amaranth microgreens grown under greenhouse conditions. Two cultivars, red amaranth and small red-centered amaranth, were harvested at 7, 10 and 14 days after sowing to determine variations in plant growth, chlorophyll content, dietary fiber, vitamin C, total phenolic content and antioxidant activity. It was hypothesized that both cultivar and harvest stage significantly influence the accumulation of bioactive compounds and that a later harvest stage would enhance the nutritional and functional quality of amaranth microgreens.

MATERIALS AND METHODS

Study area: The research was conducted from November 2022 to September 2023 at the Biology Laboratory within the Department of Science and Technology at the Faculty of Liberal Arts and Science, Roi Et Rajabhat University, Roi Et, Thailand.

Plant material and growth conditions: Seeds of red amaranth and small red-centered amaranth (*Amaranthus* spp.) were obtained from a local seed supplier in Roi Et Province, Thailand. Before sowing, seeds were soaked in distilled water at room temperature for 6 hrs to promote uniform germination. The seeds were then sown in plastic germination trays containing a commercial growing substrate and cultivated under greenhouse conditions with exposure to natural morning sunlight. Irrigation was applied daily to maintain adequate moisture throughout the cultivation period. The microgreens were harvested at 7, 10 and 14 days after sowing. Each treatment consisted of three replicates and each replicate contained 50 seeds. The experiment was arranged in a completely randomized design with a factorial combination of two cultivars and three harvest stages.

Growth measurements: At each harvest stage, plant height, fresh weight, dry weight and leaf number were recorded. Plant height was measured from the base of the hypocotyl to the tip of the seedling using a vernier caliper. Fresh weight was determined immediately after harvest using an analytical balance. For dry weight determination, samples were dried in a hot-air oven at 70°C until constant weight was reached. Leaf number was counted manually for each sampled plant.

Chlorophyll determination: Chlorophyll content was determined by acetone extraction. Fresh leaf tissue (0.1 g) was homogenized with 6 mL of 80% acetone using a mortar and pestle. The homogenate was filtered and absorbance was measured at 663 and 645 nm using a UV-Vis spectrophotometer. Chlorophyll a, chlorophyll b and total chlorophyll contents were calculated according to the equations of Arnon and expressed as mg/g fresh weight[12,13].

Dietary fiber determination: Dietary fiber content was determined using a gravimetric procedure. Fresh samples (5 g) were boiled in distilled water for 10 min and then boiled in 50% NaOH for 5 min. The samples were rinsed thoroughly with distilled water and dried in a hot-air oven at 100°C for 2 hrs. Dietary fiber content was calculated as the percentage of dry residue relative to fresh sample weight[12,13].

Vitamin C determination: Vitamin C content was determined using the 2,6-dichlorophenolindophenol titrimetric method. Fresh leaf tissue (6 g) was homogenized in 40 mL of extraction solution containing 3% oxalic acid and 8% acetic acid. The homogenate was centrifuged at 15,000 rpm for 20 min at 4°C. An aliquot of 2 mL of the supernatant was titrated with standardized dye solution until a persistent pink color was observed for 15 sec. Results were expressed as mg ascorbic acid g^{-1} fresh weight[12,13].

Total phenolic content: Total phenolic content was determined using the Folin-Ciocalteu colorimetric method. Dried sample (1 g) was extracted with 10 mL of 80% methanol by shaking for 2 hrs at room temperature. The extract was centrifuged at 5000 rpm for 10 min. A 0.5 mL aliquot of the supernatant was mixed with 2.5 mL of 10% Folin-Ciocalteu reagent and allowed to stand for 5 min. Then, 2 mL of 7.5% sodium carbonate solution was added and the mixture was incubated in the dark for 30 min at room temperature. Absorbance was measured at 765 nm using a spectrophotometer. Results were expressed as mg gallic acid equivalents g^{-1} fresh weight[12,13].

Antioxidant activity: Antioxidant activity was evaluated using the DPPH radical scavenging assay. Dried sample (5 g) was extracted twice with 50 mL of methanol and the extracts were combined and adjusted to a final volume of 100 mL. An aliquot of the extract was mixed with DPPH solution and incubated in the dark for 30 min at room temperature. Absorbance was measured at 517 nm using a spectrophotometer. Antioxidant activity was expressed as a percentage of radical scavenging activity[12,13].

Statistical analysis: Data was analyzed by analysis of variance using a factorial arrangement with cultivar and harvest stage as sources of variation. Mean comparisons were performed using Duncan's multiple range test at the 5% probability level. All results are presented as Mean±Standard Deviation of three replicates.

RESULTS AND DISCUSSION

Growth performance of amaranth microgreens: The growth of both amaranth microgreen cultivars was markedly affected by harvest stage. In general, plant height, fresh weight and dry weight increased as seedlings developed from 7 to 14 days after sowing, indicating that extended cultivation promoted biomass accumulation and overall seedling vigor. In red amaranth, plant height increased from 2.98±0.27 cm at 7 days to 3.14±0.23 cm at 10 days and 3.20±0.26 cm at 14 days. Fresh weight followed a similar pattern, rising from 5.37±1.09 mg at 7 days to 7.59±1.00 mg at 10 days and 7.71±0.99 mg at 14 days. Dry weight also increased substantially, from 0.00±0.00 mg at 7 days to 0.55±0.31 mg at 10 days and 0.68±0.27 mg at 14 days. Seedlings harvested at 14 days therefore showed significantly greater height and biomass than those harvested at 7 days, whereas the 10 day harvest generally produced intermediate values (Table 1). In contrast, leaf number remained unchanged throughout the cultivation period, with all seedlings maintaining two leaves per plant.

A comparable trend was observed in small red-centered amaranth. Plant height increased from 2.59±0.23 cm at 7 days to 2.70±0.29 cm at 10 days and 2.98±0.13 cm at 14 days. Fresh weight rose sharply from 3.46±0.78 mg at 7 days to 6.38±2.06 mg at 10 days, followed by a slight decline to 6.00±0.42 mg at 14 days, although the final value remained significantly higher than that at 7 days. Dry weight showed the same overall pattern, increasing from 0.00±0.00 mg at 7 days to 0.36±0.15 mg at 10 days and 0.42±0.20 mg at 14 days (Table 2). As in red amaranth, leaf number did not differ significantly among harvest stages. When the two cultivars were compared, red amaranth consistently showed greater growth performance than small red-centered amaranth, particularly at the later harvest stages. At 14 days after sowing, red amaranth was taller and produced greater fresh and dry biomass, indicating stronger growth vigor under the conditions of this study. This pattern is consistent with previous reports showing that delayed harvesting generally improves yield-related traits in microgreens[12]. Similar increases in plant height and fresh biomass with extended growth duration have also been reported in other microgreen species[13], supporting the view that harvest timing is a major determinant of microgreen productivity.

Table 1: Growth characteristics of red amaranth microgreens at different harvest stages

Age (days)	Plant height (cm)	Fresh weight (mg)	Dry weight (mg)	Leaf number
7	2.98 ± 0.27^{b}	5.37 ± 1.09^{b}	0.00 ± 0.00^{b}	2.00 ± 0.00^{a}
10	3.14 ± 0.23^{ab}	7.59 ± 1.00^{a}	0.55 ± 0.31^{a}	2.00 ± 0.00^{a}
14	3.20 ± 0.26^{a}	7.71 ± 0.99^{a}	0.68 ± 0.27^{a}	2.00 ± 0.00^{a}

Means within a column followed by different letters are significantly different at $p<0.05$ according to Duncan's multiple range test

Table 2: Growth characteristics of small red-centered amaranth microgreens at different harvest stages

Age (days)	Plant height (cm)	Fresh weight (mg)	Dry weight (mg)	Leaf number
7	2.59 ± 0.23^{b}	3.46 ± 0.78^{b}	0.00 ± 0.00^{b}	2.00 ± 0.00^{a}
10	2.70 ± 0.29^{b}	6.38 ± 2.06^{a}	0.36 ± 0.15^{a}	2.00 ± 0.00^{a}
14	2.98 ± 0.13^{a}	6.00 ± 0.42^{a}	0.42 ± 0.20^{a}	2.00 ± 0.00^{a}

Means within a column followed by different letters are significantly different at $p<0.05$ according to Duncan's multiple range test

Table 3: Chlorophyll content of red amaranth microgreens at different harvest stages

Age (days)	Chlorophyll a (mg/g FW)	Chlorophyll b (mg/g FW)	Total chlorophyll (mg/g FW)
7	0.21 ± 0.07^{b}	0.13 ± 0.02^{a}	0.34 ± 0.02^{b}
10	0.30 ± 0.02^{a}	0.14 ± 0.01^{a}	0.44 ± 0.03^{a}
14	0.32 ± 0.01^{a}	0.17 ± 0.02^{a}	0.49 ± 0.01^{a}

FW: Fresh weight. Means within a column followed by different letters are significantly different at $p<0.05$ according to Duncan's multiple range test

Table 4: Chlorophyll content of small red-centered amaranth microgreens at different harvest stages

Age (days)	Chlorophyll a (mg/g FW)	Chlorophyll b (mg/g FW)	Total chlorophyll (mg/g FW)
7	0.22 ± 0.03^{b}	0.13 ± 0.02^{b}	0.35 ± 0.04^{b}
10	0.31 ± 0.00^{a}	0.14 ± 0.02^{ab}	0.45 ± 0.03^{a}
14	0.32 ± 0.00^{a}	0.15 ± 0.01^{a}	0.47 ± 0.01^{a}

FW: Fresh weight. Means within a column followed by different letters are significantly different at $p<0.05$ according to Duncan's multiple range test

Growth performance in microgreens is also shaped by environmental conditions, including air temperature, root-zone temperature, light availability and moisture status. Previous work has shown that fresh biomass can decline markedly under suboptimal root-zone cooling or unfavorable temperature regimes[14]. Even so, the present findings indicate that cultivar and harvest stage remain key drivers of biomass accumulation. Because different cultivars can respond differently to the same cultivation environment, the optimization of microgreen production should take both genotype and growing conditions into account[15,16].

Chlorophyll content: Chlorophyll content increased significantly with harvest stage in both cultivars, indicating progressive pigment accumulation during early seedling development. In both red amaranth and small red-centered amaranth, chlorophyll a, chlorophyll b and total chlorophyll were lowest at 7 days after sowing and highest at 14 days after sowing. In red amaranth, chlorophyll a increased from 0.21±0.07 mg/g fresh weight at 7 days to 0.30±0.02 mg/g at 10 days and 0.32±0.01 mg/g at 14 days. Chlorophyll b showed a smaller increase, from 0.13±0.02 mg/g at 7 days to 0.14±0.01 mg/g at 10 days and 0.17±0.02 mg/g at 14 days. As a result, total chlorophyll rose from 0.34±0.02 mg/g fresh weight at 7 days to 0.44±0.03 mg/g at 10 days and 0.49±0.01 mg/g at 14 days, representing an increase of approximately 44% over the cultivation period (Table 3). Small red-centered amaranth displayed a similar trend. Chlorophyll a rose from 0.22±0.03 mg/g fresh weight at 7 days to 0.31±0.00 mg/g at 10 days and 0.32±0.00 mg/g at 14 days. Chlorophyll b increased from 0.13±0.02 to 0.14±0.02 and 0.15±0.01 mg/g over the same period. Total chlorophyll increased from 0.35±0.04 mg/g fresh weight at 7 days to 0.45±0.03 mg/g at 10 days and 0.47±0.01 mg/g at 14 days (Table 4). Although both cultivars showed clear pigment accumulation with age, total chlorophyll remained slightly higher in red amaranth, especially at the final harvest stage.

These differences are consistent with previous studies reporting substantial genotypic variation in pigment profiles among amaranth accessions[17]. Chlorophyll concentration is closely associated with photosynthetic capacity and often reflects the physiological status of the plant. Its accumulation can be influenced by genetic background as well as external factors such as light intensity and spectral quality[18]. The consistently higher total chlorophyll observed in red amaranth may therefore help explain its superior growth performance. In higher plants, chlorophyll a acts as the primary photosynthetic pigment, whereas chlorophyll b broadens light capture by serving as an accessory pigment and variation in the balance between these pigments can reflect differences in developmental stage and environmental adaptation[19,20].

Table 5: Dietary fiber content of red amaranth and small red-centered amaranth microgreens at different harvest stages

Cultivar	Age (days)	Dietary fiber (%)
Red amaranth	7	3.11±0.01^{b}
	10	3.12±0.01^{ab}
	14	3.15±0.25^{a}
Small red-centered amaranth	7	3.09±0.01^{b}
	10	3.11±0.01^{b}
	14	3.18±0.25^{a}

Means within a cultivar followed by different letters are significantly different at $p<0.05$ according to Duncan's multiple range test

Table 6: Vitamin C content of red amaranth and small red-centered amaranth microgreens at different harvest stages

Cultivar	Age (days)	Vitamin C (mg/g FW)
Red amaranth	7	86.11±12.73^{a}
	10	88.89±12.73^{a}
	14	91.66±22.05^{a}
Small red-centered amaranth	7	77.89±12.91^{a}
	10	88.89±12.73^{a}
	14	94.44±12.73^{a}

FW: Fresh weight. Means within a cultivar followed by the same letter are not significantly different at $p<0.05$ according to Duncan's multiple range test

Dietary fiber content: Dietary fiber content increased slightly but significantly with cultivation period in both cultivars. Although the magnitude of change was modest compared with the shifts observed in biomass or pigment content, the trend was consistent and indicated a gradual increase in structural carbohydrate accumulation as seedlings matured. In red amaranth, dietary fiber content increased from 3.11±0.01% at 7 days after sowing to 3.12±0.01% at 10 days and 3.15±0.25% at 14 days (Table 5). In small red-centered amaranth, dietary fiber content rose from 3.09±0.01% at 7 days to 3.11±0.01% at 10 days and reached 3.18±0.25% at 14 days. At the final harvest stage, small red-centered amaranth showed slightly higher fiber content than red amaranth.

The gradual increase in fiber content with harvest age likely reflects continued cell wall development and the accumulation of structural polysaccharides during seedling growth. Although cultivar-related differences were small, they suggest that genotypes may influence fiber deposition even at the microgreen stage. The fiber values observed here are within the range reported for other leafy microgreens and further support the nutritional value of amaranth as a functional vegetable crop[21]. However, direct comparison among studies should be made cautiously because fiber content may be reported using different analytical methods and on different weight bases[22]. Previous studies on amaranth leaves have also shown that dietary fiber content varies considerably among genotypes and production conditions[23], which is in line with the modest cultivar differences observed here.

Vitamin C content: Vitamin C content tended to increase with harvest age in both cultivars, although the differences among harvest stages were not statistically significant within each recorded at 14 days after sowing, suggesting a general tendency toward ascorbic acid accumulation during seedling development. In red amaranth, vitamin C content increased from 86.11±12.73 mg/g at 7 days to 88.89±12.73 mg/g at 10 days and 91.66±22.05 mg/g at 14 days (Table 6). In small red-centered amaranth, the corresponding values were 77.89±12.91, 88.89±12.73 and 94.44±12.73 mg/g, respectively. The increase between the earliest and latest harvest stages was more pronounced in small red-centered amaranth, which also showed the highest final vitamin C concentration.

Although statistical separation was not detected, the overall trend suggests that prolonged cultivation may promote vitamin C accumulation in amaranth microgreens. Similar patterns have been reported in other microgreen species, where ascorbic acid content varies with genotype, developmental stage and growing environment[24,25]. Microgreens are often recognized as rich sources of vitamin C and other antioxidant vitamins, contributing to their value as nutrient-dense foods[26]. Moreover, cultivar-dependent differences in vitamin C concentration have been observed in several leafy vegetables and microgreens, emphasizing the importance of genetic background in determining nutritional composition[10,27]. It should also be noted that enhanced vitamin C content may improve the nutritional functionality of amaranth microgreens by supporting mineral bioavailability, particularly iron absorption.

Total phenolic content: Total phenolic content increased markedly with harvest age in both cultivars, indicating progressive accumulation of phenolic compounds during early plant development. In red amaranth, total phenolic content increased from 2.24±0.04 mg GAE/g fresh weight at

Table 7: Total phenolic content of amaranth microgreens at different harvest stages

Cultivar	Age (days)	TPC (mg GAE/g FW)
Red amaranth	7	2.24±0.04^{c}
	10	3.28±0.04^{b}
	14	4.51±0.05^{a}
Small red-centered amaranth	7	2.04±0.03^{c}
	10	3.09±0.04^{b}
	14	4.16±0.04^{a}

TPC: Total phenolic content, GAE: Gallic acid equivalents, FW: Fresh weight. Means within a column followed by different letters are significantly different at $p<0.05$ according to Duncan's multiple range test

Table 8: Antioxidant activity of red amaranth and small red-centered amaranth microgreens at different harvest stages

Cultivar	Age (days)	Antioxidant activity (%)
Red amaranth	7	27.17±0.40^{c}
	10	43.37±0.12^{b}
	14	52.27±0.23^{a}
Small red-centered amaranth	7	28.47±0.06^{c}
	10	40.03±0.12^{b}
	14	46.03±0.06^{a}

Means within a cultivar followed by different letters are significantly different at $p<0.05$ according to Duncan's multiple range test

7 days after sowing to 3.28±0.04 mg GAE/g at 10 days and 4.51±0.05 mg GAE/g at 14 days (Table 7). This represented an increase of 46.4% between 7 and 10 days and an overall increase of 101.3% between 7 and 14 days. Each harvest stage differed significantly from the others. A similar pattern was observed in small red-centered amaranth, where total phenolic content increased from 2.04±0.03 mg GAE/g fresh weight at 7 days to 3.09±0.04 mg GAE/g at 10 days and 4.16±0.04 mg GAE/g at 14 days. The final value was approximately 103.9% higher than that recorded at 7 days, indicating that phenolic accumulation nearly doubled over the cultivation period. As in red amaranth, each harvest stage differed significantly.

Across all harvest stages, red amaranth consistently showed higher total phenolic content than small red-centered amaranth. The difference between cultivars widened slightly with plant age, suggesting that red amaranth had a stronger capacity for phenolic biosynthesis and accumulation. These findings clearly identify 14 days after sowing as the most favorable stage for maximizing phenolic content in both cultivars. The marked increase in total phenolic content with harvest age agrees with previous reports showing that phenolic accumulation in microgreens is highly responsive to developmental stage and environmental conditions[28]. Light quality, in particular, has been shown to stimulate phenolic biosynthesis, with blue light frequently enhancing the production of phenolic compounds in microgreens[29]. Genotypic variation is also an important source of difference in phenolic concentration, as demonstrated in studies comparing cultivars grown under the same environmental conditions[3,30]. The relatively high phenolic values recorded in the present study further support the potential of amaranth microgreens as an important dietary source of antioxidant compounds.

Antioxidant activity: Antioxidant activity increased strongly and significantly with harvest stage in both cultivars. Among all biochemical traits measured, antioxidant activity showed one of the clearest responses to extended cultivation. In red amaranth, antioxidant activity increased from 27.17±0.40% at 7 days after sowing to 43.37±0.12% at 10 days and 52.27±0.23% at 14 days (Table 8). This nearly twofold increase between the earliest and latest harvest stages indicates a substantial enhancement of free radical scavenging capacity as seedlings matured. In small red-centered amaranth, antioxidant activity rose from 28.47±0.06% at 7 days to 40.03±0.12% at 10 days and 46.03±0.06% at 14 days. Although this cultivar also showed a strong increase with age, the final antioxidant activity remained lower than that of red amaranth.

At 7 days after sowing, small red-centered amaranth showed slightly higher antioxidant activity than red amaranth. However, red amaranth surpassed it at 10 and 14 days, suggesting a stronger capacity for antioxidant compound accumulation during later seedling development. This pattern is consistent with the higher phenolic content recorded in red amaranth and supports the close relationship between phenolic accumulation and antioxidant capacity. Similar associations have been reported in other amaranth genotypes and microgreen species, where polyphenols, flavonoids and ascorbic acid are major contributors to antioxidant potential[31,32]. Red-pigmented amaranth genotypes are often characterized by elevated levels of antioxidant-related metabolites compared with green morphs, which likely contributes to their stronger radical scavenging performance[33].

The present results demonstrate that extending cultivation from 7 to 14 days after sowing improved most growth and quality-related traits in both amaranth cultivars. The 14 day harvest stage consistently produced the highest values for plant height, dry weight, chlorophyll content, total phenolic content and antioxidant activity. Red amaranth generally showed superior growth, greater chlorophyll accumulation and stronger antioxidant potential, whereas small red-centered amaranth tended to show slightly higher dietary fiber and vitamin C content at the final harvest stage. These findings confirm that harvest stage is a major determinant of amaranth microgreen quality and that cultivar selection can further shape the balance between productivity and nutritional composition.

From a production standpoint, the results also reinforce the importance of optimizing genotype and harvest timing together rather than separately. Previous research has shown that environmental conditions such as light intensity, photosynthetically active radiation and temperature can further modify phytochemical composition and antioxidant activity in microgreens[22,34,35]. Thus, cultivar-specific production protocols may provide an effective strategy for maximizing both biomass yield and nutritional quality in commercial amaranth microgreen systems.

CONCLUSIONS

Cultivar and harvest stage significantly affected the growth and phytochemical composition of amaranth microgreens. In both cultivars, harvesting at 14 days after sowing resulted in the highest biomass, chlorophyll content, total phenolic content and antioxidant activity. Red amaranth exhibited superior phytochemical performance, particularly in chlorophyll concentration, phenolic accumulation and antioxidant capacity, whereas small red-centered amaranth showed slightly higher dietary fiber and vitamin C content. These results indicate that harvest timing is a critical factor in improving the nutritional and functional quality of amaranth microgreens, while cultivar selection can be used to target specific quality attributes. Under the conditions of this study, harvesting at 14 days after sowing provided the most favorable balance between growth and bioactive compound accumulation.

SIGNIFICANCE STATEMENT

This study demonstrates that both cultivar and harvest stage are important determinants of the nutritional and phytochemical quality of amaranth microgreens. The findings identify 14 days after sowing as the most suitable harvest stage for maximizing growth and bioactive compound accumulation, providing practical guidance for the production of high-value functional microgreens.

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