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The Effect of Harvest Time of Basil Microgreens (*Ocimum basilicum L.*) on Phenolic Content and Antioxidant Activity in a Local Wisdom–Based Horticultural System

Rivanna Citraning Rachmawati[1,2], Saiful Ridlo[1*], Woro Sumarni[1], Wiwi Isnaeni[1], Putut Marwoto[1], Sunyoto Eko Nugroho[1]

[1]Science Education, Universitas Negeri Semarang, Sekaran, Gunungpati, Kota Semarang, Jawa Tengah 50229 Indonesia

[2]Faculty of Mathematics, Natural Sciences, and Information Technology Education, Universitas PGRI Semarang, Jl. Sidodadi-Timur No.24 Semarang, Central Java 50232, Indonesia

*saiful_ridlo@mail.unnes.ac.id

Abstract. Basil microgreens are gaining attention as a potential functional food due to their nutritional value and naturally occurring bioactive compounds. Nevertheless, information regarding how these bioactive characteristics vary across different growth stages, particularly when basil is cultivated using local wisdom-based horticultural practices, is still limited. This study evaluated the total phenolic content and antioxidant activity of basil (Ocimum basilicum L.) harvested at three developmental stages: microgreens at 10 and 14 days after germination and mature plants at 30 days. The plants were cultivated using locally sourced materials, including rice husk, household organic compost, and rice washing water. Total phenolic content was assessed using the Folin–Ciocalteu method, whereas antioxidant activity was determined through the DPPH assay. Descriptive analysis revealed a gradual increase in total phenolic content, from 0.960 ± 0.146 mg GAE g^{-1} extract at day 10 to 1.056 ± 0.061 mg GAE g^{-1} extract at day 14 and 1.170 ± 0.010 mg GAE g^{-1} extract at day 30. A comparable pattern was observed for antioxidant activity, which increased from 63.659 ± 0.621% at day 10 to 66.634 ± 0.414% at day 14 and reached 72.585 ± 0.276% at day 30. Overall, the descriptive findings indicate that the later developmental stage of basil was accompanied by higher phenolic content and antioxidant activity under the cultivation conditions applied in this study.

Keywords: *Ocimum basilicum L.,* antioxidant activity, harvest stage, microgreens, phenolic compounds, local wisdom

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1. Introduction

Basil (*Ocimum basilicum L.*) is a widely consumed aromatic herb with considerable nutritional and functional value. Beyond its common use as a culinary ingredient, basil contains a variety of bioactive constituents, including phenolic compounds, flavonoids, essential oils, and vitamins, many of which contribute to its biological and antioxidant properties [1,2]. The presence of these compounds has encouraged broader interest in basil as a plant-based ingredient with potential applications in functional foods. However, its phytochemical profile is not constant. Differences among cultivars, growing conditions, and stages of plant development can lead to substantial variation in the composition and abundance of bioactive compounds [1,3].

One form of basil that has attracted increasing interest is the microgreen. Microgreens are young edible plants harvested at an early stage of growth, generally when the cotyledons are fully expanded and the first true leaves begin to appear. Their relatively short cultivation period, modest space requirements, and suitability for small-scale production make them particularly attractive for household and urban farming systems [4–6]. Despite their small size, microgreens can provide a range of nutrients and phytochemicals, including vitamins, minerals, phenolic compounds, and flavonoids [5,6]. Their biochemical characteristics, however, vary considerably among species and genotypes. In basil, Fayezizadeh et al. reported clear differences in phenolic composition and antioxidant capacity among 21 microgreen cultivars and genotypes, illustrating that the functional quality of basil microgreens is strongly influenced by genetic variation [7].

Growing conditions may further modify the biochemical characteristics of basil. Factors such as nutrient supply, light environment, genotype, and harvest conditions have been associated with changes in phenolic accumulation and antioxidant properties [8–11]. For example, varying the concentration of nutrient solutions can alter both phenolic compounds and antioxidant capacity in basil microgreens [7]. Light management also plays an important role, as different light spectra can modify secondary metabolite production [9,10,12]. Thongtip et al. observed variations in total phenolic content and DPPH radical-scavenging activity in basil-family microgreens exposed to different light spectra and sampling periods [13]. Similarly, [14]Eskandarzade et al. showed that differences in light intensity and harvesting time were accompanied by changes in phenolic and flavonoid contents as well as antioxidant activity in green and purple basil [15]. Taken together, these studies indicate that the accumulation of bioactive compounds in basil is a dynamic process shaped by several interacting factors rather than by plant age alone.

The stage at which basil is harvested is therefore an important consideration when assessing its functional properties. Although microgreens are frequently promoted as rich sources of bioactive compounds, it cannot be assumed that young plants consistently contain greater concentrations of these compounds than their mature counterparts. Comparisons involving basil and other leafy vegetables have shown that phytochemical and antioxidant responses may differ according to both genotype and developmental stage [16–18]. Recent evidence from twelve basil genotypes further demonstrated that phenolic accumulation changes throughout plant development, but the direction and magnitude of these changes vary among genotypes and individual phenolic compounds [3]. Significant genotype-by-developmental-stage variation reported in that study reinforces the view that a single harvest stage cannot be regarded as universally optimal for phenolic accumulation in basil.

In addition to plant development and cultivation conditions, the use of locally available resources offers another perspective for small-scale horticultural production. Local knowledge and accessible biological resources can contribute to resource-efficient food production, particularly within household and community-based agricultural systems [19]. In this study, a local wisdom-based horticultural system refers operationally to a simple cultivation approach that makes use of materials readily available in the local environment. Rice husk, household organic compost, and rice washing water were incorporated into the cultivation process, together with manual watering and small-scale home-gardening practices. These materials were not examined as independent experimental treatments; instead, they formed the cultivation setting in which the basil plants were grown. This approach is consistent with small-scale

urban farming practices that utilize accessible resources and limited cultivation space for food production [4].

Although interest in basil microgreens has expanded, much of the existing research has concentrated on genotype selection, nutrient management, artificial lighting, and controlled growing environments [7,20,21]. Less is known about how total phenolic content and antioxidant activity vary from the microgreen stage to a later stage of plant development when basil is grown within a simple, locally resource-based horticultural setting. Examining this pattern is relevant because biochemical characteristics at harvest may reflect the combined influence of developmental stage and cultivation environment [3,11]. Accordingly, this study aimed to evaluate the total phenolic content and antioxidant activity of basil (Ocimum basilicum L.) at three developmental stages: 10-day-old microgreens, 14-day-old microgreens, and mature plants harvested at 30 days, grown under a local wisdom-based horticultural system. The study focused on describing the pattern of these bioactive characteristics across the three harvest stages without inferring causal relationships among developmental, environmental, and biochemical factors.

2. **Methods**

2.1 Research Location and Experimental Design

The study was conducted at the Biology Laboratory of Universitas PGRI Semarang, Indonesia, from September to November 2023. Basil (*Ocimum basilicum* L.) was cultivated on a laboratory scale using a simple horticultural system based on locally available materials and manual crop management. The study was designed to describe differences in total phenolic content and antioxidant activity of basil across three harvest stages.

Three harvest treatments representing different stages of plant development were evaluated. Treatment 1 (T1) consisted of basil microgreens harvested 10 days after germination, while Treatment 2 (T2) consisted of microgreens harvested 14 days after germination. Treatment 3 (T3) comprised mature basil plants harvested 30 days after planting and was included as a later developmental-stage reference. The first two harvest times represented the microgreen stage, whereas the third represented a more advanced vegetative stage. This design enabled the biochemical characteristics of basil at the two microgreen harvest times to be descriptively compared with those of mature plants.

Because the amount of plant material obtained from the small-scale cultivation was limited, samples collected within each harvest stage were pooled before extraction. A single pooled extract was therefore prepared for each treatment, and each extract was subsequently measured in duplicate for total phenolic content and antioxidant activity. Accordingly, the two measurements represented analytical replicates rather than independent biological replicates. The resulting data were used to characterize descriptive patterns across the three harvest stages and were not treated as independent observations for inferential comparison.

2.2 Local Wisdom-Based Plant Cultivation and Sample Preparation

Basil was cultivated using a local wisdom-based horticultural approach, operationally defined in this study as a small-scale cultivation practice that incorporates locally accessible materials and simple resource-efficient management. The growing medium consisted of soil combined with rice husk and compost prepared from household organic waste. These materials were selected as locally available components of the cultivation system rather than as separate experimental treatments. This approach reflects the use of accessible resources commonly associated with small-scale and household-based horticultural practices.

Basil seeds were sown uniformly in the prepared growing medium and maintained under laboratory cultivation conditions. Watering was carried out manually each day to maintain adequate moisture in the growing medium. Rice washing water was also applied as a locally available organic nutrient supplement during cultivation. The use of synthetic chemical inputs was minimized throughout the

growing period. These cultivation practices formed the environmental context of the study and were applied consistently across the evaluated harvest stages.

Plants assigned to T1 and T2 were harvested at 10 and 14 days after germination, respectively, while plants assigned to T3 were harvested at 30 days after planting. After harvest, the collected plant material was washed with distilled water to remove adhering particles and other surface residues. The samples were then oven-dried at 40 °C for 48 h. Once completely dried, the plant material was ground using a laboratory blender and passed through a 40-mesh sieve to obtain a relatively uniform powder. The powdered samples were subsequently used for extraction and biochemical analyses.

2.3 Research Flow

This study began with implementing local wisdom-based horticultural practices, including utilizing rice husk, household organic waste compost, rice washing water, home gardening systems, and urban farming concepts. Subsequent stages included plant cultivation, determination of harvest times, sample preparation, extraction, total phenolic content analysis, antioxidant activity analysis, and result interpretation. The research flow is shown in Figure 1.

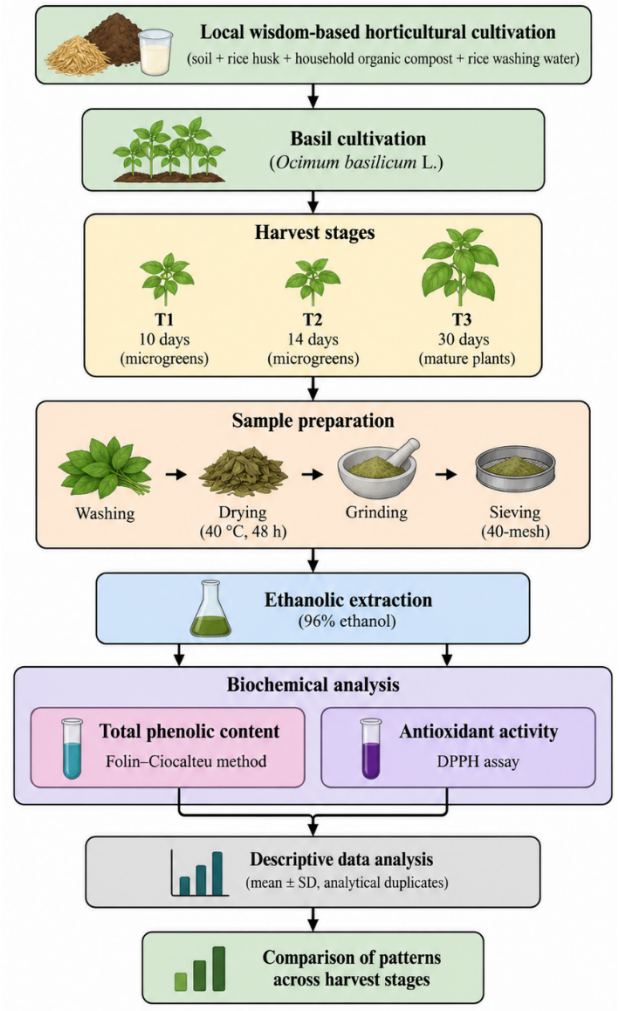

Figure 1. Research Flow

2.4 Extraction Procedure

Powdered basil material obtained from each harvest stage was extracted independently using 96% ethanol. The dried sample was combined with the solvent at a 1:4 (w/v) ratio and subjected to maceration for 24 h at room temperature. This extraction step was performed separately for each harvest stage to obtain the ethanol-soluble components from the powdered plant material.

After the maceration period, each mixture was filtered to remove the remaining solid plant material. The filtrate obtained from each treatment was collected separately and subsequently used for the determination of total phenolic content and antioxidant activity. Throughout the extraction process, samples representing the three harvest stages were maintained independently, comprising T1 (10 days), T2 (14 days), and T3 (30 days).

Plant materials collected within the same harvest stage were pooled before extraction, resulting in one pooled extract for each treatment. Each extract was then measured twice for the respective biochemical analyses. These duplicate measurements were considered analytical replicates rather than independent biological replicates.

2.5 Determination of Total Phenolic Content

Total phenolic content (TPC) of the basil extracts was determined using the Folin–Ciocalteu method, with gallic acid used as the reference standard. A series of gallic acid standard solutions ranging from 0 to 50 ppm was used to construct the calibration curve. The relationship between gallic acid concentration and absorbance produced the linear regression equation:

$$y = 0.017x + 0.07 \quad (1)$$

with a coefficient of determination of:

$$R^2 = 0.95 \quad (2)$$

Where yrepresents the measured absorbance and xrepresents the gallic acid concentration. The gallic acid equivalent concentration of each basil extract was calculated from the calibration equation based on its measured absorbance.

The total phenolic content of each sample was subsequently expressed as milligrams of gallic acid equivalents per gram of extract (mg GAE/g extract). Each pooled extract representing T1 (10 days), T2 (14 days), and T3 (30 days) was measured in duplicate, and the two measurements were treated as analytical replicates.

2.6 Statistical Analysis

The radical-scavenging activity of the basil extracts was assessed using the 2,2-diphenyl-1-picrylhydrazyl (DPPH) assay. Ethanolic extracts obtained from each harvest stage were allowed to react with the DPPH solution and were subsequently incubated for 30 min at room temperature in the dark. Following incubation, the absorbance of each reaction mixture was recorded at 517 nm. A DPPH solution without basil extract was used as the control and measured under the same conditions.

$$\text{DPPH inhibition (\%)} = \frac{A_{\text{control}} - A_{\text{sample}}}{A_{\text{control}}} \times 100 \quad (3)$$

where $A_{\text{control}}$is the absorbance of the DPPH control and $A_{\text{sample}}$is the absorbance measured in the presence of the basil extract. A higher inhibition percentage indicates a greater ability of the extract to scavenge DPPH radicals.

Measurements were carried out separately for the pooled extracts representing T1 (10 days), T2 (14 days), and T3 (30 days). Each pooled extract was analyzed in duplicate, and the duplicate readings were considered analytical replicates rather than independent biological replicates.

The results of the total phenolic content and DPPH radical-scavenging assays were evaluated using descriptive statistics. For each harvest stage, duplicate analytical measurements were summarized and reported as the mean ± standard deviation (SD). These descriptive values were used to observe changes in total phenolic content and antioxidant activity among basil harvested at 10 days (T1), 14 days (T2), and 30 days (T3).

Since the plant material collected at each harvest stage was pooled before extraction, the two measurements obtained from each extract were considered analytical replicates rather than independent biological replicates. For this reason, inferential statistical tests such as analysis of variance (ANOVA) and post-hoc comparisons were not performed. Treating repeated measurements from the same pooled extract as independent experimental observations could lead to pseudoreplication and an inappropriate estimation of biological variation. Therefore, differences among the three harvest stages were interpreted descriptively by considering their mean values and the variability between duplicate analytical measurements.

The patterns of total phenolic content and DPPH radical-scavenging activity were also examined together to determine whether the two parameters followed a similar trend across the evaluated harvest stages. This assessment was limited to a descriptive comparison, and no statistical correlation analysis was conducted.

3. Results and Discussion

3.1 Total Phenolic Content

The total phenolic content of basil showed a consistent upward pattern across the three harvest stages. As shown in Table 1, the mean TPC was lowest in basil microgreens harvested 10 days after germination (T1), increased at 14 days (T2), and reached its highest value in mature basil harvested at 30 days (T3). The individual measurements reported in Table 1 were obtained from duplicate analyses of the pooled extract prepared for each harvest stage.

Table 1. Total phenolic content of basil at different harvest stages

Harvest stage	Analytical replicate 1	Analytical replicate 2	Mean ± SD (mg GAE/g extract)
T1 – 10 days	1.063	0.857	0.960 ± 0.146
T2 – 14 days	1.099	1.013	1.056 ± 0.061
T3 – 30 days	1.163	1.177	1.170 ± 0.010

Values are expressed as mean ± SD from duplicate analytical measurements of a pooled extract for each harvest stage. The duplicate measurements represent analytical replicates and not independent biological replicates.

The mean TPC increased from 0.960 ± 0.146 mg GAE/g extract in T1 to 1.056 ± 0.061 mg GAE/g extract in T2, before reaching 1.170 ± 0.010 mg GAE/g extract in T3. Thus, within the cultivation conditions used in this study, mature basil produced the highest measured phenolic content among the three developmental stages. The pattern indicates that phenolic compounds were not concentrated exclusively at the microgreen stage but remained subject to change as the plants continued to develop.

Plant development may partly account for this pattern, although developmental stage should not be considered the only factor involved. Phenolic compounds are secondary metabolites whose accumulation can respond to several interacting biological and environmental conditions. Previous studies on basil and basil microgreens have reported that phenolic profiles can vary according to genotype, nutrient availability, light environment, and harvesting conditions [17,22]. These observations suggest that changes in phenolic content during plant growth are likely to reflect a combination of developmental and cultivation-related influences.

The findings also provide a useful perspective on the common assumption that microgreens invariably contain higher levels of bioactive compounds than plants harvested at later stages. While microgreens are recognized as valuable sources of phytochemicals, their phenolic content does not necessarily exceed that of mature plant material in every species or under all growing conditions. Earlier comparisons between microgreens and mature vegetables have demonstrated that phytochemical accumulation can differ depending on the plant material and compound being evaluated [21]. Evidence from different basil genotypes further shows that phenolic accumulation may change differently during development, with considerable variation among genotypes and individual phenolic compounds [23]. Therefore, the higher TPC observed in mature basil in the present study is more appropriately interpreted as a pattern specific to the plant material and cultivation conditions examined here rather than as a general developmental rule.

The cultivation system used in this study may also have formed part of the environmental context in which these changes occurred. Basil was grown using locally available materials, including rice husk, household organic compost, and rice washing water, together with manual watering and limited use of synthetic chemical inputs. These components were incorporated as part of the local wisdom-based horticultural system and were not evaluated as separate experimental factors. Consequently, the present data cannot determine the individual contribution of any particular cultivation component to phenolic accumulation. Instead, the results show that basil cultivated within this locally resource-based system retained measurable phenolic compounds throughout the evaluated stages, with the highest value recorded at the mature stage.

Light conditions are another possible consideration because light has been reported to influence secondary metabolite production in basil and other microgreens [9–11,24]. Recent studies on basil microgreens have shown that changes in LED light composition can influence phenolic accumulation and other nutritional characteristics, although the response may vary among cultivars and lighting conditions. [24,25]. In the present study, plants harvested later naturally remained in the cultivation environment for a longer period. Nevertheless, neither light intensity nor cumulative light exposure was manipulated as an independent variable. The higher TPC recorded in T3 therefore cannot be attributed specifically to longer light exposure. It is more appropriate to view the observed pattern as the outcome of plant development occurring within the overall cultivation environment.

Taken together, the TPC measurements followed the descriptive order T3 > T2 > T1. The duplicate measurements for T3 were also closely aligned, although this should be interpreted only as consistency between analytical readings. Because each harvest stage was represented by a pooled extract rather than independent biological replicates, the differences among T1, T2, and T3 should not be interpreted as statistically significant differences. Instead, they describe the phenolic-content pattern observed across the three developmental stages under the conditions of this study.

3.2 Antioxidant Activity

The DPPH radical-scavenging activity of basil increased progressively across the three harvest stages. The lowest antioxidant activity was recorded in 10-day-old microgreens (T1), followed by 14-day-old microgreens (T2), while the mature basil harvested at 30 days (T3) showed the highest value. The individual measurements and their descriptive means are presented in Table 2.

Table 2. DPPH radical-scavenging activity of basil at different harvest stages

Harvest stage	Analytical replicate 1 (%)	Analytical replicate 2 (%)	Mean ± SD (%)
T1 – 10 days	63.220	64.098	63.659 ± 0.621
T2 – 14 days	66.341	66.927	66.634 ± 0.414
T3 – 30 days	72.780	72.390	72.585 ± 0.276

Values are expressed as mean ± SD from duplicate analytical measurements of a pooled extract for each harvest stage. The duplicate measurements represent analytical replicates rather than independent biological replicates.

The mean DPPH inhibition increased from 63.659 ± 0.621% in T1 to 66.634 ± 0.414% in T2 and reached 72.585 ± 0.276% in T3. This pattern indicates that the capacity of the basil extracts to scavenge DPPH radicals was greater at the later developmental stages under the conditions examined in this study. Among the three stages, mature basil therefore exhibited the highest measured radical-scavenging activity.

Changes in antioxidant activity during plant development can reflect shifts in the composition and abundance of antioxidant compounds. In basil, these responses are not governed solely by plant age, as genotype, nutrient availability, light conditions, and cultivation practices may also influence the production of secondary metabolites associated with antioxidant properties [7,9–11,21]. Previous studies on basil microgreens have demonstrated that antioxidant capacity can vary among genotypes and in response to changes in the growing environment [7,21]. Light conditions have also been reported to modify antioxidant responses and secondary metabolite accumulation in basil and related microgreens [9–11].

The present results therefore should not be interpreted as indicating that mature basil invariably possesses greater antioxidant activity than basil microgreens. Rather, they show that within the cultivation system and developmental stages evaluated here, radical-scavenging activity followed an increasing pattern from T1 to T3. This interpretation is consistent with evidence showing that the biochemical characteristics of basil may change throughout plant development and that the direction of these changes can differ among genotypes and compoundsv [3]. Thus, the antioxidant potential of basil is better viewed as a dynamic characteristic influenced by both plant development and the conditions under which the plants are grown.

An interesting feature of the present findings is that the DPPH results followed the same directional pattern as total phenolic content. TPC increased from 0.960 mg GAE/g extract in T1 to 1.056 mg GAE/g extract in T2 and 1.170 mg GAE/g extract in T3, while DPPH inhibition increased from 63.659% to 66.634% and 72.585%, respectively. This parallel pattern suggests that the increase in phenolic content occurred alongside greater radical-scavenging activity across the three harvest stages. Phenolic compounds are known to contribute to antioxidant properties through their ability to participate in radical-scavenging reactions, making this descriptive similarity biologically plausible.

Nevertheless, the parallel changes in TPC and DPPH activity should be interpreted with caution. The present study did not conduct a statistical correlation analysis, and the experimental design does not allow the antioxidant response to be attributed exclusively to phenolic compounds. Basil contains other bioactive constituents that may contribute to antioxidant activity, including flavonoids and compounds associated with its essential oils [1,2,26]. Accordingly, the DPPH values obtained in this study are more appropriately regarded as reflecting the overall radical-scavenging capacity of the extracts rather than the activity of phenolic compounds alone.

The local wisdom-based cultivation system also provides an important context for interpreting these findings. Basil was grown using locally accessible materials, including rice husk, household organic compost, and rice washing water. However, these materials were components of the overall cultivation system rather than independent experimental treatments. The present findings therefore do not demonstrate that any individual local resource was responsible for the increase in antioxidant activity. Instead, they show that basil cultivated under this relatively simple, locally resource-based horticultural system maintained measurable DPPH radical-scavenging activity at all three developmental stages, with the highest value recorded in mature basil.

Overall, DPPH radical-scavenging activity followed the descriptive order T3 > T2 > T1, which was consistent with the pattern observed for total phenolic content. Because each developmental stage was represented by one pooled extract analyzed in duplicate, these differences are interpreted descriptively and should not be regarded as statistically significant differences among harvest stages.

3.3 Relationship between Harvest Stage and Bioactive Compound Accumulation

Considering the two biochemical parameters together provides a clearer picture of the changes observed during basil development. Total phenolic content increased from 0.960 mg GAE/g extract at 10 days (T1) to 1.056 mg GAE/g extract at 14 days (T2), before reaching 1.170 mg GAE/g extract in mature basil (T3). A similar progression was observed for DPPH radical-scavenging activity, which rose from 63.659% in T1 to 66.634% in T2 and 72.585% in T3. Thus, both measurements followed the same descriptive order, with the lowest values recorded at the earliest microgreen stage and the highest values found in mature basil. These patterns are consistent with the original laboratory measurements.

The concurrent increase in TPC and DPPH activity is biologically plausible, since phenolic compounds are among the plant metabolites that can contribute to antioxidant properties. Nevertheless, the similarity between the two patterns does not necessarily indicate that phenolic compounds were solely responsible for the observed antioxidant activity. Basil contains various bioactive constituents, including flavonoids and compounds associated with essential oils, which may also contribute to its overall antioxidant potential [1,2,26]. The present results should therefore be understood as showing that greater phenolic content occurred alongside stronger DPPH radical-scavenging activity, rather than demonstrating a direct causal relationship between the two variables.

Plant development may be one of the factors underlying these changes. As plants grow, their physiological functions and secondary metabolism continue to develop, potentially altering the production and distribution of bioactive compounds. However, such changes do not necessarily follow the same direction in every basil genotype or for every phenolic compound. Recent evidence involving different basil genotypes has shown that developmental stage can interact with genotype in determining phenolic characteristics [3]. This variation suggests that plant age by itself is insufficient to predict when phenolic compounds will reach their highest levels.

Growing conditions may further shape these developmental responses. Previous studies have reported that light conditions, nutrient availability, genotype, and harvest timing can influence phenolic accumulation and antioxidant properties in basil and basil microgreens [11,20,27]. Growing conditions may also shape the phytochemical profile of basil microgreens, as environmental and cultivation-related factors can influence the accumulation of secondary metabolites [28]. Consequently, differences in biochemical characteristics across harvest stages are more likely to reflect an interaction between plant development and the environment in which the plants are cultivated rather than a response to chronological age alone.

This interpretation is relevant to the present finding that the mature basil extract had higher TPC and DPPH values than extracts obtained from the two microgreen stages. Microgreens are widely recognized as valuable sources of nutrients and phytochemicals, yet this does not mean that every bioactive constituent is necessarily present at its maximum concentration during early plant development. Comparisons between young and mature plant material have shown that phytochemical profiles may vary according to species, genotype, compound type, and developmental stage [3,16]. The present findings therefore do not diminish the functional value of basil microgreens. Instead, they indicate that the biochemical characteristics measured in this study continued to change as the plants developed beyond the 10- and 14-day microgreen stages.

The cultivation system used in this study also forms part of the context in which these results should be interpreted. Basil was grown with locally available materials, including rice husk, household organic compost, and rice washing water, combined with manual watering and limited synthetic chemical inputs. These practices represented the local wisdom-based horticultural system applied throughout cultivation. Since the individual components were not evaluated as separate experimental treatments, their specific contributions to phenolic content or antioxidant activity cannot be determined from the present data. The findings instead demonstrate that basil cultivated within this locally resource-based setting exhibited measurable phenolic content and radical-scavenging activity throughout the three developmental stages.

From an applied perspective, the results indicate that the choice of harvest stage may involve different considerations. Harvesting basil at 10 or 14 days provides the practical advantage of a shorter production

period while still producing microgreens with measurable phenolic content and DPPH radical-scavenging activity. Extending cultivation to 30 days, however, resulted in the highest measured values of both parameters under the conditions of this study. These observations may be useful when considering harvest strategies for small-scale horticultural production, although they are not sufficient to define a universally optimal harvest time. Such a conclusion would require additional information on crop yield, production costs, resource use, nutritional composition, and biological variability.

The interpretation of these findings should also take the experimental design into account. Plant material from each harvest stage was pooled before extraction, while duplicate measurements were performed on the resulting pooled extracts. The duplicate values therefore represent analytical repeatability rather than biological variation among individual plants. For this reason, the differences observed among T1, T2, and T3 cannot be interpreted as statistically significant differences between developmental stages. In addition, environmental factors such as light intensity, temperature, and nutrient availability were not independently controlled as experimental variables. The study also focused on total phenolic content rather than identifying individual phenolic compounds that may have contributed differently to antioxidant activity.

Future studies could address these limitations by including independent biological replicates at each developmental stage and by monitoring important environmental variables throughout cultivation. More detailed phytochemical profiling would also help identify which individual compounds change as basil develops and how these changes relate to antioxidant properties. Combining such measurements with crop yield and resource-use data could provide a stronger basis for identifying a harvest stage that balances functional quality with practical production considerations.

Overall, the findings reveal a consistent descriptive pattern in which both TPC and DPPH radical-scavenging activity increased from the 10-day microgreen stage to the mature stage, following the order T3 > T2 > T1. Rather than establishing a universal optimum for basil harvesting, the results emphasize that developmental stage should be considered when evaluating its bioactive characteristics. At the same time, the study provides initial evidence that a simple horticultural system using locally available resources can support basil production from the microgreen stage through later development while retaining measurable phenolic content and antioxidant activity.

4. Conclusion

The biochemical characteristics of basil varied across the developmental stages examined in this study. Total phenolic content increased from 0.960 ± 0.146 mg GAE/g extract in 10-day-old microgreens to 1.056 ± 0.061 mg GAE/g extract at 14 days, with the highest value of 1.170 ± 0.010 mg GAE/g extract recorded in mature basil harvested at 30 days. DPPH radical-scavenging activity showed a comparable pattern, increasing from 63.659 ± 0.621% at 10 days to 66.634 ± 0.414% at 14 days and 72.585 ± 0.276% at the mature stage.

Under the cultivation conditions applied in this study, mature basil therefore exhibited the highest measured phenolic content and radical-scavenging activity. The results also indicate that the bioactive characteristics of basil may continue to change beyond the microgreen stage, highlighting the relevance of developmental stage when determining harvest time for functional purposes. However, these findings should be interpreted within the scope of the experimental design, as the analyses were based on pooled extracts with analytical duplicates rather than independent biological replicates. Further research incorporating biological replication and more closely controlled growing conditions is needed to clarify how plant development and cultivation factors contribute to changes in the bioactive properties of basil.

Declaration of AI and AI assisted technologies in the writing process

During the preparation of this work the author(s) used [ChatGPT (OpenAI)] to assist with language refinement, paraphrasing, and improving the clarity and readability of the text. After using this tool/service, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the content of the publication.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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