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ANALYSES OF MORPHOLOGICAL DYNAMICS INTO THE VEGETATIVE PHASE OF WHITE CABBAGE (*BRASSICA. OLERACEA* VAR. *CAPITATA* F. *ALBA*) ACROSS DIVERSE PLANTING SCHEDULES

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Abstract

Cabbage (Brassica oleracea var. capitata f. alba) stands as an economically significant vegetable crop cultivated on a global scale. The life cycle encompasses four distinct vegetative stages: seedling, rosette, folding, and heading. Rosette leaves, contribute substantially to the energy allocation necessary for the development of the characteristic leafy head. This study delves, firstly, into a detailed morphological analysis to investigate the early developmental stages of cabbage seedlings, unravelling the intricate dynamics of their overall morphology. Secondly, an exploration was carried out into the quantities of assimilatory pigments within the cabbage seedlings which provides valuable aspects of early cabbage development. The third study delves into the influence of planting dates and densities on the morphological characteristics of cabbage plants during the vegetative phase. Through analyses of plant morphology, the study discerns nuanced developmental responses influenced by varied planting schedules. This research aims to contribute not only to the scientific understanding of white cabbage cultivation but also to practical implications for optimizing planting strategies.

***Key words**: seedlings, carotenoid pigments, planting strategies, Brassicaceae, heading stage.*

INTRODUCTION

Cabbage (*Brassica oleracea* L. var. *capitata* f. *alba*) is a vegetable plant belonging to the *Brassicaceae* family, recognized as the largest plant family. As a cool-season vegetable characterized by short roots, cabbage is primarily cultivated for its substantial leafy head. Its cultivation traces its origins to Western Europe, with historical records attesting to its initial introduction and cultivation in the region (Singh et al., 2006).

The cultivation of this plant primarily focuses on its sizeable foliage. The morphological attributes of various cabbage cultivars, including head size, shape, colour, and leaf texture, exhibit considerable diversity (Nieuwhof, 1969).

Cabbage leaves are recognized for their considerable nutritional value, containing antioxidant phytochemicals (Singh et al., 2006, Sharma et al., 2018), a spectrum of macro- and micronutrients (Turan et al., 2014), and notable levels of vitamins C, E, and K (Ibukunoluwa Moyin-Jesu, 2015). Cabbage holds a prominent position among vegetables, serving as a crucial component in maintaining a healthy diet. A sample of 100 g leaves contains 93 mL water, 15 g protein, 0.2 g fat, 4 g carbohydrates, 4 g calcium, and 0.5 g iron (Moamogwe, 1995). Cabbage is rich in essential micronutrients pivotal for human health and plant functions, including copper, zinc, and iron (Nkosi and Msimango, 2022).

White headed cabbage stands out and attracts consumer preference due to its superior nutritional profile, providing significant health benefits for human consumption. Rich in vitamins, fibres, polyphenols, and flavonoids, it represents a valuable source of nutrients (Nawaz et al., 2018).

Initially, its leaves exhibit a rosette-like configuration and subsequently develop compound heads composed initially of 7-15 leaves that fold inward (Chura et al., 2021).

Plants quality relies on plant genotypes, environmental conditions, and agro-management practices (Gruda, 2019). While genetic material is acknowledged for its impact on quality, seedlings are primarily focused on increasing yield, optimizing harvest timing, and addressing plant diseases and abiotic stress. Early utilization of high-quality planting material in cabbage crops substantially enhances overall success, efficiency, performance, hastens time to harvest, and improves profitability, regardless of the cultivation environment.

Leafy vegetables, particularly cabbage, demand high levels of nitrogen, phosphorus, and potassium, especially nitrogen fertilizer (Pradhan et al., 2007). However, excessive and indiscriminate use of chemical fertilizers can raise planting costs and pose environmental risks. Thus, enhancing fertilization practices and fertilizer efficiency is critical for supporting sustainable development in agriculture.

The proper selection of planting date and plant spacing significantly influences cabbage production practices by affecting yield-contributing factors and overall harvest. These decisions also play a primary role in influencing the quality attributes of cabbage heads.

The utilization of appropriate high-yielding cultivars and optimal spacing techniques could aid farmers in attaining increased yields per unit area, along with enhanced nutrient assimilation and solar energy capture efficiency. Variations in both morphological characteristics and phenological responses among cultivars lead to differential reactions to plant density (Prasad et al., 2010). Furthermore, diverse cultivars exhibit discrepancies in growth, yield, and quality attributes, which are contingent upon varying environmental conditions (Thapa et al., 2012).

Optimal cabbage plant population recommendations commonly range from 20.000 to 70.000 plants ha^{-1} (Ghanti et al., 1982; Tenday and Kuzyk, 2001; Kumar and Rawat, 2002). However, these findings report inconclusive results.

The response of cabbage yield and quality to plant density is influenced by various factors, including plant genotype, climate conditions, soil, water regime, nutrient status, market requirements, and others (Parmar et al., 1999; Tiwari et al., 2003).

Increasing plant population in cabbage has the potential to enhance yield and profit. While high plant density in cabbage may reduce head weight and size (Csizinszky and Schuster, 1985), a greater number of heads per unit area has been shown to increase total yield (Stepanović et al., 2000). Maximizing benefits in cultivation systems requires enhancing genetic, temporal, and spatial diversity (Ditzler et al., 2021).

The agricultural technique of intercropping, involving the simultaneous cultivation of multiple crops in close proximity, holds potential for augmenting crop diversity. Crop diversification contributes to increased yield through the strategic exploitation of factors such as niche differentiation and optimal resource utilization (Li et al., 2020; Yu et al., 2015).

Recent meta-analyses suggest that intercropping enhances yield by around 30% compared to monocultures (Beillouin et al., 2019; Li et al., 2023).

Intercropping has the potential to alleviate pest outbreaks by disrupting pest host-searching behavior (Finch and Collier, 2000; Mansion-Vaquié et al., 2020), diminishing host plant concentration (resource concentration hypothesis) (Root, 1973), or augmenting the abundance, diversity, and control efficiency of natural enemies (natural enemies hypothesis) (Khan et al., 1997; Nilsson et al., 2016; Tajmiri et al., 2017; Trenbath, 1993).

Comprehensive studies have elucidated the impact of genetic and abiotic factors on cabbage yield and crucial traits. Parameters such as genotype, planting density, season, and planting date exert influence on total and marketable yield, head weight, shape, firmness, as well as core dimensions (de Moel and Everaarts, 1990; Fornaris-Rullan et al., 1989; Howe and Waters, 1994; Strandberg and White, 1979).

Specifically, de Moel and Everaarts (1990) observed smaller, lighter heads and reduced marketable yield in crops planted in June and July compared to those planted in May, with an associated increase in core length in the Netherlands.

Fornaris-Rullan et al. (1989) documented head weight variations from 0.63 to 1.73 kg, diameters ranging from 12.4 to 18.6 cm, and lengths spanning 13.8 to 16.3 cm among 10 cabbage cultivars cultivated in Puerto Rico.

Howe and Waters (1994) highlighted substantial year × cultivar interactions affecting marketable yield, head weight, size, and other characteristics across 16 cabbage cultivars planted in two seasons in Florida. Similar variations among cultivars in significant traits were observed in Louisiana, North Dakota, and Pennsylvania (Greenland et al., 2000; Orzolek et al., 2000; Sundstrom and Story, 1984).

Sowing and planting dates vary by geographical regions. In the high hills of India, seeds are sown in May - June for summer/ autumn harvests. In hilly areas with abundant rainfall, planting is limited, occurring only in autumn. In the northern regions, sowing is recommended between August and November for late varieties. In the eastern regions, sowing typically begins in mid to late September (Tnau, 2017; Gupta et al., 2020).

Recommended row spacing for white cabbage in USA ranges from 60 cm to 90 cm, with plant spacing of 22 cm to 38 cm for early plantings and 22 cm to 45 cm for late plantings, based on variety traits, soil fertility, and intended cultivation purpose (Kemble et al., 2018).

In Romania, autumn cabbage crops are established both through seedlings and by direct sowing. Seedlings are transplanted between June 15 and July 15. The planting is done in two rows, with a spacing of 70 cm to 80 cm between rows and 25 cm of 30 cm between plants within a row, resulting in an approximate density of 45.000 to 50.000 plants per ha^{-1} (Munteanu, 2019).

Hence, further research on cabbage growth is imperative, particularly in the face of contrasting and constantly changing climatic conditions. By analysing the morphological characteristics of cabbage plants during the vegetative phase and exploring relationships among key head traits.

Anticipated outcomes include an enhanced comprehension of the effects of planting date and densities on indicators of cabbage quality in the northeastern part of Romania, leading to more efficient cultivar development, evaluation, and selection.

This research aims to contribute to the scientific insights of the white cabbage cultivation and to provide practical implications for refining planting strategies.

This is achieved through the determination of the optimal sowing period for acquiring high-quality seedlings by evaluating their morphological and physiological traits.

Furthermore, the study seeks to identify the optimal combinations of experimental factors, including planting time and density, to attain superior cabbage mother-plants. This experiment is a component of a more comprehensive study dedicated to improving cabbage seed production technology.

MATERIALS AND METHODS

Plant material

The study is centered on the assessment of the vegetative phase of the late-season white cabbage cultivar, 'Silviana' patented at the Vegetable Research and Development Station Bacau in 2014. 'Silviana' cultivar is characterized as a sturdy and crack-resistant cabbage variety with a good yield potential. The cabbage head displays uniformity and exhibits a range from round to elliptical in longitudinal section, featuring a height between 19-22 cm and a diameter of 22-25 cm. The calculated shape index falls within the range of 0.8-0.95, and the average weight varies from 1.7-3.3 kg. The leaves possess a delicate texture, while the head form in longitudinal section ranges from round to elliptical, with leaves displaying hues from raw green to medium intensity green. The cultivar 'Silviana' exhibits the potential to achieve elevated yields ranging from 100 to 120 tons per hectare.

Site description

The studies were conducted in the VRDS experimental field, located at coordinates 46.585205 N, 26.950087 E. The field is located in the north-eastern region of Bacau, situated on a river terrace with an elevation of 5-7 meters and a height of 165 meters above sea level. Positioned in the Bistrița - Siret interfluve, approximately 4 kilometres north of their confluence, the trial took place on a well-developed, loamy-sandy textured polished cambic chernozem.

Experimental design

The experiment involved a randomized complete block design with three replications. For the study, a methodology encompassing morphological observations, biometric determinations, and physiological studies were employed. The cabbage seeds were sown in three distinct dates and maintained in a greenhouse while receiving regular watering, typically once per day, through overhead misters until field planting according to the following periods. The initial planting took place on July 10th (E_1), followed by the second on August 10th (E_2), and the third on September 10th (E_3). Each planting period involved the establishment of three distinct planting densities.

The highest density was achieved with a spacing of 25×140 cm between plants and rows, resulting in an average of approximately 28.500 plants ha^{-1} (D_1). The medium density was attained with a spacing of 40×140 cm, yielding an average of approximately 17.850 plants ha^{-1} (D_2). The lowest density was achieved with a spacing of 55×140 cm, resulting in an approximate of 12.900 plants ha^{-1} (D_3).

After reaching 40 days and achieving planting maturity, the cabbage seedlings that had not been planted were extracted from the greenhouse and transported to the laboratory for analysis. Plant samples were randomly hand-picked for the assessment of various morphological traits.

Determination of assimilatory pigments

The seedling quality was assessed through the determination of assimilatory pigments. Physiological studies were conducted for chlorophyll A, chlorophyll B, chlorophyll A+B, chlorophyll A/B ratio, carotenes, xanthophylls, and the ratio of total chlorophyll/carotenes and xanthophylls. The spectrophotometric method was employed to evaluate these pigments, utilizing the BOECO S-20 Spectrophotometer. For pigment extraction, a one-gram leaf sample (fresh plant material) was extracted with 80% acetone, and the absorption of the extracts was measured at wavelengths 663, 646, and 470 nm compared to the control sample – acetone 80%. Pigment content was calculated following the formulas developed by Mackinney (1941) and expressed in mg 100 g^{-1}.

$$Chlorophyll\ A = [(12.21 \times DO_{663}) - (2.81 \times DO_{646})] \times 5$$

$$Chlorophyll\ B = [(20.13 \times DO_{646}) - (5.03 \times DO_{663})] \times 5$$

$$Carotenes\ and\ xanthophylls = [(1000 \times DO_{470}) - (3.27 \times Chl.A) - (1.04 \times Chl.B)] \div 229$$

Data collection

The evaluation of the seedlings characteristics included the thickness of the seedling at the stem base (mm), the height of the seedling at planting maturity (cm), number of leaves, total seedling weight (g), weight of aerial part of the seedling (g) and roots weight (g). Regarding the study of the morphological features of cabbage plants during the vegetative phase, assessments were conducted on parameters such as head diameter (cm), head height (cm), leaf count and plant height (cm).

Data analysis

The acquired morphological data resulted from the observation of the dynamics in plant growth and developmental processes. Statistical-mathematical methods, including the ANOVA method and Tukey's post-hoc test, were applied to process the obtained data, with reported results presented as means ± standard errors. Software tools such as Microsoft Excel and IBM SPSS Statistics version 26.0 were utilized for data analysis. A significance threshold of $P \leq 0.05$ was employed to discern significant differences between data groups.

RESULTS AND DISCUSSIONS

Table 1 provides data on variations recorded from pigment analyses of cabbage leaves, conducted on three seedling sets, with each set representing a period of establishing the mother plant crop.

Table 1. Results regarding the analysis of pigments in the seedling leaves (mg 100 g^{-1} fresh plant material)

V	Chl. A	Chl. B	Chl. A+B
E_1	14.58±1.12 b	14.48±1.58 c	29.06±2.66 c
E_2	16.27±0.82 b	23.58±0.97 b	39.86±1.51 b
E_3	23.32±0.42 a	28.48±0.97 a	51.80±1.38 a
V	**CX**	**A/B**	**AB/CX**
E_1	7.08±0.41 b	1.05±0.06 a	4.03±0.17 c
E_2	6.90±0.38 b	0.69±0.03 b	5.87±0.27 a
E_3	10.26±0.22 a	0.82±0.01 b	5.04±0.05 b

E_1 - 10.07; E_2 - 10.08; E_3 - 10.09; V - Variant; Chl. A - Chlorophyll A; Chl. B - Chlorophyll B; Chl. A+B - Total Chlorophyll; CX - Carotenes and xanthophylls; A/B - Chlorophyll ratio; AB/CX - Total Chlorophyll/ Carotenes and Xanthophylls ratio; a - the highest value. The values represent the mean ± standard error, and letters indicate significant differences between variants according to the Tukey test for $p \leq 0.05$.

The analysis of experimental data regarding chlorophyll pigments (A) content indicates that the mean varied between 14.58 mg 100 g^{-1} and 23.32 mg g^{-1}. The maximum value was recorded for seedlings from the third planting period, while the minimum was observed for the first period.

In the case of chlorophyll (B), the mean ranged from 14.48 mg 100 g^{-1} fresh plant material to 28.48 mg 100 g^{-1}. The maximum value was obtained in the third period, and the minimum was recorded for the second period.

Concerning total chlorophyll pigments (A+B), the maximum value of 51.58 mg 100 g^{-1} was recorded for the planting date of 10.09, corresponding to the third period. Therefore, the average content of carotenes and xanthophylls (CX) reached a maximum of 10.26 mg 100 g^{-1} fresh plant material for seedlings from the third period.

Regarding the chlorophyll ratio (A/B), the highest mean was recorded during the first period, reaching 1.05 mg 100 g^{-1}. As for the total chlorophyll/carotenes and xanthophylls ratio (AB/CX), the average ranged from 4.03 mg 100 g^{-1} to 5.87 mg 100 g^{-1}, with the highest value recorded during E_2 (10.08).

Results from cabbage seedling analysis showed significant variation between periods. Overall, the values indicate the health, photosynthetic capacity, and adaptability of cabbage seedlings to the sowing date, offering essential insights into physiological processes during the initial plant life cycle stage.

Table 2 summarizes variations in morphological characteristics among the three sets of 40-day-old seedlings, each corresponding to the specific planting period for mother-plant crop. The main objective was to identify the optimal sowing time for quality seedling production.

Table 2. Results regarding the analysis of morphological characteristics of the seedlings

V	TSB (mm)	HS (cm)	NL
E_1	2.05±0.06 b	11.66±0.67 c	5.10±0.23 ns
E_2	2.44±0.10 a	14.66±0.35 b	4.63±0.15 ns
E_3	2.37±0.12 ab	20.47±0.55 a	5.09±0.21 ns
V	**SM (g)**	**MAS (g)**	**RM (g)**
E_1	2.85±0.18 b	2.75±0.19 b	0.107±0.004 b
E_2	2.98±0.09 b	2.86±0.10 b	0.120±0.005 b
E_3	5.09±0.21 a	4.91±0.21 a	0.176±0.008 a

E_1 - 10.07; E_2 - 10.08; E_3 - 10.09; V - Variant; TSB - Thickness of the seedling at the stem base; HS - Height of the seedling at planting maturity; NL - Number of leaves; SW - Total seedling mass; WAS - Mass of aerial part of the seedling; RW - Roots mass; a - the highest value; ns - not significant. The values represent the mean ± standard error, and letters indicate significant differences between variants according to the Tukey test for $p \leq 0.05$.

The analysis of seedling thickness at the stem base revealed that the maximum mean was recorded in E_2 (10.08) with a diameter of 2.44 mm, while the E_1 (10.07) showed an average of 2.05 mm. Regarding the comparison of seedling planting height across all periods, the highest average height was recorded in E_3 with a value of 20.47 cm, and the lowest was recorded E_1 with a value of 11.66 cm.

Leaf counts showed minimal, insignificant variations, ranging from 4.63 in E_2 to an average of 5.10 leaves per plant, with the highest mean recorded by E_1. The total mass of seedlings exhibited significant variations across periods, ranging from a minimum of 2.85 g in E_1 to a maximum of 5.09 g in E_3. Similarly, the mass of aerial part showed a range from 2.75 g to 4.91 g, with E_3 recording the highest value and E_1 the lowest.

Root mass averages showed significant variation, ranging from 0.107 g to 0.176 g, with E_3 recording the highest and E_1 the lowest means.

Morphological analysis revealed significant differences between sowing periods, suggesting the E_3 is potentially the most suitable for high-quality seedling development. However, these findings are limited and warrant further study for a comprehensive understanding of the sowing period's impact on cabbage seedling development.

Table 3 presents observed differences in morphological characteristics, including plant height, leaf count, head diameter, and head height, concerning the effect of the establishment period on mother-plants crop quality.

Table 3. Results regarding the analysis of the influence of the planting dates on mother-plants

V	NL	PH (cm)
E_1	24.68±0.41 a	56.70±0.87 a
E_2	22.96±0.30 b	49.05±0.88 b
E_3	19.90±0.50 c	37.51±0.90 c
V	**HD (cm)**	**HH (cm)**
E_1	23.30±0.38 a	19.14±0.35 a
E_2	18.53±0.43 b	15.49±0.34 b
E_3	-	-

E_1 - 10.07; E_2 - 10.08; E_3 - 10.09; V - Variant; NL - Number of leaves; PH - Plant height; HD - Head diameter; HH - Head height; a - the highest value. The values represent the mean ± standard error, and letters indicate significant differences between variants according to the Tukey test for $p \leq 0.05$.

Plants established in E_1 had a higher leaf count compared to those in E_2 and E_3, with the maximum mean of 24.68 cm and the minimum mean of 19.90 cm recorded by E_3 (10.09). The first period (10.07) proves to be the most conducive for leaf system development.

Regarding plant height, there is a notable variation among those plants that have been established in E_1, with an average of 56.70 cm, compared to those in E_3 which recorded an average of 37.51 cm.

The head diameter and head height could only be analysed for plants established in the first and second periods because the plants from the third period did not reach the head-forming stage until they were covered with soil for winter protection in preparation for the upcoming seed crop. Consequently, both head diameter and height showed significantly higher averages for plants analysed in the first period compared to the second period.

It has been highlighted that the planting date influences head characteristics. In their study, Kleinhenz and Wszelaki (2003) reported no differences in cabbage head length and width for crops planted in May compared to those planted in June-July in the state of Ohio. De Moel and Everaarts (1990) emphasized that plants cultivated in June and July had smaller and lighter heads compared to those cultivated in May, observing an increase in head length with later planting in the Netherlands.

The results of the analysis on the influence of planting densities on morphological characteristics in the vegetative phase are presented in Table 4.

Table 4. Results regarding the analysis of the influence of densities on mother-plants

V	NL	PH (cm)
D_1	21.68±0.50 ns	49.47±1.58 ns
D_2	22.98±0.53 ns	47.53±1.28 ns
D_3	22.88±0.42 ns	46.25±1.28 ns
V	**HD (cm)**	**HH (cm)**
D_1	20.11±0.61 ns	16.87±0.54 ns
D_2	21.57±0.52 ns	17.60±0.46 ns
D_3	21.07±0.75 ns	17.47±0.56 ns

D_1 - 28.500 plants ha^{-1}; D_2 - 17.850 plants ha^{-1}; D_3 - 12.900 plants ha^{-1}; V - Variant; NL - Number of leaves; PH - Plant height; HD - Head diameter; HH - Head height; ns–not significant. The values represent the mean ± standard error, and letters indicate significant differences between variants according to the Tukey test for $p \leq 0.05$.

From the analysis of the obtained data, it can be observed that the number of leaves were not significantly influenced by the planting densities. The means ranged between 21.68 and 22.98 leaves per plant, with values very close to each other. The maximum mean was recorded for the density of 17.800 plants ha^{-1}, while the minimum mean was recorded by the density of 25 × 140, equivalent to 28.500 plants ha^{-1}.

Regarding plant height, the obtained values varied insignificantly. As expected, the D_1 with 28.500 plants ha^{-1} recorded the highest average height, reaching 49.47 cm. With increasing plant density, the plants tend to elongate in search of the necessary light for physiological processes.

Regarding head diameter, the averages varied insignificantly. The maximum average of 21.57 cm was achieved with by the density of 17.850 plants ha^{-1}, while the minimum average of 20.11 cm was recorded with a density of 28.500 plants ha^{-1}. Semuli (2005) noted that reducing the distance between plants increases competition for nutrients, light, air, and humidity, potentially leading to a decrease in head diameter and weight. Stoffella and Fleming (1990) reported increases in head height and width with greater spacing between plants in rows, ranging from 8 cm to 38 cm. The smallest distance between plants resulted in a significantly larger equatorial diameter than the polar diameter.

The planting density did not significantly impact head height. Heights ranged from 16.87 cm to 17.60 cm, with the maximum mean recorded at a density of 17.850 plants ha^{-1} and the minimum at 28.500 plants ha^{-1}.

Overall, these findings suggest that the planting density used does not significantly influence the morphological characteristics of white cabbage parent plants. However, other important variables that may affect plant development should also be considered, which could vary depending on the planting density.

The outcomes of the analysis regarding the influence of planting time and density on morphological traits are displayed in Table 5.

The assessment of head diameter and height was limited to plants cultivated in the first and second periods, as those from the third period had not reached the requisite developmental stage for head formation at the time of soil covering. Following the analysis for the experimental data for leaf number per plant, a notable mean variation is found, ranging from 17.94 to 25.38. The lowest value, 17.94, occurred for the $E_3 \times D_1$ variant (10.09 × 28.500 plants ha^{-1}), and the highest value, 25.38, was observed for the E_1 (10.07) with D_2 (17.850 plants ha^{-1}) combination.

Table 5. Results regarding the analysis of the combined influence of planting dates and densities on mother-plants

V	NL	PH (cm)
$E_1 \times D_1$	24.33±0.67 ab	59.05±1.39 a
$E_1 \times D_2$	25.38±0.71 a	55.43±1.51 ab
$E_1 \times D_3$	24.33±0.77 ab	55.62±1.58 ab
$E_2 \times D_1$	22.77±0.51 abc	51.82±1.71 bc
$E_2 \times D_2$	23.38±0.62 ab	49.86±1.12 bc
$E_2 \times D_3$	22.72±0.46 abc	45.48±1.36 c
$E_3 \times D_1$	17.94±0.59 d	37.56±2.10 d
$E_3 \times D_2$	20.16±0.99 cd	37.31±1.35 d
V	HD (cm)	HH (cm)
$E_1 \times D_1$	22.47±0.60 ab	18.77±0.61 ab
$E_1 \times D_2$	22.77±0.76 ab	18.61±0.64 ab
$E_1 \times D_3$	24.66±0.55 a	20.03±0.54 a
$E_2 \times D_1$	17.75±0.75 cd	14.98±0.65 c
$E_2 \times D_2$	20.37±0.62 bc	16.58±0.58 bc
$E_2 \times D_3$	17.48±0.71 d	14.90±0.50 c
$E_3 \times D_1$	-	-
$E_3 \times D_2$	-	-
$E_3 \times D_3$	-	-

$E_1 \times D_1$ - 10.07×28.500 plants ha^{-1}; $E_1 \times D_2$ - 10.07×17.850 plants ha^{-1}; $E_1 \times D_3$ - 10.07×12.900 plants ha^{-1}; $E_2 \times D_1$ - 10.08×28.500 plants ha^{-1}; $E_2 \times D_2$ - 10.08×17.850 plants ha^{-1}; $E_2 \times D_3$ - 10.08×12.900 plants ha^{-1}; $E_3 \times D_1$ - 10.09×28.500 plants ha^{-1}; $E_3 \times D_2$ - 10.09×17.850 plants ha^{-1}; $E_3 \times D_3$ - 10.09×12.900 plants ha^{-1}; V - Variant; NL - Number of leaves; PH - Plant height; HD - Head diameter; HH - Head height; a - the highest value. The values represent the mean ± standard error, and letters indicate significant differences between variants according to the Tukey test for $p \leq 0.05$.

Regarding plant height, a notable mean variation was detected, ranging from a minimum average of 37.31 cm for E_3 (10.09) with D_2 (17.850 plants ha^{-1}) to a maximum average of 59.05 cm for E_1 (10.07) with D_1 (28.500 plants ha^{-1}).

Regarding head diameter, significant differences are noticeable among the mean values of the studied variants. The $E_1 \times D_3$ experimental variant consistently achieved the maximum values, at 24.66 cm, while the $E_2 \times D_3$ variant recorded the minimum average at 17.48 cm. Head height displayed significant variation of mean values, with the $E_1 \times D_3$ variant (10.07×12.900 plants ha^{-1}) reaching the maximum mean of 20.03 cm and the $E_2 \times D_3$ variant (10.08×12.900 plants ha^{-1}) registering the minimum mean at 14.90 cm.

Abed et al. (2015) reported that the interaction between planting date and plant density had no significant impact on cabbage head characteristics. Variations in head width, height, volume, and firmness were ascribed to the independent effects of planting date or plant density.

Results indicate that both planting date and density exerted significant influence on head morphology, particularly in terms of length and width. The earliest planting period, coupled with the lowest density, returned the greatest means for head length and width. Consequently, plants sown during D_1 (10.07) exhibited distinctly larger heads compared to those planted later, such as during D_3 (10.09), which did not reach the stage of head formation.

CONCLUSIONS

In the pursuit of determining the optimal sowing period for producing superior seedlings, it was noted that the third period returned the most favourable outcomes, ensuring the attainment of seedlings of superior quality.

In terms of assimilatory pigment content in seedlings, E_3 (10.09) revealed the highest chlorophyll a and b content, while E_2 (10.08) exhibited the highest mean ratio of total chlorophyll to carotenes and xanthophylls.

The study on the influence of the planting period of cabbage plants morphology indicates that the first period (E_1) positively impacted the leaf system, averaging 24.68 leaves per plant. Plant height averaged 56.70 cm, with the highest head diameter and height values also linked to the first period, highlighting its significant positive effect on the evaluated morphological traits.

Regarding density influence, it manifested non-significant variability in the main morphological characteristics of the mother plants, with closely aligned means. Specifically, density D_1 (28.500 plants ha^{-1}) was linked to the maximum height at 49.47 cm, while D_2 (17.850 plants ha^{-1}) demonstrated the highest head diameter values.

In examining the effects of planting period and mother-plant crop density on morphological traits, noteworthy variations emerged across all analysed characteristics. Prominently, combinations such as $E_1 \times D_2$ and $E_1 \times D_3$ demonstrated superior outcomes, exerting a significant positive impact on the development of cabbage morphological traits.

These findings suggest that experimental factors greatly influence plant development, and selecting the optimal factors can notably enhance the morphological traits of white cabbage, fostering the growth of viable mother-plants used for future seed production.

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