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Increasing highland cabbage adaptability in tropical lowland through the utilization of shading and planting materials selection

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ABSTRACT: The use of shade and planting materials is expected to provide an effective solution to increase the introduction of highland cabbage in the tropical lowlands. This research aims to evaluate the growth response of cabbage plants under different shading intensities and planting materials. The experiment was arranged following a split-plot design with shading intensity as the main plot, and the subplots were planting material. The results showed that morphological alterations were found in cabbage grown under different shading intensities, especially under heavier shading treatment (80%). Denser shading caused elongation of stems and internodes due to etiolation. On the other hand, it decreased the stem diameter, number of leaves, canopy area, leaf area, leaf fresh weight, leaf dry weight, and inhibited root development during the plant development process from 2 to 12 weeks after transplanting. The use of different planting materials did not have any significant effect on all traits of highland cabbage cultivated in the lowlands. The cultivation of highland cabbage should be practiced under direct sunlight, not requiring shading treatment. Canopy growth of cabbage planted under direct sunlight showed a denser visual appearance, as reflected in the ability of cabbage to form a crop.
Keywords: crop vegetable; morphological traits; plant acclimation; sunlight intensity; vegetative propagation.

Aumentando a adaptabilidade do repolho das terras altas em planícies tropicais através da utilização de sombra e seleção de materiais de plantio

RESUMO: Espera-se que o uso de sombras e de materiais de plantio forneça uma solução eficaz para aumentar a introdução de repolho de terras altas em terras baixas tropicais. Esta pesquisa visa avaliar a resposta de crescimento de plantas de repolho sob diferentes intensidades de sombreamento e diferentes materiais de plantio. O experimento foi organizado no delineamento de parcelas subdivididas, com a intensidade de sombreamento como parcela principal e o material de plantio como subparcela. Os resultados mostraram que alterações morfológicas foram observadas em repolho cultivado sob diferentes intensidades de sombreamento, especialmente no tratamento mais intenso (80%). O sombreamento mais denso causou alongamento de caules e entrenós devido ao estiolamento. Por outro lado, diminuiu o diâmetro do caule, o número de folhas, a área da copa e a área foliar, reduziu o peso fresco e o peso seco da folha e inibiu o desenvolvimento da raiz ao longo do processo de desenvolvimento da planta, de 2 a 12 semanas após o transplante. O uso de diferentes materiais de plantio não teve efeito significativo sobre todas as características do repolho de terras altas cultivado em terras baixas. O cultivo de repolho de terras altas deve ser realizado sob luz solar direta, sem necessidade de tratamento de sombreamento. O crescimento da copa do repolho plantado sob luz solar direta apresentou uma aparência visual mais densa, refletida na capacidade do repolho de formar uma cultura.
Palavras-chave: hortaliça cultivada; características morfológicas; aclimatação da planta; intensidade de luz solar; propagação vegetativa.

1. INTRODUCTION

Cabbage (*Brassica oleracea* L. var *capitata*) is a kind of vegetable that is often consumed by the community. Moreb et al. (2020) reported that cabbage contains macronutrients, vitamins, antioxidants, and other phytochemicals that are beneficial to human health. Several studies have confirmed that this vegetable is suitable for highland areas (TRAN MINH et al., 2020; TABOR et al., 2022). Wi et al. (2020) also added that cabbage is generally cultivated in areas with an altitude above 700 m above sea level (masl). Although cabbage is a highland crop, it does not rule out the possibility of being cultivated in lowland areas. Several studies have reported that highland plants such as turnip shallot (Rahman et al., 2023), carrot, white cabbage and tomato (Cimo et al., 2020) are able to grow well in lowland areas.

Urban areas generally have limited land for agricultural practice. Population growth in urban areas requires the availability of built-up land such as residential areas, industry, trade, and public facilities (GE et al., 2020). However, the phenomenon of population growth in urban areas also needs to provide adequate food, including vegetables. Viana et al. (2022) stated that sustainable food security is an important urgency along with population growth. Currently, vegetable demand in lowland urban areas is supplied by highland farmers. The land resources and ecosystems of highland areas could optimize vegetable production (USMA; YUSUF, 2022). However, the increasing demand for vegetables in lowland urban areas should be anticipated to maintain sustainable food availability.

The alternative solution to address the increasing demand for vegetables in lowland urban areas is intensification through the introduction of highland vegetables. This effort is also highly recommended to reduce dependence on highland vegetable supplies. Nevertheless, climatic factors are a major challenge in the introduction of highland vegetables. Different climatic conditions require innovations in the development of agricultural systems, especially in lowland ecosystems. According to Kogo (2021), climate change and variability affect the agricultural system. Moreover, Ahmed et al. (2020) stated that climatic factors strongly influence plant growth and productivity. Therefore, climatic factors have a significant impact on plant growth. Climatic differences such as rainfall, sunlight intensity and humidity are essential factors in agricultural systems.

Using shade and selecting the proper planting materials are effective methods of overcoming the climatic differences between the highlands and the lowlands. The use of shade is a solution to manage higher temperatures and sunlight intensity in the lowlands. Although cabbage is a plant that needs sunlight for photosynthesis, direct exposure to sunlight can cause heat stress and damage the plant (CERVENSKI, 2022). Shade is used to reduce the negative effects of direct sunlight. It also maintains a stable microclimate for the plant and increases the humidity around the plant (QUARSHIE, 2023). In this study, cabbage plants in the lowlands grow significantly faster, avoiding the stress of high temperatures and producing higher yields. In addition, the use of stem cuttings as planting material has several advantages, particularly in accelerating plant propagation. Plant propagation with stem cuttings allows cabbage plants to grow faster and are more resistant to extreme environmental conditions (NTUI et al., 2024). Through the use of shade and planting materials, it is expected to provide an effective solution to increase the introduction of highland cabbage in the lowlands.

Research related to the introduction of highland cabbage into lowland urban areas is still rarely carried out. Research about highland cabbage cultivation in lowland urban areas will provide specific knowledge regarding cabbage adaptation to different environmental characteristics. This study aims to explore the potential of highland cabbage cultivation in the tropical lowlands by determining the effects of different shades and planting materials on the growth and development of cabbage.

2. MATERIAL AND METHODS

2.1. Research site and agroclimatic conditions

The research was carried out at the Jakabaring Research Facility in Palembang, South Sumatra, Indonesia (104°46'44" E, 3°01'35' S). The study began in September 2024 and continued through December 2024. The study site is a tropical lowland urban ecosystem at an altitude of 8 meters above sea level (masl). This ecosystem is confirmed by the high rainfall, air humidity, air temperature and duration of sunshine (Figure 1).

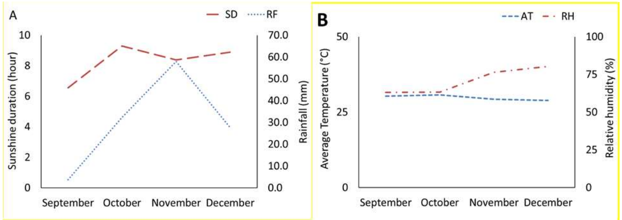

Figure 1. Agroclimatic characteristics of the research site include sunshine duration (SD) and total monthly rainfall (RF) (A), and average temperature (AT) and relative humidity (RH) (B). (Source: Indonesian Agency for Meteorology, Climatology, and Geophysics).
Figura 1. Características agroclimáticas do local de pesquisa, incluindo a duração da insolação (SD) e a precipitação mensal total (RF) (A), e a temperatura média (AT) e a umidade relativa (RH) (B). (Fonte: Agência Indonésia de Meteorologia, Climatologia e Geofísica).

2.2. Research protocol

The planting materials used were obtained from highland Pagar Alam at an altitude of 280 masl. Technically, the planting materials were stem cuttings with a different number of leaves retained. The planting materials were divided into 3 treatments, namely: stem cuttings with no leaf retained (SC-0), stem cuttings with a single leaf retained (SC-1L), and stem cuttings with two leaves retained (SC-2L). Each stem cutting used was 10 cm (length). Each planting material was transplanted into a pot measuring 26 cm (height) × 22 cm (diameter of bottom) × 30 cm (diameter of top). As the growing substrate, the pots were filled with topsoil. The planted pots with the tested planting materials were arranged in the shade. The shading used was made from woven polyethylene with a density adjusted to the determined shading intensity. There were several shading intensities compared, namely direct sunlight (without shading), 55% shading, and 80% shading, symbolized as SD-0, SD-55, and SD-80, respectively. As a maintenance procedure, watering was performed regularly in the afternoon when there was no rain, while pest and weed control was carried out mechanically without chemicals. Meanwhile, fertilization was performed 3 WAT by NPK (16:16:16) fertilizer at a dose of 5 g/plant.

2.3. Data collection

The collected data consisted of cabbage growth and soil moisture data. The cabbage growth data consisted of non-destructive and destructive data. The destructive data consist of stem and root length, stem diameter, internode and petiole length, and fresh and dry weight of stem and root. Meanwhile, non-destructive data consist of plant height, number of leaves, canopy area, relative water content, specific water content and specific leaf area. Non-destructive observations were carried out every week starting from the second week until the twelfth week after planting (WAP), while destructive observations were carried out at 15 WAP. The canopy area was measured using a digital image scanner, Easy Leaf Area for Android (Easlon and Bloom, 2014). Substrate moisture was measured using a soil moisture meter (Lutron Soil Moisture Meter PMS-714).

2.4. Experimental design and statistical analysis

The experiment was arranged based on a split-plot design with three replications. The shading intensity was set as the main plot, consisting of sunlight (without shading (SD-0)), 55% shading (SD-55), 80% shading (SD-80). Furthermore, the planting materials as subplots consisted of stem cuttings with no leaf retained (SC-0), stem cuttings with a single leaf retained (SC-1L), and stem cuttings with two leaves retained (SC-2L). All the collected data were analyzed using the RStudio software version 1.14.1717 (R CORE TEAM, 2024). Subsequently, significant differences among the treatments were tested using the least significant difference procedure at $p<0.05$.

3. RESULTS

The cabbage stem morphology was affected by shade treatment. The denser shade intensity prevents direct sunlight exposure to cabbage plants. Consequently, cabbages exposed to low levels of sunlight cause etiolation. Etiolation is characterised by the cabbage stem becoming elongated at a faster rate. Interestingly, stem cuttings propagation with leaf cutting actually inhibits the growth of stem height, especially stem cuttings with two leaves (Figure 2). The shade response stimulates etiolation. The etiolation of cabbage stems is also reflected in the smaller stem diameter. Cabbage grown in denser shade has longer and smaller stem morphology. This is reflected in the diameters of the stems planted in different shading treatments (Table 1).

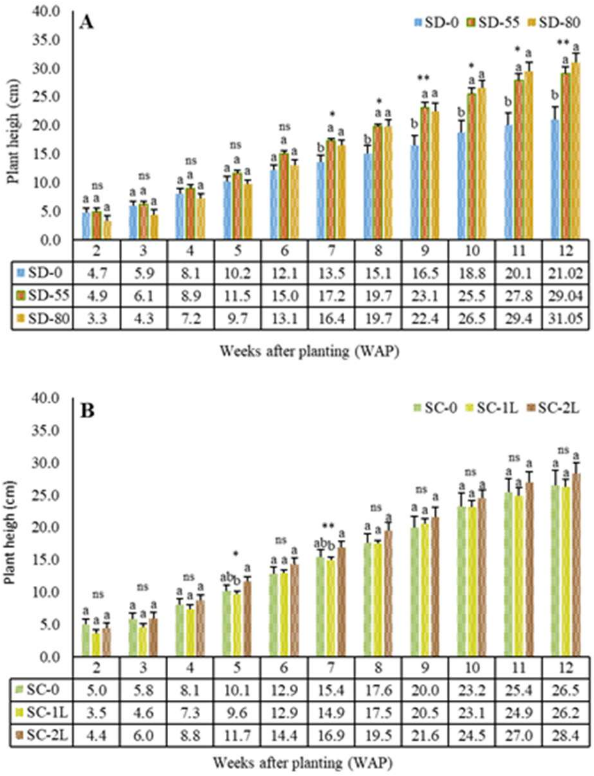

Figure 2. Effect of shading (A) and stem cutting propagation with (B) on plant height. Data are presented as the average ± standard error. ns: non-significant difference, *: significant difference at $p < 0.05$, **: significant difference at $p < 0.01$; ***significant difference at $p < 0.001$.

Figura 2. Efeito do sombreamento (A) e da propagação por estacas (B) na altura da planta. Os dados são apresentados como média ± erro padrão. ns: diferença não significativa; *: diferença significativa a p < 0,05; **: diferença significativa a p < 0,01; ***: diferença significativa a p < 0,001.

The shading intensity has a significant effect on cabbage weight and stem diameter. Plants not exposed to sufficient sunlight inhibited growth, such as the growth of cabbage stems, especially the diameter and weight of the stems. In addition, the shading intensity stimulates etiolation, which was characterised by faster stem growth and the wider internodal distance of cabbage grown under shade. Propagation material leaf stem cuttings with single inhibited growth as reflected in stem length and stem weight (Table 1). The decrease in cabbage stem fresh and dry weight grown under shade can be attributed to the ability of shade to intercept light waves, thus lowering light intensity. This is due to exposure to direct sunlight as an essential factor in the photosynthetic process.

The number of cabbage leaves was affected by shade intensity. The appropriate environmental condition for cabbage leaf growth is considered to be shade treatment with an intensity of 55%. Leaf growth consistently with 55% shade intensity, recording a higher number of leaves than direct sunlight exposure. Meanwhile, propagation material stem cuttings with leaf cuttings tends not affect the growth of cabbage plant leaves (Figure 3).

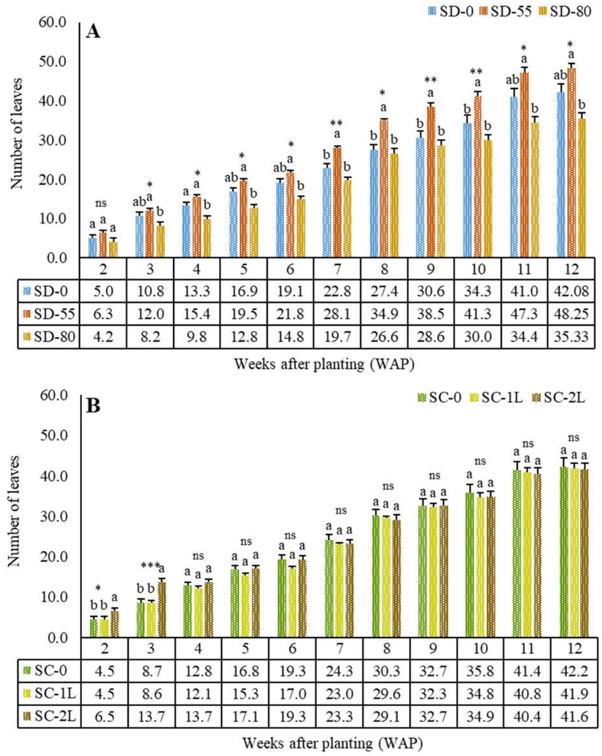

Figure 3. Effect of shading (A) and stem cutting propagation (B) on the number of leaves. Data are presented as the average ± standard error. ns: non-significant difference,*: significant difference at $p < 0.05$, **: significant difference at $p < 0.01$, ***: significant difference at $p < 0.001$.

Figura 3. Efeito do sombreamento (A) e da propagação por estacas (B) sobre o número de folhas. Os dados são apresentados como média ± erro padrão. ns: diferença não significativa; *: diferença significativa a p < 0,05; **: diferença significativa a p < 0,01; ***: diferença significativa a p < 0,001.

Light is essential for the process of plant growth and development. According to this research, cabbage leaf growth was inhibited by the influence of shade intensity and planting material using stem cuttings, leafless, as evidenced by the canopy area. This is an indication that plants receiving lower light intensities stimulate the elongation of leaf organs more rapidly. Light significantly influences the process of plant growth and development. According to the results of the study, both shade intensity and planting material with stem cutting leafless inhibited the growth of cabbage leaves, as evidenced by the canopy area. This indicates that plants receiving lower light intensities stimulate the elongation of leaf organs more rapidly. Meanwhile, leaf growth, especially in the canopy area, was inhibited by planting material, especially on stem cuttings with no leaves (Figure 4).

The process of leaf elongation was not inhibited by shading intensities of 55% and 80%, and the shading intensity treatment stimulated leaf elongation or etiolation. In contrast to leaf width, the influence of shade intensity inhibits growth, especially in leaf width. The research finding showed that cabbage leaf growth is inhibited at 80% shade intensity. Cabbage exposed to direct sunlight shows a faster leaf growth process and maximum leaf size and thickness than leaves grown under shade (Figure 5).

Table 1. The effect of shading intensity and stem cutting treatments on stem-related traits.
Tabela 1. Efeito da intensidade do sombreamento e dos tratamentos de corte do caule sobre as características do caule.

Treatments	Stem Length (cm)	Stem Diameter (mm)	Internode Length (cm)	Stem Fresh Weight (g)	Stem Dry Weight (g)
Shade Intensity					
SD-0	31.78 ± 1.66 b	29.75 ± 0.47 a	0.83 ± 0.09 c	128.11 ± 0.94 a	15.37 ± 0.94 a
SD-55	40.43 ± 2.32 a	22.16 ± 1.15 b	1.22 ± 0.11 b	128.01 ± 1.05 a	15.73 ± 1.05 a
SD-80	44.81 ± 2.74 a	12.73 ± 0.79 c	2.26 ± 0.05 a	62.69 ± 6.58 b	7.49 ± 0.73 b
Significant	*	**	**	**	**
LSD	11.03	2.43	0.26	23.81	1.63
Stem Cutting					
SC-0	41.11 ± 2.83 a	21.27 ± 2.31 a	1.41 ± 0.26 a	109.88 ± 13.74 a	13.81 ± 1.55 a
SC-1L	35.21 ± 2.93 b	21.47 ± 3.06 a	1.55 ± 0.21 a	95.21 ± 16.34 a	11.29 ± 1.83 a
SC-2L	40.71 ± 2.70 a	21.90 ± 2.38 a	1.35 ± 0.22 a	113.71 ± 10.90 a	13.50 ± 1.32 a
Significant	*	ns	ns	ns	ns
LSD	4.73	2.56	0.31	21.19	2.71

Data are presented as the average ± standard error. ns = non-significantly difference; * = significantly difference at $p < 0.05$; and ** = significantly difference at $p < 0.01$. LSD = Least Significant Difference.
Os dados são apresentados como média ± erro padrão. ns = diferença não significativa; * = diferença significativa com $p < 0{,}05$; e ** = diferença significativa com $p < 0{,}01$. LSD = Diferença Mínima Significativa.

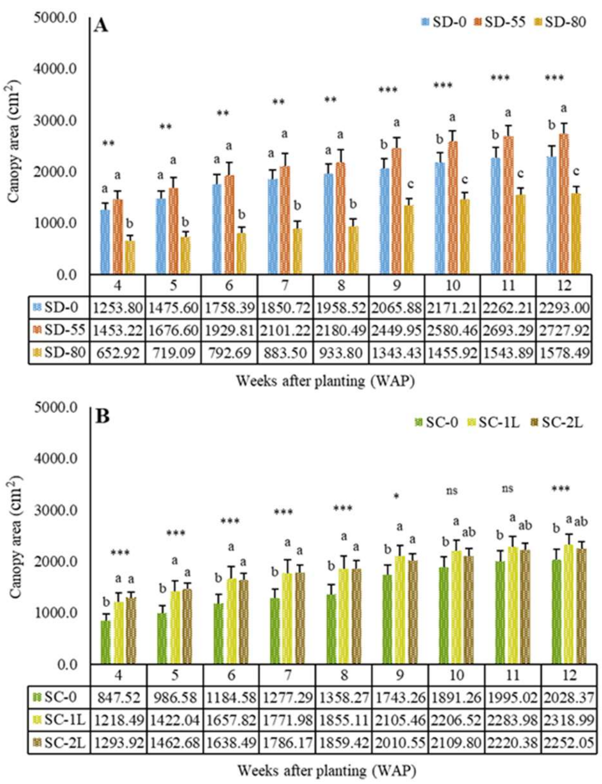

Figure 4. Effect of shading (A) and stem cutting propagation (B) on canopy area. Data are presented as the average ± standard error. ns: non-significant difference, *: significant difference at $p < 0.05$; **: significant difference at $p < 0.01$; ***: significant difference at $p < 0.001$.
Figura 4. Efeito do sombreamento (A) e da propagação por estacas (B) na área da copa. Os dados são apresentados como média ± erro padrão. ns: diferença não significativa; *: diferença significativa a $p < 0{,}05$; **: diferença significativa a $p < 0{,}01$; ***: diferença significativa a $p < 0{,}001$.

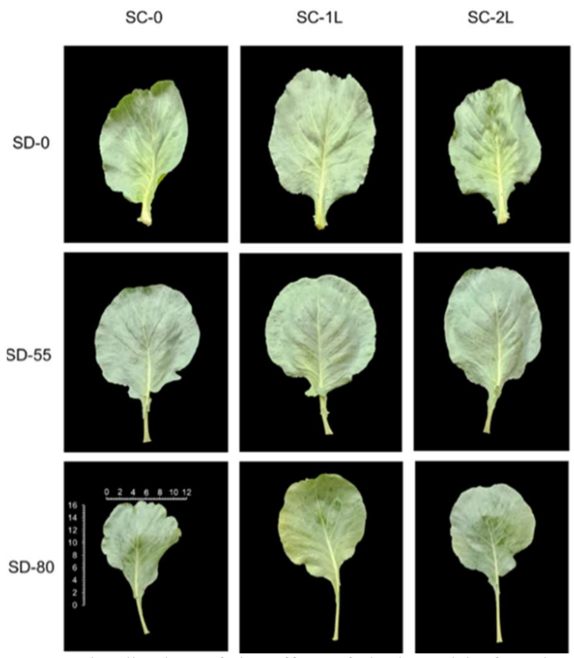

Figure 5. Visualization of the effect of shade and leaf cutting on plants; 55% (SD-55), and 80 % (SD-80), and plants receiving full sunlight (SD-0). Meanwhile, 1 leaf (SC-1L), 2 Leaves (SC-2L) and leafless (SC-0).
Figura 5. Visualização do efeito do sombreamento e do corte de folhas nas plantas: 55% (SD-55), 80% (SD-80) e plantas expostas à luz solar plena (SD-0). Enquanto isso, 1 folha (SC-1L), 2 folhas (SC-2L) e sem folhas (SC-0).

Meanwhile, shade intensity (80%) stimulates the growth of leaf petioles. Shading has an impact on the morphological characteristics, especially the internode. The internodal distance is wider than that of plants exposed to direct sunlight (Figure 6). This phenomenon was evidenced by an increase in shade intensity, causing etiolation of cabbage, which has an effect on inhibiting the growth and yield of cabbage.

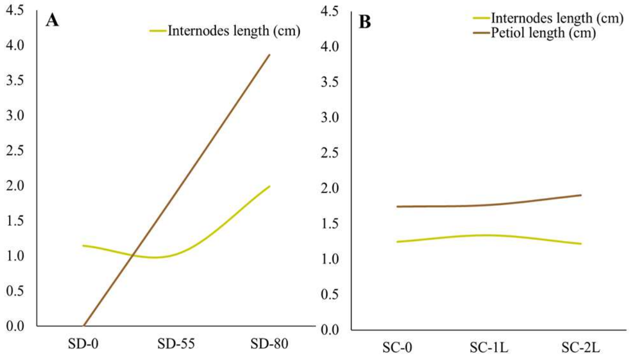

Figure 6. The effect of shading (A) (0%,55%, 80%) and stem cutting propagation (B) with (0, 1, 2 leaves) on internodes and petiole length.
Figura 6. Efeito do sombreamento (A) e da propagação por estacas (B) sobre o comprimento dos entrenós e do pecíolo.

The function of shade is to control the microclimate. One indication of the microclimate is media humidity. The cabbage growing media under shade had a higher water content. This is indicated by the humidity level of the cabbage growing media, which is grown in 80% shade (Figure 7). The 80 % shading intensity, which has a low light intensity, causes the plant media to lose air more slowly. Meanwhile, planting material with stem cuttings did not affect the water content of the planting media (Figure 8).

The dense shade 80% reduces evaporation. This reduces the potential for water loss. This is evidenced by the soil moisture, which is higher than in other shade areas. This condition also shows that water availability is more adequate in shade 80%. Sunlight received by plants is reduced by the intensity of dense shade. The shading could contribute to maintaining soil moisture.

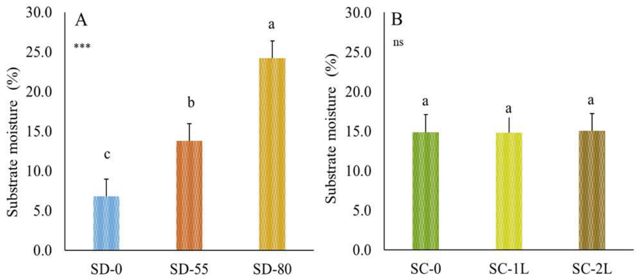

Figure 7. Effect of shading (A) and stem cutting (B) on soil temperature. ns: non-significant difference; ***: significant difference at $p < 0.001$.
Figura 7. Efeito do sombreamento (A) e do corte do caule (B) na temperatura do solo. ns: diferença não significativa; ***: diferença significativa ($p < 0,001$).

Relative water content indicates the ability of plant tissue to absorb water. The ability of leaves to absorb water decreases during the day and evening. Increases in shade intensity affect the water uptake capacity of cabbage leaves (Figure 8). The denser the shading intensity, the lower the ability of the leaves to absorb water. Furthermore, cabbage that was planted using stem cuttings with no leaves has a high relative water content. Planting material with stem cuttings will affect the ability of the leaves to absorb water.

The cabbage leaf is a valuable organ because it has commercial value. Observations of growth in length and width were carried out to estimate leaf area. Leaf area estimation is carried out to identify predictors of leaf area determination in a non-destructive manner. Leaf length x width (LW) was selected as a predictor from several regression models. The L x W using a linear with zero intercept regression model was confirmed as the most reliable model ($y = 0.5981x$; $R2 = 0.9848$) (Table 3).

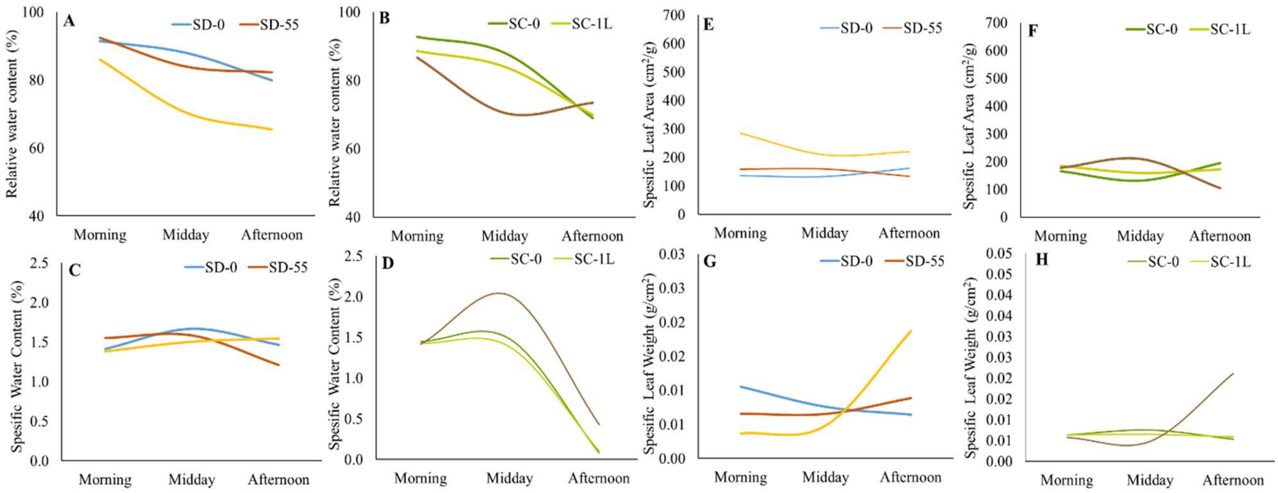

Figure 8. The effect of shading (A) and stem cutting propagation (B) on leaf water content.
Figura 8. Efeito do sombreamento (A) e da propagação por estacas (B) sobre o teor de água foliar.

To overcome the high light intensity, shading is an alternative. Shading intensity influences the morphological characteristics of the roots. As indicated by the shorter morphology of the plant roots and less weight compared to cabbage grown under direct sunlight. Interestingly, planting material, stem cuttings, leafless, stimulates faster root growth. This is reflected in the length and weight of the roots (Table 2). The canopy growth of cabbage planted under direct sunlight shows a denser visual appearance. The growth of new leaves on the plant causes a denser canopy. Crop formation progressed slowly and began at around 13 weeks after planting. This is reflected in the ability of cabbage to form a crop; the crop size is 8 × 10 cm and a weight of 0.856 g (Figure 9). On the other hand, etiolation phenomena occur when plants are grown in high-intensity shade (55% and 80%). This phenomenon caused the stem to elongate but did not produce new leaves, and the effect is a sparse canopy (Figure 10).

Table 2. The effect of shade intensity and stem cutting treatments on root-related traits.
Tabela 2. Efeito da intensidade da sombra e dos tratamentos de corte do caule sobre características relacionadas às raízes.

Treatments	Root Length (cm)	Root Fresh Weight (g)	Root Dry Weight (g)
		Shade Intensity	
SD-0	32.44 ± 4.61 a	31.80 ± 4.94 a	3.40 ± 0.51 a
SD-55	29.57 ± 3.28 a	23.10 ± 4.39 a	2.62 ± 0.62 ab
SD-80	14.26 ± 3.20 b	8.46 ± 1.82 b	1.68 ± 0.84 b
Significant	**	**	*
LSD	16.33	18.48	2.25
		Stem Cutting	
SC-0	31.73 ± 5.49 a	27.22 ± 5.90 a	3.97 ± 0.83 a
SC-1L	19.67 ± 3.51 a	15.53 ± 4.15 a	1.57 ± 0.43 a
SC-2L	24.89 ± 3.81 a	20.63 ± 4.60 a	2.81 ± 0.52 a
Signifcant	ns	ns	ns
LSD	13.23	12.78	1.29

Data are presented as the average ± standard error. ns: non-significant difference, *: significant difference at $p < 0.05$, **: significant difference at $p < 0.01$. SD-0, SD-55, and SD-80 = shading intensity at 0, 55%, and 80%, respectively. SC-0, SC-1L, and SC-2L = stem cutting without leaf, with 1 leaf, and with 2 leaves, respectively. LSD = Least Significant Difference.
Os dados são apresentados como média ± erro padrão. ns: diferença não significativa; *: diferença significativa a $p < 0,05$; **: diferença significativa a $p < 0,01$. SD-0, SD-55 e SD-80 = intensidades de sombreamento de 0%, 55% e 80%, respectivamente. SC-0, SC-1L e SC-2L = estaca sem folha, com 1 folha e com 2 folhas, respectivamente. LSD = Diferença Mínima Significativa.

Figure 9. Visualization of the formation process of cabbage plants grown under full sunlight.
Figura 9. Visualização do processo de formação de plantas de repolho cultivadas sob luz solar plena.

Table 3. Cabbage leaf estimation involves leaf length (LL), leaf width (LW), and LL x LW as predictors. Remark: The coefficient of determination (R2) indicated the level of each predictor and the regression.
Tabela 3. A estimativa da folha de repolho envolve o comprimento da folha (CL), a largura da folha (LF) e o produto CL x LF como preditores. Observação: o coeficiente de determinação (R^2) indica o nível de cada preditor e da regressão.

Predictors	Regression Type	Equation	R^2
Leaf length (LL)	Linear	$y = 19.057x - 152.72$	0.8542
	Exponential	$y = 21.444e^{0.1124x}$	0.8298
	logarithmic	$y = 317.47\ln(x) - 712.9$	0.8117
	Polynomial	$y = 0.3266x^2 + 7.097x - 51.025$	0.8608
	Power	$y = 0.6192x^{1.954}$	0.859
	Linear with zero-intercept	$y = 11.693x$	0.9544
	Polynomial with zero intercept	$y = 0.474x^2 + 1.4496x$	0.8594
Leaf width (LW)	linear	$y = 19.447x - 122.25$	0.8798
	Exponential	$y = 26.507e^{0.1128x}$	0.8529
	logarithmic	$y = 293.82\ln(x) - 610.19$	0.8433
	Polynomial	$y = 0.2452x^2 + 11.286x - 59.968$	0.8829
	Power	$y = 1.2512x^{1.7833}$	0.8804
	Linear with zero-intercept	$y = 12.976x$	0.9635
	Polynomial with zero intercept	$y = 0.4572x^2 + 3.9054x$	0.8805
Leaf length (LL) x Leaf width (LW)	Linear	$y = 0.569x + 12.774$	0.9123
	Exponential	$y = 59.632e^{0.0032x}$	0.8617
	logarithmic	$y = 112.61\ln(x) - 425.65$	0.6711
	Polynomial	$y = 9E\text{-}05x^2 + 0.507x + 21.16$	0.9129
	Power	$y = 3.5056x^{0.6988}$	0.8989
	Linear with zero-intercept	$y = 0.5981x$	0.9848
	Polynomial with zero intercept	$y = -6E\text{-}05x^2 + 0.6268x$	0.9112

Figure 10. Visualization of the effect of shading; 55% (SD-55), 80 % (SD-80) and plants receiving full sunlight (SD-0) on canopy area.
Figura 10. Visualização do efeito do sombreamento: 55% (SD-55), 80% (SD-80) e plantas recebendo luz solar plena (SD-0) na área da copa.

4. DISCUSSION

The artificial shade treatment is an attempt to determine the adaptation of plants to low light intensity. Cabbage plant height growth shows a positive response to shade treatment. Some plants show a positive adaptability to shade. Some vegetables tolerate low-intensity shade, such as celery (Jaya et al., 2021) and eggplant (NGUYEN et al., 2022).

Each plant has a different ability to respond to light stress. Plants show specific symptoms in response to light intensity. The shading intensity has a significant effect on cabbage weight and stem diameter. Besides, plants not exposed to sufficient sunlight inhibited growth, such as the growth of cabbage stems, especially the diameter and weight of the stems. Furthermore, the shading intensity stimulates etiolation, which was characterised by faster stem growth and the wider internodal distance of cabbage grown under shade. However, some vegetables have been shown not to grow optimally in shade, such as purple pak choy (Fadhilah et al., 2022) and chillies (KESUMAWATI et al., 2020).

On the other hand, based on observations, cabbage growth in denser shade was inhibited. According to Reeza et al (2024), green and Chinese spinach plants grown under low light inhibit 90% of the growth. In addition, Alves et al (2022) reported that lettuce plants grown in direct sunlight showed faster growth and better leaf quality than plants grown in the shade. The metabolism of highland cabbage is thought to be impaired by a lack of sunlight. The denser shade intensity causes low light intensity that the plant can receive. Stirbet (2019) reported that light has an important effect on the photosynthetic process. Furthermore, light is also involved in stomatal conductance by promoting stomatal opening; this mechanism promotes plants optimizing photosynthesis and water use efficiency (YUMORI et al., 2020).

Generally, leafy vegetables have a high light requirement for growth support (SONG et al., 2018). Each plant has a different ability to tolerate low-light conditions. Plants show specific symptoms in response to low light intensity. Cabbage grown in the shade inhibited leaf and canopy growth (Figures 2 and 3).

This research showed that cabbage plants are vegetables that respond to light. According to research by De Oliveira et al. (2020), there are differences in the canopy due to the influence of shading. On the other hand, the shade response stimulates etiolation (Figure 1). Etiolation due to low light intensity is a common effect in a variety of plant species. Etiolation is characterized by elongation of the stems and wider internode spacing. Furthermore, according to Huber et al. (2021), there is a mechanism for elongating stems and petioles in response to shade. Wang et al. (2021) also expressed the same thing as one of the responses of plants to low light, namely, by a mechanism to elongate stems and petioles in an attempt to find a light source. Using shade also reduces the width of the leaves. This is because the increasingly reduced intensity of solar radiation received by plants causes the process of photosynthesis to decrease, thereby inhibiting vegetative growth, especially on leaves. Different levels of shading have been shown to influence internode length (AHMED et al., 2023). However, the tolerance of plants to shade differs. Not all plants require the same intensity of light for photosynthesis (MIAO et al., 2023).

As a leafy vegetable, the leaf is an important organ in yield components. The leaves with the highest water content are the largest. The increased RLWC of cabbage plants in the morning is due to the higher relative humidity of the soil media. In the morning, the leaves have not lost much air through transpiration. According to Upreti et al. (2021), leaves lose water through transpiration, which generally occurs in the morning. We assumed that transpiration does not occur at night because leaf stomatal conductance increases in the early morning.

Destructive observations of estimated leaf area growth were conducted to observe leaf growth (HAGHSHENAS et al., 2022). Developing a leaf area estimation model is to determine leaf area non-destructively, quickly, and accurately. In order to determine the right time to harvest leafy vegetables, leaf area measurement is conducted. The wider leaves, the more light can be absorbed and utilized for plant growth. The L x W value has consistently been shown to be an accurate predictor for estimating leaf area. The prediction model was tested on leaves with similar shapes, such as cauliflower leaves (Da Silva et al., 2021) and cabbage leaves (LAKITAN et al., 2022). In addition, the choice of regression type affects the reliability of the predictor in predicting leaf area. According to this research, the linear model with zero-intercept using the L x W predictor is the most accurate. The use of the zero-intercept regression model to estimate leaf area has been confirmed to be accurate in oranges (Budiarto, 2021; Muda et al., 2023) and cabbage (CHEN et al., 2020).

Plants have different responses to different types of stress. Plant morphology alteration is one of the responses of plants to light stress. The observations showed that differences in the stems, leaves, and root morphology of highland cabbage were due to the shading. In addition, research has shown that highland cabbage can grow and adapt in lowland areas. The growth of the cabbage plants shows a positive response when grown under direct exposure to sunlight. This is reflected in the cabbage's ability to form crops. In contrast, plants in the shade show inhibited growth. Furthermore, according to Artemyeva et al. (2021), light intensity significantly influences the productivity of Chinese cabbage, pakchoi, and leaf radish. Hence, shading treatment significantly inhibits leaf growth, especially leaf width. This is reflected in the dwarfing morphology of the leaves, which affects the ability of the plant to form a crop. According to Miao et al. (2023), the quality of Shawen spinach leaves decreases due to low light intensity.

The low intensity of sunlight visually inhibits stem growth. Plants under low levels of sunlight will respond, and a visible response in plants that lack sunlight can be seen in the morphology of the stem. Iqbal et al. (2022) argue that plant growth under low light intensity conditions affects the morphological characteristics of plants. Furthermore, light intensity has an effect not only on leaf and stem growth but also on root growth.

The fresh weight of the root increased with the increasing light intensity. Shade can affect the intensity and quality of sunlight received by plants, and can therefore have a major impact on various plant metabolic activities. Shade stress led to a reduction in root biomass compared with under natural light (CHEN et al., 2020). Sunlight exposure through shading affects both the length and weight of cabbage roots. Fadilah et al. (2022) reported that shading influences root length in pak choy, while Timotiwu et al. (2021) found that root weight in lettuce is also affected by shade intensity.

5. CONCLUSIONS

The growth of highland cabbage plant rows in lowland areas with 80% shade intensity inhibits plant growth, as evidenced by changes in leaf, stem and root morphological characteristics.

Highland cabbage plants require environmental conditions with direct exposure to sunlight. This was demonstrated by the fact that, in contrast to those cultivated in shade, it was still able to form crops when grown in direct sunlight. However, it was still comparatively slower than when the plants were grown in a highland area.

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