Agronomy Research **20**(S1), 938–950, 2022
https://doi.org/10.15159/AR.22.057

Effects of shading on the growth of the purple pakchoy (*Brassica rapa* var. Chinensis) in the urban ecosystem

L.N. Fadilah[1], B. Lakitan[2,3,*] and M. Marlina[2]

[1]Program of Crop Science, Faculty of Agriculture, Universitas Sriwijaya, Jalan Padang Selasa No. 524, Bukit Besar, Palembang 30139, South Sumatera, Indonesia
[2]Faculty of Agriculture, Universitas Sriwijaya, Jalan Raya Palembang–Prabumulih Km 32, Indralaya, Ogan Ilir 30662, South Sumatera, Indonesia
[3]Research Center of Sub–optimal Lands, Universitas Sriwijaya, Jalan Padang Selasa No. 524, Bukit Besar, Palembang 30139, South Sumatera, Indonesia
[*]Correspondence: blakitan60@unsri.ac.id

Received: June 21st, 2022; Accepted: September 4th, 2022; Published: September 12th, 2022

Abstract. Open green spaces in urban area can be utilized in many ways. Recently, more of the open spaces have been cultivated for vegetable production, gradually shifted from aesthetical purpose to the need for fresh healthy foods. Urban vegetable farming can be conventionally practiced on a limited backyard. Our research was aimed to assess the effects of shading treatments on growth and yield of purple pakchoi (*Brassica rapa* var. *chinensis*). The research was arranged based on the randomized block design with 4 levels of shading treatment. The results showed that shading treatments at 0%, 45%, 55%, and 80% significantly affected morphological growth traits, including plant height, number of leaf, lengths of petiole, length of leaf midrib, width of leaf blade, canopy diameter, and leaf SPAD index, total leaf fresh and dry weights, total fresh and dry roots, and lengths of stem; but did not significantly affect the leaf thickness. In all affected traits, heavier shading inhibited growth, confirming that the purple pakchoi prefers full sunlight. The leaf of purple pakchoi reached its maximum size at less than 14 days counted from the first day of leaf blade was fully unfolded. Purple pakchoi can be harvested at 35 days after transplanting. The accurate leaf area estimation in purple pakchoi can be achieved by using LW as predictor and calculated using the power regression ($R^2 = 0.9806$).

Key words: aesthetic value, fresh vegetable, green space, healthy food, morphological trait, urban farming.

INTRODUCTION

The open green space in urban area is continuously decreasing due to socio-economic pressures, public policies, and the physical condition (Ustaoglu & Williams, 2017). Increase in economic value of urban land enhanced conversion of the green space to urban settlements (Rondhi et al., 2018). Essentially, the function of green space in urban area should be conserved in order to maintain comfortability, aesthetic value, and healthy environment. Intensification of the urban agricultural activities could ecologically and aesthetically improve living environment and also increase availability of fresh and healthy vegetables for urban community (Lakitan, 2021). Urban farming has been globally practiced and well accepted by city dwellers (Grebitus et al., 2020).

Urban farming opened opportunity for the knowledgeable community to apply science and technology in producing fresh foods (Orsini et al., 2013; Ferreira et al., 2018), especially fruits and vegetables (Lal, 2020). Walters & Midden (2018) suggested to grow vegetable crops with shallow roots. This farming activity may also improve community welfare (Surya et al., 2020).

Green pakchoi *(Brassica rapa* var. *chinensis)* has been globally recognized, including in Indonesia (Priadi & Nuro, 2017); however, purple pakchoi has not been widely known. Purple pakchoi and other colorful vegetables have attracted urban community to grow them for their aesthetic value (Zhang et al., 2014), encouraged the community to consume natural healthy substances, including anthocyanins (Zhu et al., 2017; Hao et al., 2020), and considered as a good selenium supplement for humans (Li et al., 2020). Leaf of pakchoi has a good tasted, high economic value, and easy to cultivate (Wahyuningsih et al., 2016).

In the tropical agroecosystem, shading was commonly practiced in the cultivation of purple pakchoi (Abdel–Ghany & Al–Helal, 2020). Shading application has been reported to increase number of leaf in pakchoi (Mansyur et al., 2014; Andini & Yuliani, 2020). However, it should be specified at what ranges or peak that the optimal shading percentage for the purple pakchoi can be achieved.

This research was aimed to specify optimum shading percentage for maximizing growth and yield of the purple pakchoi *(Brassica rapa* var. *chinensis)* in the tropical urban ecosystem.

MATERIALS AND METHODS

The study was carried out in the tropical lowland climate at the research facility in Jakabaring (104°46′44″E; 3°01′35″S), Palembang, South Sumatera, Indonesia. Average air temperature is 31 °C and relative humidity is 51% during period of cultivation. Seeds of purple pakchoi *(Brassica rapa* var. *chinensis)* were purchased from commercial seed producer. The seeds soaked in tap water for 15 minutes for breaking the dormancy. After soaked, seeds were sown in seedling trays filled with mixture of soil and chicken manure (1:1 v/v). Chemical characteristics of soil used include pH = 6.63, N-total 0.27%, P_2O_5-total 720.53 mg per 100 g, K_2O-total 63.94 mg per 100 g, Mg-total 123.09 mg per 100 g, and Available P Bray II 1306.4 ppm. Nutrient contents of the commercial chicken manure used were 3–5% nitrogen, 1.5–3.5% phosphorous, and 1.5–3.0% potassium.

The seedlings were transplanted to plastic pots at 14 days after sowing (DAS). The seedlings had two unfolded leaves at time of the transplantation. Each pot was filled with a mixture of soil and chicken manure at ratio of 3:1 v/v (Jaya et al., 2021). Fourteen days prior to transplanting, the growing mix was sterilized using bio-sterilization and aerobic decomposers (*Streptomyces* sp.; *Geobacillus* sp.; and *Trichoderma* sp.) at dose 200 mL plant^{-1}. The plants were daily watered at 5 p.m. for maintaining soil moisture near the field capacity (35%). The maximum wet-dry cycle was around 30 to 35 in the morning and 25 to 30 at late afternoon. Therefore, the purple pakchoi plants were never under water stress condition.

Experimental design

The experimental design used in this study was the randomized block design. Seedlings of the purple pakchoi were directly allocated in each of the 45%, 55%, and 80% shading house and on an open space for 0% shading at time of transplanting. Percentage of shading was calculated by substracting light intensity under full sunlight with the directly measured light intensity using a light meter (Krisbow KW06-291). Three shade houses were constructed for each shading treatment. Dimension of the house was 4 m length × 2 m width × 2 m height. The knockdown frames made of 1.5 inch PVC pipes were used in constructing the shading house. Each of the shading house was covered in all sides with black polyethylene net at different shading levels.

Data measurement

Collected data on plant growth included plant height, number of leaf, petiole length, leaf blade length, leaf blade width, leaf thickness, canopy diameter, and leaf chlorophyll index. The leaf chlorophyll index was measured using an instrument for soil plant analysis and development (SPAD) produced by the Konica Minolta (SPAD–502 Plus). The mature plants were harvested at 49 DAS or 35 days after planting (DAP). The measured traits at time of harvest included above ground organs, i.e., whole-plant weight, fresh and dry weight of leaf blade, fresh and dry weight of petiole, fresh and dry weight of stem; and under ground organs, i.e., root length, root fresh and dry weights. The measurement of all dimensional traits used the transparent regular ruler, except for leaf thickness that was measured using a digital caliper. Weight-related traits were measured using a digital scale.

Calculation of leaf growth rate was carried out based on directly measured length (L) and width (W) of the leaf blade for 18 consecutive days until the leaf was fully expanded. Leaf area (LA) estimation model was developed based on directly measured data on leaf length and width. Direct LA measurement used digital image analysis software (LIA32, developed by Kazukiyo Yamamoto, Nagoya University, Japan). The LIA32 digital measurement software recognizes all visible color spectrum (Kitao et al., 2022).These two morphological traits were used as predictors, individually (L or W) or in combination (LW). The zero-intercept linear model was used if LW was used as predictor. The power and polynomial regression was used if individual L or W was selected as predictor.

Data analysis

Analysis of variance (ANOVA) were carried out using statistical analysis software (SAS 9.0 for Windows, SAS Institute Inc., USA). Significant differences amongst treatments were tested using the Least Significant Difference *(LSD)* test at $P > 0.05$. Trend analysis between predictor and the leaf area was using the zero-intercept linear, power, and polynomial regressions (Meihana et al., 2017; Lakitan et al., 2021a). Leaf area estimation model was tested for accuracy based on the determination coefficient (R^2). The predictors used were leaf length (L), leaf width (W), and the multiplication of leaf length and width (LW).

RESULTS AND DISCUSSION

Growth responses to shading

The purple pakchoi has a short single stem without any branch; therefore, the shoot was dominated by leaf petioles and blades. Both stem growth and increase in number of leaves in the purple pakchoi were significantly halted if the sunlight received on the surface of the leaves is reduced as a result of being partially blocked by shading. The differences due to the effect of shading were increasingly noticeable as the purple pakchoi plant continued to grow (Fig. 1).

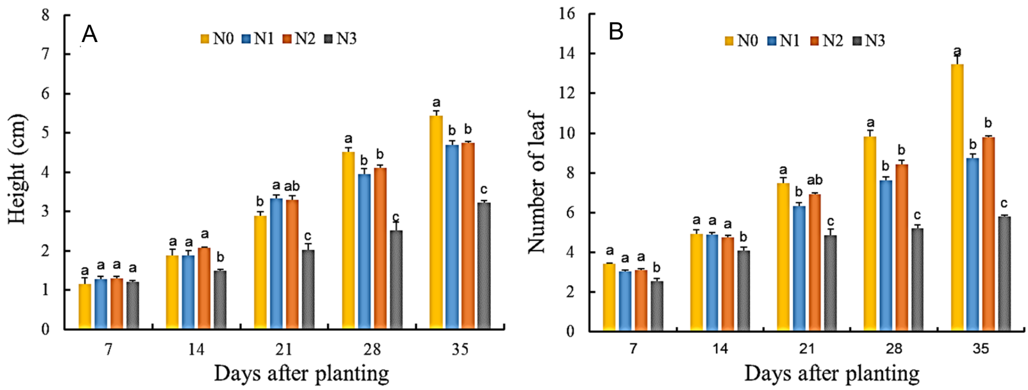

Figure 1. Stem height and number of leaf in purple pakchoi as affected by shading measured at 7 to 35 days after planting.

A common response of plants exposed to shade conditions is etiolation, i.e., excessive elongation of the stem (Armarego-Marriott et al., 2020). However, the symptoms of etiolation were not seen in the purple pakchoi plant in this study. On the contrary, the lengthening process of the stem was hampered in the shaded conditions. The incidence of etiolation resulting from lack of light occured only during the seedling phase in leafy vegetables, including green and purple pakchoi (Kong & Zheng, 2018).

The process of leaf formation was also hampered by shading treatments. Higher shading intensity (80%) suppressed stem lengthening and new leaf formation more strongly than moderate shading intensity (45% and 55%). Thus, the incidence of shading is believed to inhibit the overall growth of the purple pakchoi plant. The difference in stem length and number of leaves between plants that experienced different shade intensities became more noticeable as the purple pakchoi plant grew larger. Low light intensity (55% shading) significantly decreased the shoot and root growth in pakchoi (Yang et al., 2009).

Shading has direct and indirect effects on plant growth and development since shading alters microclimate condition underneath the shade screen. In addition to directly reducing the intensity of sunlight, the shading treatments also indirectly affects various climatic elements on the microscale at a position below the shade screen. Effects of shading on the length of leaf midrib, width of leaf blade, and length of petiole exhibited similar patterns to the effects on stem length and number of leaf. Higher shading intensity (80%) severely limit all measured components of leaf growth in purple pakchoi. Differences amongst 0, 45, 55, and 80% shading treatments were much clearer at 35 days after transplanting (Fig. 2).

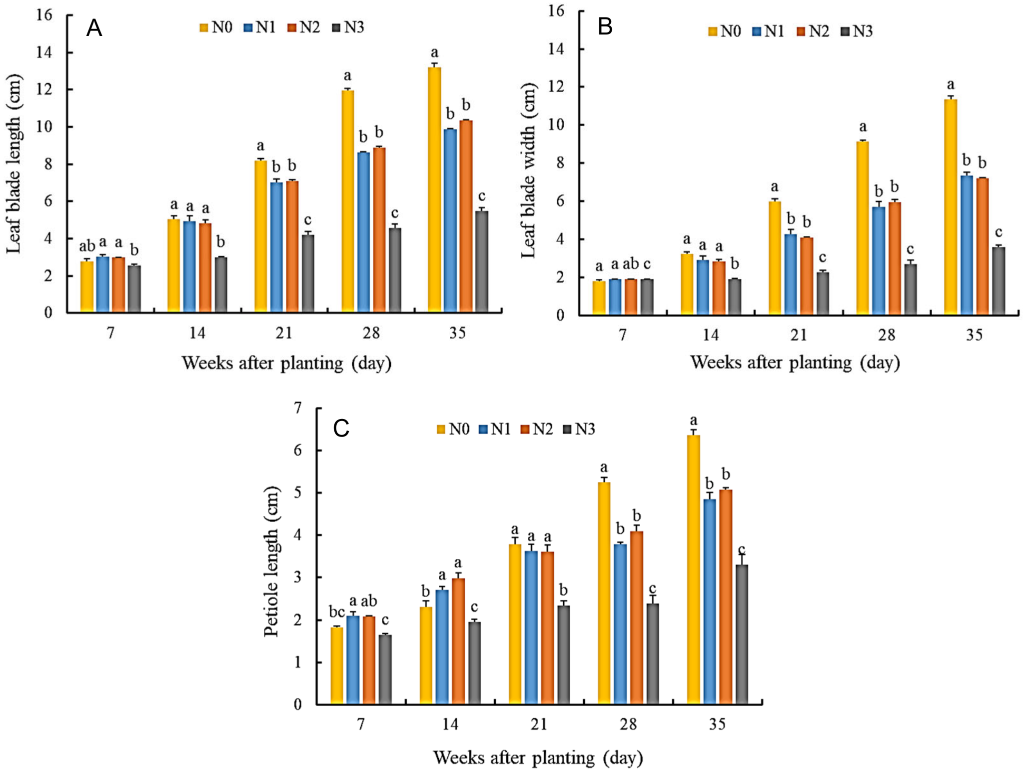

Figure 2. Leaf midrib length (A), leaf blade width (B), and petiole length (C) in purple pakchoi as affected by shading application measured at 7 to 35 days after planting.

Decrease in sunlight intensity would lower air and soil temperatures, increase relative humidity, decrease evapotranspiration, and increase soil moisture (Mahmood et al., 2018; Lakitan et al., 2021b). Furthermore, higher soil moisture could reduce oxygen transport into the soil matrix (Uteau et al., 2022), in turn, could decrease root metabolisms (António et al., 2016). In contrast, Budiarto et al. (2019) also reported that shading significantly improved the plant growth and number of leaves at early vegetatif growth.

The diameter of canopy also negatively affected by shading but the leaf thickness was not affected by shading (Fig. 3). The resistance to enlargement of the canopy area of purple pakchoi plant due to the influence of shading proportionally followed a pattern of resistance to all observed morphological traits, except for the thickness of the leaves. The leaf maintains the ability to form lateral cell additions throughout their life cycle and then develop into a flattened structure. The flattened leaf shape is advantageous for plants to capture more light needed for photosynthetic activity.

Du et al. (2018) explained that the flattened structures can optimally fulfill this function by precisely control the initiation, shape, and polarity of leaves. Leaf development underlies their morphogenesis to establish the three-dimensional leaf flattening forms.

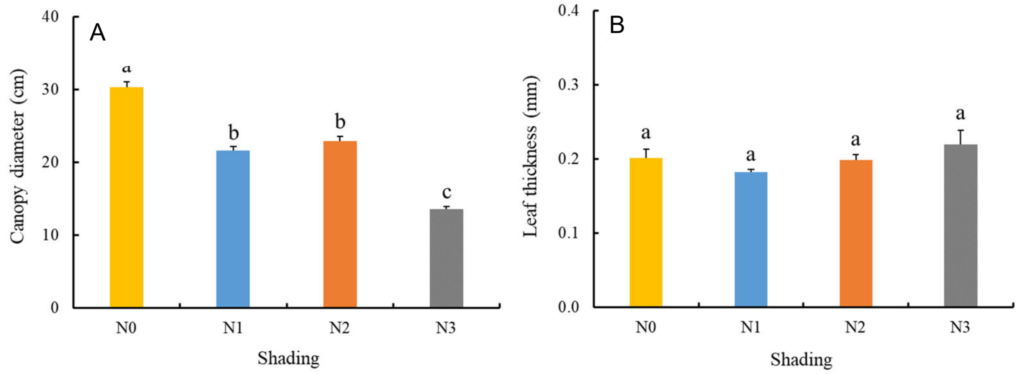

Figure 3. Canopy diameter (A) and leaf thickness (B) in purple pakchoi as affected by shading application.

Overall average of the mature leaf SPAD index was around 47.7 in purple pakchoi. The leaf SPAD index was above average in plant exposed to full sunlight intensity and reversely the index falled to below average in the heavily shaded purple pakchoi plant, i.e., exposed to 80% shading. The distributions of SPAD values on mature leaves were relatively the same at measurements on 21, 28, and 35 DAP. The highest SPAD value was always obtained in plants exposed to full sunlight, regardless of the age of the plant at the time of measurements (Fig. 4).

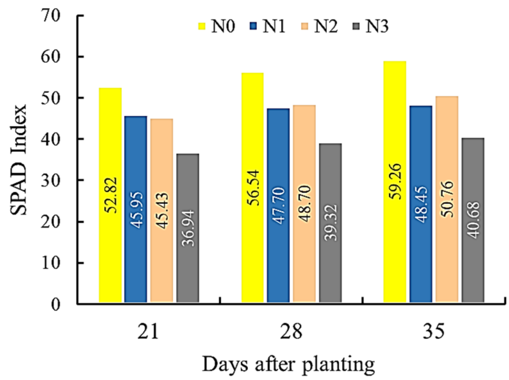

Figure 4. The effect of shading on the SPAD index on mature leaves in purple pakchoi.

The standard SPAD index measurement is on mature leaves that are characterized by their maximum size and have not shown symptoms of senescence. It should also be understood that the SPAD meter only measures the total chlorophyll concentration based on the optical principle and cannot distinguish between chlorophyll a and b. Technical details about the SPAD meter are provided by Süß et al. (2015). In addition addition to determining the total chlorophyll concentration, SPAD meter is also widely used as an indicator of leaf nitrogen status (Rongting et al., 2020). SPAD measurements in this study were used to monitor the effect of shading on the growth and health of pakchoi plants through changes in the green color intensity of the leaves.

Leaf surface area were measured daily for 18 consecutive days from the time the leaves began to unfold until they reached their full size. Knowledge of when the leaves cease to enlarge is a very useful in determining the right harvest time for leafy vegetables such as purple pakchoi. Leaf area monitoring based on leaf length and width separately is shown in Fig. 5 and monitoring based on the multiplication results between leaf length and width is presented in Fig. 6. The result of these two monitorings was consistent with each other.

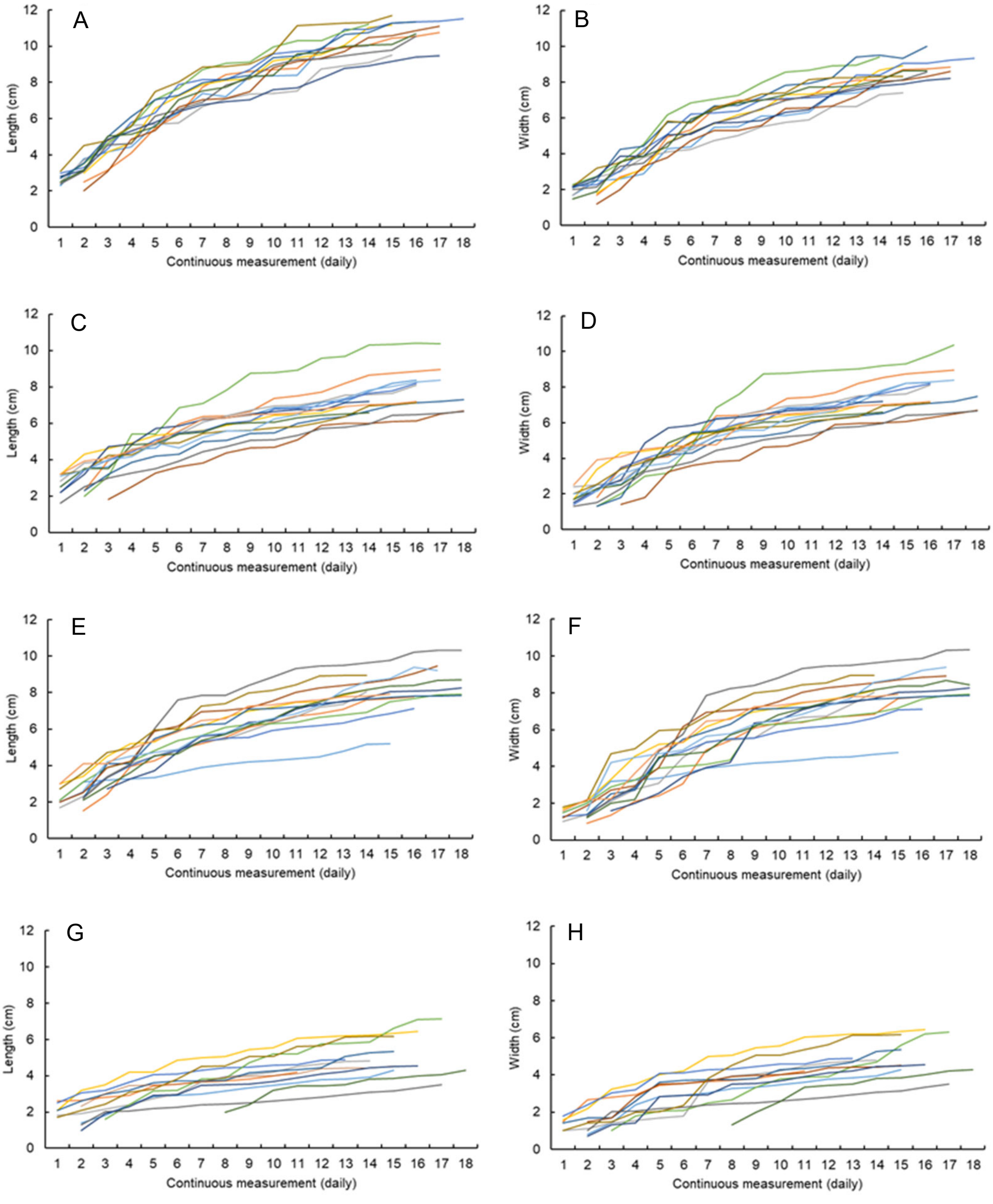

Figure 5. Continuous leaf growth based on their length and width in purple pakchoi exposed to full sunlight (A, B); 45% shading (C, D); 55% shading (E, F); and 80% shading (G, H).

Based on the results of this study, the final leaf area differed according to the percentage of shading treatment imposed to each group of the pakchoi plants. Plants exposed to full sunlight exhibited the largest leaf size, plants that were shaded 45% and 55% produced almost the same medium size leaves, and plants with 80% shade produced the smallest leaf size. However, the number of days it took to reach the full leaf size was about the same, which was between 13 to 15 days.

Healthy purple pakchoi has spoon-like leaves with distinctive elliptical shape of its leaf blade as indicated in plant exposed to full sunlight, i.e., the leaf length exceeds its width. Increase in shading treatment to 80% gradually alter the leaf shape of the purple pakchoi from elliptical to more rounded shape, i.e., measurement of the leaf length and its width are almost similar. Therefore, increase in shading exposure not only decreases the leaf size but also changing the shape of purple pakchoi leaf.

In this study, if leaf growth was represented by the length or width of the leaf, then the growth patterns was seen following an asymptotic curve, not fully following the Sigmoid curve (Fig. 5). This actually happened because the slow initial growth phase (as in an early segment of the full Sigmoid curve) occured when the leaf blade had not yet opened. The length or width of the leaves was still too small (< 5 mm), fragile, and had not been perfectly formed to be measured manually. In this phase, it is estimated that the leaf lengthening rate is still less than 1 mm per day. Meanwhile, if leaf growth was represented through the result of multiplication of leaf length by width, then the shape of the Sigmoid curve is slightly visible (Fig. 6). The technical information obtained from this study is that the growth of purple pakchoi leaves will start to grow rapidly when the leaf blade begins to unfold.

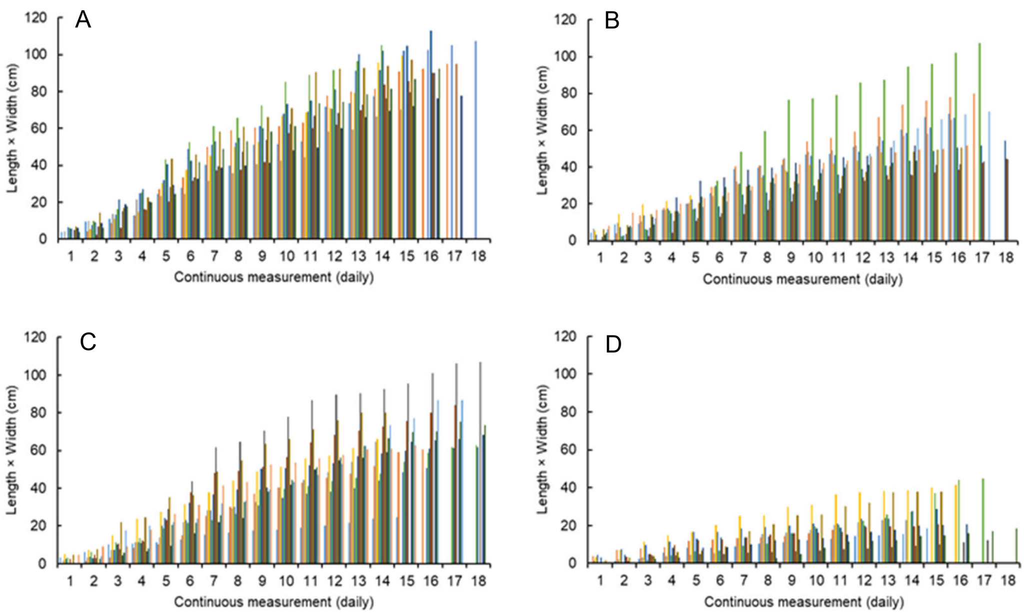

Figure 6. Growth of leaf blade length × width at 0% (A), 45% (B), 55% (C), and 80% (D) shading.

The growth pattern of leaves as well as individual plants generally follows the Sigmoid curve. Ding et al. (2022) reported that leaf growth (based on leaf length and width) and plant growth (based on plant height and canopy width) followed sigmoidal curves in three pakchoi cultivars. Similarly, Baker & Wang (2021) found that growth of bokchoy, measured based on image analysis of its canopy, consistently followed the Sigmoid curve.

Yield and biomass components

Leaf blade, petiole, and stem of purple pakchoi were negatively affected by shading (Table 1). Increase in shading intensity decreased fresh and dry weight of all above ground organs and also spesifically on the yield components, i.e., leaf blade and petiole. A sharp drop was observed at 80% shading treatment. Similar effects were also found in underground organs as indicated by decrease in root length, fresh weight, and dry weight (Table 2). More severe drop in roots of plant exposed to 45% shading than 55% shading indicated that the drops may not be solely due to shading treatment, it may confound with indirect effect of soil moisture condition. Heavy shading treatment caused low evaporation rate; therefore, increased soil moisture content.

Table 1. Effect of shading application on above-ground organs including leaf blade, petiole, and stem at fresh and dry weight conditions in purple pakchoi

	Leaf FW	Leaf DW	Petiole FW	Petiole DW	Stem FW	Stem DW
N0	39.9 ± 1.79^a	5.4 ± 0.32^a	0.5 ± 0.04^a	1.3 ± 0.11^a	5.4 ± 0.32^a	0.5 ± 0.04^a
N1	13.6 ± 2.93^b	1.8 ± 0.12^b	0.2 ± 0.02^b	0.2 ± 0.01^b	1.8 ± 0.12^b	0.2 ± 0.02^b
N2	13.2 ± 0.59^b	2.3 ± 0.10^b	0.2 ± 0.01^b	0.3 ± 0.02^b	2.3 ± 0.10^b	0.2 ± 0.01^b
N3	1.9 ± 0.10^c	0.5 ± 0.04^c	0.0 ± 0.01^c	0.0 ± 0.01^c	0.5 ± 0.04^c	0.0 ± 0.01^c
LSD	6.54	0.75	0.08	0.10	0.75	0.08

Data were presented as mean ± standard error. The means followed by different letters within each column indicate significant difference at the $LSD_{.05}$

Shading not only decreases the quantity of yield (fresh weight of leaf blade and petioles) but also has an impact on reducing the yield quality of purple pakchoi plants (the intensity of their attractive purple color becomes faded). In our study, the deep and blackish purple colors were found in all plant fully exposed to sunlight. Meanwhile, under heavy shading (80%), only a thin, uneven layer of soft purple color covered the surface of the leaf so that in some spots the green color was also visible. The result of the observations showed that exposure to shade for a long time inhibited the formation of a purple layer on young leaves and at the same time eroded the purple layer that had formed on the surface of mature leaves.

Table 2. Effect of shading application on under-ground organs including root length, root fresh weight and dry weight conditions in purple pakchoi

	Root Length	Root FW	Root DW
N0	26.27 ± 0.54^a	6.12 ± 0.24^a	0.616 ± 0.020^a
N1	13.87 ± 0.72^b	0.79 ± 0.06^c	0.078 ± 0.003^{cb}
N2	17.75 ± 0.07^b	1.69 ± 0.40^b	0.123 ± 0.018^b
N3	7.22 ± 0.55^c	0.20 ± 0.03^c	0.016 ± 0.001^c
LSD	4.55	0.73	0.07

Data were presented as mean + standard error. The means followed by different letters within each column indicate significant difference at the $LSD_{.05}$.

Song et al. (2020) proved that the purple color in pakchoi leaf was associated with the anthocyanin content. The ratio of anthocyanin to chlorophyll content was responsible for the color formation in purple pakchoi. If the ratio was high, the leaf appeared reddish purple. If the ratio was low, the leaf appeared deep purple or even blackish purple. Zhu et al. (2017) added that the purple color on the leaf surface decreased and turned green if the pakchoi plant was exposed to shading conditions for a longer period of time.

Estimating purple pakchoi leaf area

Leaf area can be estimated using appropriate regression models such as linear, polynomial, and power regression. Some dimensional traits can be used as predictors such as leaf length (L), leaf width (W), and multiplication of these two traits (LW). The accuracy can be very high if regular shape leaves are used. The purple pakchoi has a regular oval shape. Results of this study shown that if single predictor was used (L or W), the zero–intercept linear model was not suitable as indicated by lower coefficient of determination. Meanwhile, both polynomial and power models were very reliable in predicting LA if single predictor was used. Meanwhile, the simpler zero–intercept linear model was also very reliable in predicting LA if LW was used as predictor (Table 3).

Table 3. Regression models for leaf area estimation using individual and combination of the leaf length and width in purple pakchoi

Predictor	Regression model	Leaf Area (LA)	R^2
Leaf length (L)	Power	LA = 0.3305 $L^{2.1412}$	0.9357
	Polynomial	LA = 0.7135 L^2 - 3.0651 L + 6.8704	0.9299
	Zero-intercept linear	LA = 5.266 L	0.6933
Leaf width (W)	Power	LA = 1.0348 $W^{1.8859}$	0.9477
	Polynomial	LA = 0.469 W^2 + 3.7209 W - 6.6256	0.9504
	Zero-intercept linear	LA = 6.9926 W	0.8185
LW	Power	LA = 0.5191 $LW^{1.0428}$	0.9806
	Polynomial	LA = 0.0002 LW^2 + 0.6213 LW - 0.6181	0.9784
	Zero-intercept linear	LA = 0.6428 LW	0.9774

R^2 is the coefficient of determination used as the indicator for accuracy level of the leaf area estimation models.

Leaf is the most important and dominant organ in leafy vegetables, including purple pakchoi. Continuous measurement of leaf growth requires a non-destructive approach such that measurement of leaf morphological traits can be collected using the same individual leaf. Purple pakchoi has a spoon shape leaf which is relatively easy to estimate with high accuracy. Each leaf has three dimensions, i.e., length (L), width (W), and thickness (T). However, only L and W individually and in combination (LW) are commonly used as predictors. Leaf thickness is considerably negligible, compared to L or W (Walia & Kumar, 2016; Fascella et al., 2018).

Three most commonly used regression models are linear if LW is used as predictor and polynomial order–2 or quadratic and power regression are used if L or W is used separately as predictor. To ensure LA = 0 if L = 0 and W = 0 then zero-intercept linear regression is recommended (Lakitan et al., 2021a).

In this study, the best results were obtained with the power regression model on all predictors, with values of $R^2 = 0.9357$ (L), $R^2 = 0.9477$ (W), and $R^2 = 0.9806$ (LW). In previous studies, polynomial and zero-intercept linear regression were also used in estimating LA of tatsoi, a herbaceous leafy vegetable (Kartika et al., 2021). The power regression has been proven accurate for estimating the leaf area in many herbaceous vegetables, including leaf celery (Lakitan et al., 2021a), and *Talinum paniculatum* (Lakitan et al., 2021b). The zero–intercept linear regression is very accurate if LW is used as predictor ($R^2 = 0.9774$).

For future research, a study on the interaction effects of shading and split fertilizer applications in the pakchoi leaf area is proposed.

CONCLUSIONS

The full sunlight intensity produced the best results on growth and yield in purple pakchoi. Therefore, the purple pakchoi can be classified as sun plant. The shading density at 45–80% reduced growth and yield of the purple pakchoi plant and also affected leaf SPAD values. Shading was not only reduced yield quantity but also yield quality. The atractive purple color of pakchoi leaves was diminished after long shading exposure. Leaves of the purple pakchoi reached their maximum size at 13–15 days, counted after the young leaves were fully unfolded. The purple pakchoi can be harvested starting at 35 DAP. The power and polynomial regression model can be used for estimating leaf area in all predictors, including L, W, and LW. However, the zero–intercept linear regression is recommended only for LW as predictor. It is recommended to urban communities to choose a location that is directly exposed to sunlight in cultivating purple pakchoi vegetable.

ACKNOWLEDGEMENTS. Our high appreciation goes to the editor-in-chief and his staff for his/her kind attention and positive response. Our gratitude is also extended to the reviewers for their comments and suggestions to our manuscript. This research was funded by the Program Penelitian Profesi, Universitas Sriwijaya, Indonesia. Grant No. 0111/UN9.3.1/SK/2022.

REFERENCES

Abdel–Ghany, A.M. & Al–Helal, I.M. 2020. Toward sustainable agriculture: net-houses instead of green houses for saving energy and water in arid regions. Stagner, J.T.D.K. (ed): *proceedings of the Sustaining Resources for Tomorrow*. Springer. Cham, pp. 83–98.

Andini, C. & Yuliani. 2020. Effect of shading treatment on the growth of pokcoy *(Brassica chinensis* L.) in low land area. *Lentera Bio.* **9**(2),105–108.

António, C., Päpke, C., Rocha, M., Diab, H., Limami, A.M., Obata, T., Fernie, A.R. & van Dongen, J.T. 2016. Regulation of primary metabolism in response to low oxygen availability as revealed by carbon and nitrogen isotope redistribution. *Plant Physiology* **170**(1), 43–56. doi: 10.1104/pp.15.00266

Armarego-Marriott, T., Sandoval-Ibañez, O. & Kowalewska, L. 2020. Beyond the darkness: recent lessons from etiolation and de-etiolation studies. *Journal of Experimental Botany* **71**(4), 1215–1225. doi: 10.1093/jxb/erz496

Baker, R.L. & Wang, D.R. 2021. Working with longitudinal data: quantifying developmental processes using function-valued trait modeling. *American Journal of Botany* **108**(6), 905–908. doi:10.1002/ajb2.1677

Budiarto, R., Poerwanto, R., Santosa, E., Efendi, D. & Agusta, A. 2019. Agronomical and physiological characters of kaffir lime *(Citrus hystrix* DC) seedling under artificial shading and pruning. *Emirates Journal of Food and Agriculture* **31**(3), 222–230. doi: 10.9755/ejfa.2019.v31.i3.1920

Ding, X., Zhang, H., He, L., Jin, H., Zhou, Q., Yang, J., Zhu, W., Yu, J. & Qian, T. 2022. Changes in leaf and growth of pak choi in a semi-closed greenhouse in Eastern China. *HortScience* **57**(5), 643–651. doi: 10.21273/HORTSCI16523-22

Du, F., Guan, C. & Jiao, Y. 2018. Molecular mechanisms of leaf morphogenesis. *Molecular plant* **11**(9), 1117–1134. doi: 10.1016/j.molp.2018.06.006

Fascella, G., Rouphael, Y., Cirillo, C., Mammano, M.M., Pannico, A. & DePascale, S. 2018. Allometric model for leaf area estimation in Bougainvillea genotypes. *Acta Horticulturae* **12**(15), 449–452. doi: 10.17660/ActaHortic.2018.1215.81

Ferreira, A.J.D., Guilherme, R.I.M.M., Ferreira, C.S.S. & Oliveira, M.D.F.M.L. 2018. Urban agriculture a tool towards more resilient urban communities? *Current Opinion in Environmental Science and Health* **5**, 93–97. doi: 10.1016/j.coesh. 2018.06.004

Grebitus, C., Chenarides, L., Muenich, R. & Mahalov, A. 2020. Consumers' perception of urban farming-an exploratory study. *Frontiers in Sustainable Food Systems* **4**(79), 1–13. doi: 10.3389/fsufs.2020.00079

Hao, X., Jia, J., Mi, J., Yang, S., Khattak, A.M., Zheng, L., Gao, W. & Wang, M. 2020. An optimization model of light intensity and nitrogen concentration coupled with yield and quality. *Plant Growth Regulation* **92**, 319–331. doi: 10.1007/s10725-020-00641-0

Jaya, K.K., Lakitan, B. & Bernas, S.M. 2021. Responses of leaf celery to floating culture system with different depths of water-substrate interface and NPK–fertilizer application. *Walailak Journal* **18**(12), 1–14. doi: 10.48048/wjst.2021.19823

Kartika, K., Lakitan, B., Ria, R.P. & Putri, H.H. 2021. Effect of the cultivation systems and split fertilizer applications on the growth and yields of Tatsoi *(Brassica rapa* subsp. *Narinosa)*. *Trends in Sciences* **18**(21), 1–12. doi: 10.48048/tis.2021.344

Kitao, M., Harayama, H., Yazaki, K., Tobita, H., Agathokleous, E., Furuya, N. & Hashimoto, T. 2022. Photosynthetic and growth responses in a pioneer tree (Japanese white birch) and competitive perennial weeds (*Eupatorium* sp.) grown under different regimes with limited water supply to waterlogging. *Frontiers in Plant Science* **13**, e835068. doi: 10.3389/fpls.2022.835068

Kong, Y. & Zheng, Y. 2018. Variation of phenotypic responses to lighting using a combination of red and blue light-emitting diodes versus darkness in seedlings of 18 vegetable genotypes. *Canadian Journal of Plant Science* **99**(2), 159–172. doi: 10.1139/cjps-2018-0181

Lakitan, B. 2021. Urban Olericulture: Contribution to increase vegetable production for urban community. In Herlinda, S. (ed): *proceeding of National Conference on Sub–optimal Land.* Sriwijaya University, Palembang, South Sumatera, pp. 1–10.

Lakitan, B., Kartika, K., Susilawati & Wijaya, A. 2021a. Acclimating leaf celery plant *(Apium graveolens)* via bottom wet culture for increasing its adaptability to tropical riparian wetland ecosystem. *Biodiversitas* **22**(1), 320–328. doi: 10.13057/biodiv/ d220139

Lakitan, B., Kartika, K., Widuri, L.I., Siaga, E. & Fadilah, L.N. 2021b. Lesser–known ethnic leafy vegetables *Talinum paniculatum* grown at tropical ecosystem: Morphological traits and non–destructive estimation of total leaf area per branch. *Biodiversitas* **22**(10), 4487–4495. doi: 10.13057/biodiv/d221042

Lal, R. 2020. Home gardening and urban agriculture for advancing food and nutritional security in response to the COVID–19 pandemic. *Food Security* **12**, 871–876. doi: 10.1007/s12571-020-01058-3

Li, S., Liu, C., Tan, X., Tan, B., He, Y. & Li, N. 2020. Interactive effects of light and nitrogen on pakchoi *(Brassica chinensis L.)* growth and soil enzyme activity in an underground environment. *Agronomy* **10**(11), 1–14. doi: 10.3390/agronomy10111772

Mahmood, A., Hu, Y., Tanny, J. & Asante, E. A. 2018. Effects of shading and insect–proof screens on crop microclimate and production: A review of recent advances. *Scientia Horticulturae* **241**, 241–251. doi: 10.1016/j.scienta.2018.06.078

Mansyur, A.N., Triyono, S. & Tusi, A. 2014. Influence of shading on the growth of green mustard *(Brassica juncea* L.) cultured in hydroponic DFT (deep flow tecnique). *Journal of Teknik Pertanian Lampung* **3**(2), 103–110.

Meihana, M., Lakitan, B., Susilawati., Harun, M.U., Widuri, L.I., Kartika, K., Siaga, E. & Kriswantoro, H. 2017. Steady shallow water table did not decrease leaf expansion rate specific leaf weight and specific leaf water content in tomato plants. *Australian Journal of Crop Science* **11**(12), 1635–1641. doi: 10.21475/ajcs.17.11.12.pne808

Orsini, F., Kahane, R., Nono–Womdim, R. & Gianquinto, G. 2013. Urban agriculture in the developing world: a review. *Agronomy for Sustainable Development* **33**(4), 695–720. doi: 10.1007/s13593-013-0143-z

Priadi, D. & Nuro, F. 2017. Seedling production of pakchoy *(Brassica rapa* L. *var chinensis)* using organic and inorganic nutrients. *Biosaintifika: Journal of Biology & Biology Education* **9**(2), 217–224. doi: 10.15294/biosaintifika.v9i2.8537

Rondhi, M., Pratiwi, P.A., Handini, V.T., Sunartomo, A.F. & Budiman, S.A. 2018. Agricultural land conversion land economic value and sustainable agriculture: A case study in East Java Indonesia. *Journal Land* **7**(4), 1–19. doi: 10.3390/land 7040148

Rongting, J.I., Weiming, S.H.I., Yuan, W., Zhang, H. & Ju, M. 2020. Nondestructive estimation of bok choy nitrogen status with an active canopy sensor in comparison to a chlorophyll meter. *Pedosphere* **30**(6), 769-777. doi: 10.1016/S1002-0160(20)60037-6

Song, B., Xu, H., Chen, L., Fan, X., Jing, Z., Chen, S. & Xu, Z. 2020. Study of the relationship between leaf color formation and anthocyanin metabolism among different purple Pakchoi lines. *Molecules* **25**(20), e4809. doi: 10.3390/molecules25204809

Süß, A., Danner, M., Obster, C., Locherer, M., Hank, T., Richter, K. & EnMAP Consortium. 2015. Measuring leaf chlorophyll content with the Konica Minolta SPAD-502Plus. GFZ Data Services, Potsdam, Germany. doi: 10.2312/enmap.2015.010

Surya, B., Syafri, S., Hadijah, H., Baharuddin, B., Fitriyah, A.T. & Sakti, H.H. 2020. Management of slum–based urban farming and economic empowerment of the community of Makassar City. South Sulawesi Indonesia. *Sustainability* **12**(18), 1–42. doi: 10.3390/SU12187324

Ustaoglu, E. & Williams, B. 2017. Determinants of urban expansion and agricultural land conversion in 25 EU countris. *Environmental Management* **60**(4), 717–746. doi: 10.1007/s00267 -017-0908-2

Uteau, D., Horn, R. & Peth, S. 2022. Millimetre scale aeration of the rhizosphere and drilosphere. *European Journal of Soil Science* **73**(4), e13269. doi: 10.1111/ejss.13269

Wahyuningsih, A., Fajriani, S. & Aini, N. 2016. The nutrition and growth media composition on the growth and yeild of pakchoy *(Brassica rapa* L.) using hydroponics system. *Journal of Produksi Tanaman* **4**(8), 595–601.

Walia, S. & Kumar, R., 2016. Development of the nondestructive leaf area estimation model for valeriana *(Valeriana jatamansi* Jones). *Communications in Soil Science and Plant Analysis* **48**(1), 1–23. doi: 10.1080/00103624.2016.1253723

Walters, S.A. & Midden, K.S. 2018. Sustainability of urban agriculture: Vegetable production on green roofs. *Agriculture* **8**(168), 1–16. doi: 10.3390/ agriculture8110168

Yang, J., Zhu, Z. & Gerendás, J. 2009. Interactive effects of phosphorus supply and light intensity on glucosinolates in pakchoi *(Brassica campestris* L. *ssp. chinensis var. communis)*. *Plant and soil* **323**(1), 323–333. doi: 10.1007/s11104-009-9940-1

Zhang, Y., Che, G., Dong, T., Pan, Y., Zhao, Z., Tian, S. & Hu, Z. 2014. Anthocyanin accumulation and transcriptional regulation of anthocyanin biosynthesis in purple bok choy *(Brassica rapa* var. *chinensis)*. *Journal of Agricultural and Food Chemistry* **62**, 1–36. doi: 10.1021/jf503453e

Zhu, H., Li, X., Zhai, W., Liu, Y., Gao, Q., Liu, J., Ren, L., Chen, H. & Zhu, Y. 2017. Effects of low light on photosynthetic properties, antioxidant enzyme activity and anthocyanin accumulation in purple pak–choi *(Brassica campestris* ssp. *Chinensis Makino*). *PLoS ONE* **12**(6), 1–17. doi: 10.1371/journal.pone.0179305