



Effect of Shading Percentage and Potassium Dosages on Growth and Yield of Cutleaf Groundcherry (*Physalis angulata* L.)

Wiwin Sumiya Dwi Yamika*, Nurul Aini, Budi Waluyo and Agus Prayitno Kurniawan

Department of Agronomy, Faculty of Agriculture, Universitas Brawijaya, Malang, Indonesia

*Corresponding author: wiwin.fp@ub.ac.id

Abstract

Cutleaf groundcherry is a medicinal herbaceous plant that has not been widely cultivated. Adjustment to the light intensities supported by the fulfillment of essential macro-nutrient underlies the agronomic consideration for cropping system determination. The study aimed to examine the growth and yield of cutleaf groundcherry grown under shade nets of various shading percentages and potassium application at different dosages. A split-plot design was used for this pot experiment repeated three times. The main plot was the shading percentages (0, 25, 50 and 75), while potassium dosages (0, 60, 120 and 180 kg ha⁻¹) were the subplot. The result showed that several growth variables were affected by the interaction between shading percentages and potassium dosage, whereas yield variables were not. Under the high level of shading, leaf number (41 to 50%), leaf area (28 to 50%), and shoot dry weight (70 to 85%) were reduced at all potassium dosages. Potassium dosage at 120 kg ha⁻¹ was required to achieve better growth under full sun or soft shading. Shading at 50% and upper significantly decreased fruit production by 30% lower fruit number, 50 to 80% lower fruit weight, and 15% lower total soluble solids (TSS). In addition, potassium fertilizer at 120 kg K₂O ha⁻¹ improved fruit weight but did not affect TSS. It can be concluded that cutleaf groundcherry is able to grow well under high intensity of light and need an adequate supply of potassium to improve growth, yield and fruit quality.

Keywords: abiotic stress; light intensity; nutrient; photosynthesis; TSS

Cite this as: Yamika, W. S. D., Aini, N., Waluyo, B., & Kurniawan, A. P. (2023). Effect of Shading Percentage and Potassium Dosages on Growth and Yield of Cutleaf Groundcherry (*Physalis angulata* L.). *Caraka Tani: Journal of Sustainable Agriculture*, 38(2), 260-272. doi: <http://dx.doi.org/10.20961/carakatani.v38i2.72687>

INTRODUCTION

Physalis angulata L., also known as cutleaf groundcherry, is an annual and branched herbaceous plant belonging to Solanaceae family (Firdaus et al., 2022). *Physalis* species is known to have an excellent adaptation to various environmental conditions. It is evidenced by the distribution of the plant, which is widespread in tropical and subtropical regions worldwide. In Indonesia, cutleaf groundcherry can be found in various locations spread in low and medium land areas and has various local names. The plant mostly grows wild and even as a weed in the field,

garden, shrubs and others. Cutleaf groundcherry is considered to be a medicinal plant that contains pharmacological chemicals, such as physalins (A, B, D and F), glycosides, flavonoids, alkaloids, saponins, tannins, terpenoids and withanolides (Kusumaningtyas et al., 2015; Ferreira et al., 2019; Shah and Bora, 2019). The bioactive compounds in cutleaf groundcherry has anti-inflammatory, antiproliferative, antinociceptive, antitumor and other properties (Lima et al., 2014; Sun et al., 2017). Recently, physalis fruit began to be commercialized and got an impressive response from consumers since herbal medicine from plant sources tends to be preferred. Cutleaf

* Received for publication March 30, 2023
Accepted after corrections May 30, 2023

groundcherry should be one of the attractive species due to its higher antioxidant capacity compared to some physalis species (Medina-Medrano et al., 2015). Interestingly, those beneficial compounds were found not only in the fruit but also in all parts of the plant, i.e., the leaf, stem bark and calyx or rind of the fruit (Iwansyah et al., 2019). The facts underlie the potential use of cutleaf groundcherry as a functional plant.

The cutleaf groundcherry has the potential to be widely developed for both fruit or medicinal plants. In cutleaf groundcherry cultivation, the intercropping system can be used as a cultivation method, since multiple cropping is used for optimizing land productivity amid land scarcity. The evidence revealed that the shade-tolerant plants are potential to be developed for multiple cropping systems. The low light intensity (shading) condition can be simulated using an artificial shading net, which allows for adjusting the shading percentage. Despite regulating light intensity, the shading screen was reported to change microclimate elements, such as reducing leaf temperature and leaf transpiration rate (Masabni et al., 2016; Yusof et al., 2021). In fruit plants, delaying fruit maturity, decreasing fruit size and production, as well as an alteration in phytochemical properties might be caused by lower light intensity received by the plant. The alteration in light-intensity radiance might significantly affect morphological and anatomical changes, as well as physiological and biochemistry processes involved in the plant reactions (Jiang et al., 2011; Shao et al., 2014; Li et al., 2016). Plant requirements and tolerance toward unfavorable light intensity (excess or low) depend on their genetic trait (Sulistiyowati et al., 2016). Information about cutleaf groundcherry tolerance toward various light intensities will be necessary for crop development strategy.

Light intensity contributes to the absorption of elements, including macronutrients, by providing energy to the plant root (Xu et al., 2021). Few studies demonstrated the interaction between light and nutrient uptake in which higher amount of light captured by a plant contributed to elevate growth and nutrient uptake (Ma et al., 2016; Zhou et al., 2019; Esmaeili et al., 2022). Potassium is one of the essential macronutrients playing a vital role in the formation and quality improvement of yield through their function as an activator of some key enzymes, such as sugar transport, protein synthesis and other nutrients metabolism (Oosterhuis et al., 2014; Singh et al., 2021).

In addition, potassium regulates cell osmotic pressure, which is involved in stomatal opening and closing (Ahammed et al., 2022). Through these processes, under unfavorable (shading) conditions, the management of potassium fertilizer positively affects fruit crop yield. Understanding exemplary environmental and nutritional aspects is critical for the sustainable production of good-quality plants (high phytochemical content) (Biondi et al., 2021). Information about low light intensity effects resulted from shading and nutrient management, especially potassium, on cutleaf groundcherry is still limited. Therefore, this research aimed to examine the growth and yield of cutleaf groundcherry under full sunlight and various shading percentages and potassium application at different dosages.

MATERIALS AND METHOD

Experimental site and design

The experiment was carried out from October to December 2021 at the experimental garden of Universitas Brawijaya, located in Lowokwaru Sub-district, Malang, East Java, Indonesia with the coordinate points of 112°37'02.9" E and 7°56'21.8" S. The location is approximately 445 m above sea level, with an average daily temperature of 24 °C and relative humidity of 76%.

A pot experiment was set in three replications based on a split-plot design. The shading level was the main plot consisting of the control treatment (full-sun) or 0% shading as well as 25%, 50% and 75% shading levels, while the sub-plot was potassium dosage consisting of 0, 60, 120 and 180 kg K₂O ha⁻¹.

Plants were fully grown inside the shading-net cage based on the treatment. Meanwhile, in the control treatment, plants were grown under full sunlight. The shading-net material used was a black net with different pore densities revealing shade percentages. The net was tied with rope in the steel frame sized at 3.0 and 9.0 m in width and length, respectively, and 2.0 m in height.

Planting material and preparation

The seeds of *P. angulata* belonged to researcher's genotype collection, namely PA-03. The seeds were extracted from mature fruit and air-dried in a shading place. Seeds were sown in the tray with 72 cells containing the mixture of soil and compost (2:1). At 30 days after sowing, seedlings (with four leaves) were transplanted into polybags containing 8 kg of soil. Cow manure

was added in a dosage of 107 g polybag⁻¹ (equal to 40 tons ha⁻¹).

Plant caring and fertilizer treatment

Plants were irrigated daily with about 500 ml of tap water per polybag. Macronutrient fertilization (N-P-K) was applied in the form of single fertilizer, i.e., Urea (46% N), SP 36 (36% P₂O₅) and KCl (60% K₂O). Nitrogen with 150 kg ha⁻¹ was applied in two equal splits at 2 and 5 weeks after transplanting (WAT), whereas phosphorus with 60 kg ha⁻¹ was applied at full dosage on 2 WAT. Potassium (KCl, 60% K₂O), based on the dosage treatments (0, 60, 120 and 180 kg ha⁻¹), was applied in two equal splits at 2 and 5 WAT.

Plants were mainly attacked by pests, namely, aphids and leaf caterpillars. However, diseases found were downy mildew and virus wilt. Pest and disease were controlled by chemical insecticide and fungicide with the active ingredients of Abamectin and Mankozeb.

Cutleaf groundcherry needs a stake to support its growth. Bamboo, 1 m in length, was stuck near each plant. Then, the stem was tied loosely to the bamboo stake using a raffia line. Stem was pruned into a single stem, and all side shoots were pinched.

Growth and yield observation

Plant height, leaf number, leave area and shoot dry weight were observed during plant growth at 6 WAT. Plant height was evaluated by measuring the plant's height from the stem's basal (above growth medium) to the tip of the highest shoot. Leaf number was evaluated by manual counting of all fully opened leaves. Leaf area was measured using leaf area meter (LAM). Shoot dry weight was evaluated by calculating the weight of above-ground biomass after oven-drying for 48 hours.

Chlorophyll content was estimated using a non-destructive method with a chlorophyll meter Konica Minolta SPAD-502. Chlorophyll content per unit area was relatively indicated by the numeric value shown by SPAD-502. Measurement was carried out by nipping a single leaf in three different areas. Three leaves were used in a plant for each treatment (Jiang et al., 2017).

The number of fruits was evaluated by manually counting mature fruit seen from its green calyx that turned brown or yellowish. Fruits were harvested and followed by calculating fruit fresh weight including and excluding their calyx.

Fruit properties were evaluated by calculating fruit diameter and total soluble solids (TSS). Fruit diameter was measured using a digital caliper on five fruit samples. Total soluble sugar evaluation was performed using a hand refractometer, and the result was expressed in °Brix. The fruit was brought to the laboratory for other qualities test, i.e., β-Carotene content and antioxidant activity.

Data analyzes

Data collected were analyzed using analysis of variance (ANOVA) and examined with the F test at α 5% error. Further, an honestly significant difference (HSD) test at 5% error was used to determine the difference between the treatments.

RESULTS AND DISCUSSION

Interaction between shading level and potassium dosage significantly affected leaf number, leaf area, plant dry weight and fruit β-carotene. On the other hand, main effect shading level was significant on all growth and yield variables, while main effect of potassium dosage was significant on leaf area, fruit weight (with and without calyx), as well as β-carotene and antioxidant activity of fruit (Table 1).

Growth variables

The results indicated that the interaction between shading percentages and potassium dosage did not significantly affect the plant height of cutleaf groundcherry. Regardless of potassium treatment, shading percentages mainly affected plant height (Figure 1). At 50% and 75% shading, plant height was lower than plant exposed to full sunlight by up to 14%. It revealed that high shading levels might have disrupted plant growth, including the height of the plant. On the contrary, low shading levels exhibited plant height that was not significantly different from full sunlight treatment. This finding was different from other studies, which reported the taller plant obtained from shaded plants, such as Yusof et al. (2021) on *Polygonum minus*; Kesumawati et al. (2020) on chili; Argade et al. (2018) on tomato cherry and Yasoda et al. (2018) on cauliflower. This could be caused by the hormonal effect, especially auxin, triggered by low light intensity conditions. The different results might have confirmed that variation in plant responses occurred among species.

Another result is that leaf number, leaf area and shoot dry weight were affected significantly by the interaction between shading level and potassium dosage (Figures 2 and 3). They were

Table 1. Summary of the effect (p-value) of shading level and potassium dosage and their interaction on growth and yield of cutleaf groundcherry

Variables observed	Source of variation		
	Interaction	Shading level	Potassium dosage
Plant height	0.7149603 ^{ns}	0.0002839 ^{**}	0.4499332 ^{ns}
Leaf number	0.0189769 [*]	0.0000093 ^{**}	0.1971426 ^{ns}
Leaf area	0.0000296 ^{**}	0.0000022 ^{**}	0.0037427 ^{**}
Plant dry weight	0.0485366 [*]	0.0000022 ^{**}	0.6257883 ^{ns}
Chlorophyll index	0.3046677 ^{ns}	0.0003106 ^{**}	0.5578116 ^{ns}
Fruit number	0.6062838 ^{ns}	0.0110204 ^{**}	0.4429002 ^{ns}
Fruit weight			
With calyx	0.5215572 ^{ns}	0.0000141 ^{**}	0.0006080 ^{**}
Without calyx	0.1710965 ^{ns}	0.0000053 ^{**}	0.0000040 ^{**}
Fruit diameter	0.9269380 ^{ns}	0.0121401 [*]	0.0695581 ^{ns}
TSS	0.9934792 ^{ns}	0.0037381 ^{**}	0.8717068 ^{ns}
β-carotene	0.0003044 ^{**}	0.0006589 ^{**}	0.0000001 ^{**}
Antioxidant activity	0.1727723 ^{ns}	0.0000263 ^{**}	0.0103416 [*]

Note: * = significant at α 0.05; ** = significant at α 0.01; ns = not significant

mainly decreased under 50% and 75% shading at various potassium dosages. Furthermore, leaf number was not different at full sunlight and 25% shading among all potassium treatments, while leaf area increased in potassium at 120 kg ha⁻¹ under 25% shading. At the higher shading levels (50% and 75%), potassium application did not affect leaf number and leaf area. A consistent result was also obtained from shoot dry weight, which was not influenced by potassium application on each shading level.

Sunlight is the primary source of energy for plant photosynthesis regulating the overall growth and yield of plants. As the essential part of plants for capturing sunlight, leaves altered their morphology and anatomy (Rezai et al., 2018; Setiawati et al., 2018). The results show that high shading levels reduced leaf number and

leaf area. It suggested that cell multiplication and enlargement were influenced by sunlight. The plant maximized light absorption in the low light intensity by enlarging the leaf size rather than producing more leaves. However, leaf size was changed, causing lower leaf area per plant found. Insufficient light for photosynthesis caused the production of ATP to be not high enough for carbon fixation and carbohydrate biosynthesis (Shao et al., 2014). It led to a decrease in overall growth. Plant dry matter represented as shoot dry weight was reduced as a consequence. However, shoot dry weight was reduced to 70% over no shading (full sunlight) treatment.

In addition to the shading effect, potassium levels influenced plant growth. Since potassium is involved in enzyme activation, it has affected the production of protein, starch and ATP,

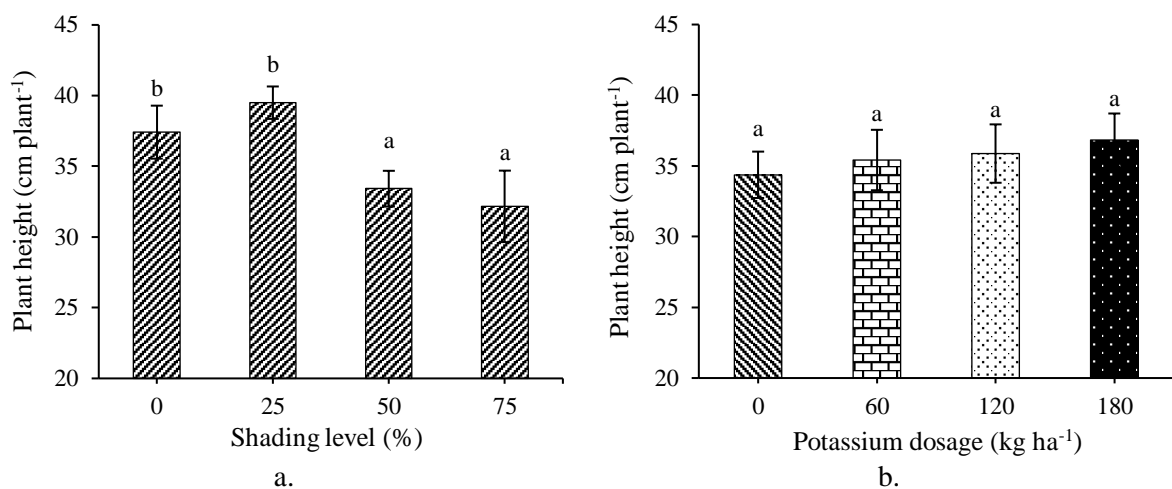
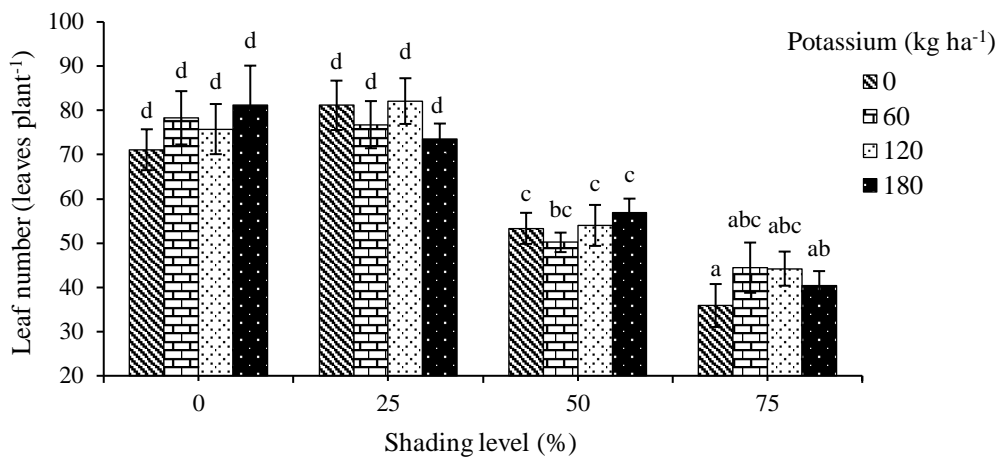
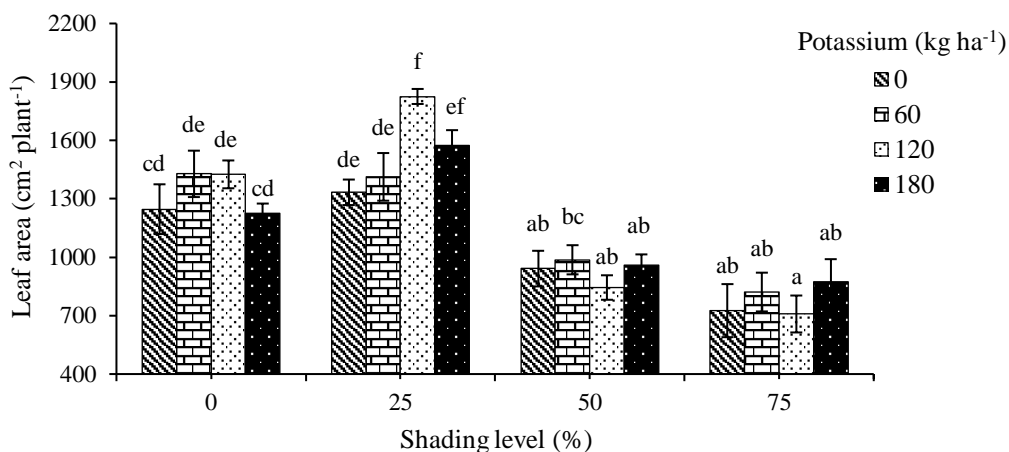


Figure 1. Plant height affected by (a) shading percentages, (b) potassium dosages

Note: Means followed by different letters on each bar indicated significant differences at HSD 5%



a.



b.

Figure 2. Leaf number (a) and leaf area (b) affected by the interaction between shading percentages and potassium dosages

Note: Means followed by different letters on each bar indicated significant differences at HSD 5%

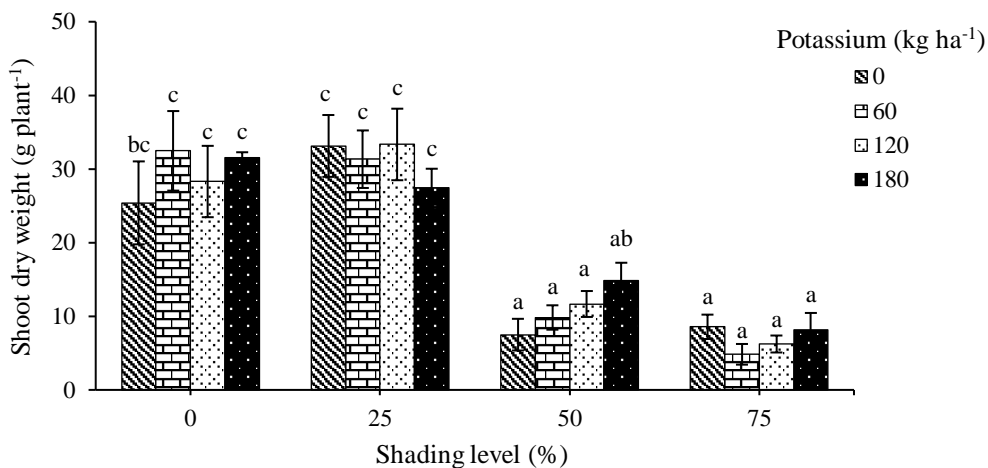


Figure 3. Shoot dry weight affected by the interaction between shading percentages and potassium dosages

Note: Means followed by different letters on each bar indicated significant differences at HSD 5%

which is associated with the photosynthesis rate (Cui and Tcherkez, 2021). It was evidenced that insufficient potassium levels might decrease the growth and yield of a plant. Attributed to the shading level, the plant required an increasing potassium dosage under full sunlight (no shading) and a low level of shading to produce more leaves and a greater leaf area. Plants were more responsive to potassium deficiency in high light intensity rather than low light intensity. Potassium was required in higher dosages to increase the efficiency of light energy utilization in the fixation of CO₂ and the relation of source-sink (Hasanuzzaman et al., 2018; Tränkner et al., 2018).

The absolute chlorophyll content was not directly observed in this study. Researchers used soil plant analysis development (SPAD) value to be the relative indicator of chlorophyll content. A higher SPAD value indicated an increasing chlorophyll content per unit area. Several studies have revealed a positive relationship between SPAD value and chlorophyll content in various species (Jiang et al., 2017). The results indicated that the SPAD value was lower under high shading (50% and 75%) (Figure 4). Those findings confirmed that chlorophyll content was changed due to light availability, and its reduction decreased chlorophyll content. It was in line with Khalid et al. (2019) study on the soybean plant. On the contrary, several studies reported the enhancement of chlorophyll content under shading conditions (Gaurav et al., 2014; Muhidin et al., 2018; Wan et al., 2020; Hemon et al., 2021). The mechanism of inducing chlorophyll synthesis gene expressions by shading underlined the alteration of chlorophyll content (Chen et al., 2021).

Yield variables

The interaction between shading percentages and potassium dosages did not significantly affect all yield variables, except β -Carotene. Then, the main effect of each treatment was evaluated separately. Regardless of potassium dosages, high shading percentage affected fruit number, weight, diameter and TSS, which were generally reduced under 50% and 75% shading (Table 2). Less fruit production was found under 75% shading by 30.18% lower compared to full-sun. Fruit weight, both with and without calyx, was significantly reduced by under 50% and 75% shading up to 50% and 80%, respectively. In addition to fruit number and weight, fruit size was affected by shading level, as described by reduced fruit diameter under high shading level (75% up to 80%). On overall yield variables, 25% shading resulted in insignificant data from full sunlight (open field) treatment. Shading altered microclimate conditions, which mainly affected the quantity of PAR (photosynthetically active radiation) (Zhang et al., 2020). To ensure optimum fruit production, a certain level of daily light integral must be sufficient (Nguyen et al., 2022). It underlined that fruit production was not reduced under 25% shading due to the plant's daily light being sufficient. Yield reduction under constraining sunlight radiation was attributed to lower photosynthesis and respiration (Kläring and Krumbein, 2013). The ability to improve the photosynthesis rate contributed to the carbon supply for fruit assimilation. It led to an increase in fruit production (Jiang et al., 2017). Rapid determination of fruit quality indicated by TSS found that lower TSS of up to 15% was obtained from fruit produced under 50% and 75% shading. TSS could represent soluble sugar content as

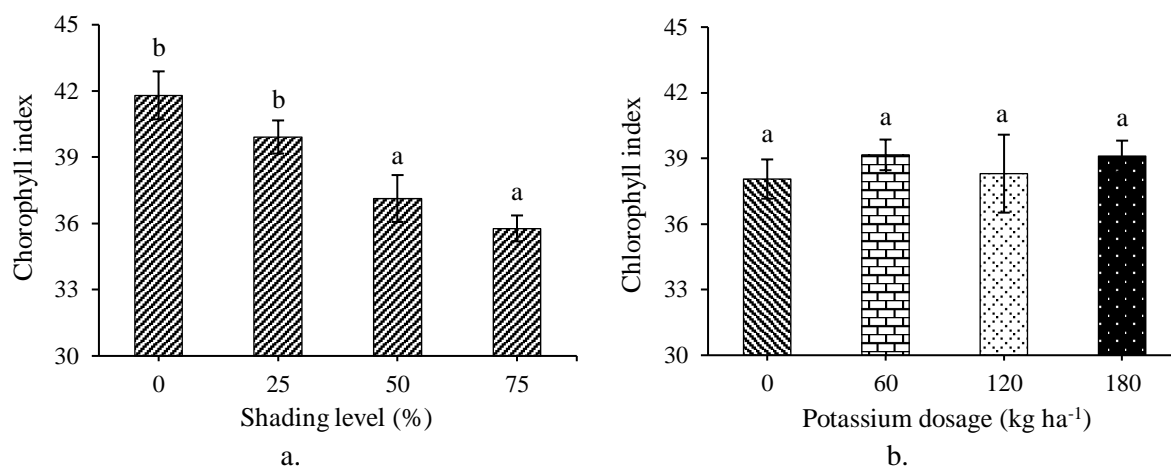


Figure 4. Chlorophyll index affected by (a) shading percentages, (b) potassium dosages
Note: Means followed by different letters on each bar indicated significant differences at HSD 5%

Table 2. Yield components affected by shading percentages and potassium dosages

Treatments	Fruit number (Fruits plant ⁻¹)	Fruit weight (g plant ⁻¹)		Fruit diameter (mm)	TSS (°Brix)
		With calyx	Without calyx		
Shading level (%)					
0	27.31 ^{bc}	54.95 ^c	48.35 ^c	14.17 ^b	10.81 ^b
25	28.13 ^c	58.04 ^c	53.87 ^c	14.24 ^b	10.89 ^b
50	20.43 ^{ab}	24.87 ^b	19.91 ^b	12.57 ^{ab}	9.17 ^a
75	19.07 ^a	12.26 ^a	9.00 ^a	11.60 ^a	9.08 ^a
HSD 5%	7.42	10.76	8.79	2.10	1.29
Potassium dosage (kg ha ⁻¹)					
0	22.24	31.75 ^a	27.62 ^a	12.72	9.81
60	23.14	36.34 ^{ab}	32.09 ^b	13.10	9.90
120	25.11	40.77 ^b	35.56 ^{bc}	13.37	10.14
180	24.45	41.26 ^b	35.85 ^c	13.38	10.10
HSD 5%	ns	6.04	3.64	ns	ns

Note: Means followed by different letters indicated significant differences at HSD 5%. ns = not significant

the most significant part of soluble solids, which was essential to determine the quality and flavor of the fruits (Wu et al., 2022). The lower soluble solid was also found under shade in several Solanaceae fruit crops, such as tomato (Angmo et al., 2021) and sweet pepper (Ilić et al., 2017). However, this finding indicated a varied response of physalis species to the presence of shading. The soluble solid contents of *P. peruviana* and *P. pubescens* were higher under 50% black net shading, while those of *P. minima* and *P. ixocarpa* were not different from the full sun (Da Silva et al., 2016; Morales et al., 2018). Higher light intensity might initiate gene and enzymatic activity for regulating the fruit ripening stage related to the increased sugar content of the fruits (Kapoor et al., 2022).

Potassium dosage significantly affected fruit weight both with and without the calyx. The increasing potassium dosage up to 120 kg ha⁻¹ resulted in greater fruit weight by up to 28%, however the increase in potassium dosage of 180 kg ha⁻¹ did not significantly increase the result. The results of this study were supported by the results of previous studies (Ahmad et al., 2015; Woldemariam et al., 2018), that in the case of on tomato plants, an adequate supply of potassium fertilizer was essential to enhance fruit yield. The positive effect is related to the involvement potassium in enzyme activation and ATP production (Cui and Tcherkez, 2021). Potassium might have a positive or negative interaction with other nutrients. Besides potassium, calcium and magnesium were the essential macronutrients in fruit development. An inadequate or excessive supply of potassium causes the imbalance of Ca/K and Mg/K, influencing the fruit yield (Çolpan et al., 2013).

The lack of potassium level in the plant caused assimilate partitioning disruption (Gerardeaux et al., 2010).

Increasing potassium dosage did not improve TSS of cutleaf groundcherry fruit significantly. This finding contrasted to the results few studies, which revealed that the application of potassium increased soluble content in apple and glucose concentration in orange (Zhang et al., 2018; Wu et al., 2021). In addition, Javaria et al. (2012) reported that quality improvement of tomato fruit was achieved by increasing potassium concentration. Cutleaf groundcherry, which has a different response to potassium fertilizer, was possibly due to the genetics of the variety tested and environmental conditions. However, the increasing potassium dosage tends to improve TSS with a slightly different.

Fruit quality represented as β -Carotene indicated significant reduction under the increasing shading level when potassium fertilizer was not applied (Figure 5). In comparison, the application of potassium made the reduction not occur except in the application of 120 kg ha⁻¹ potassium under 25% level, which proved higher β -Carotene compared to plants under full sunlight treatment. In line with the result, 25% shading also improved β -Carotene of tomato fruit (Setyorini et al., 2018). In plant life, carotenoids play a role as colored pigment for attractants to pollinator insects. They can also have a role in light harvesting and protecting photosynthesis apparatus from excessive light (Simkin et al., 2022). Lower β -Carotene content under shading conditions might be associated with fruit maturity affecting light. Based on visual observation, cutleaf groundcherry fruit exhibits longer ripening stages under a high level of shading.

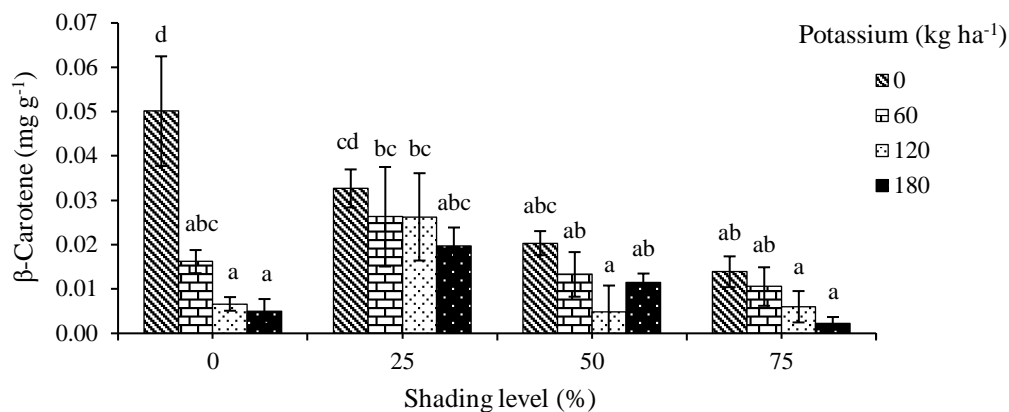


Figure 5. β -Carotene content of fruit affected by the interaction between shading percentages and potassium dosages

Note: Means followed by different letters on each bar indicated significant differences at HSD 5%

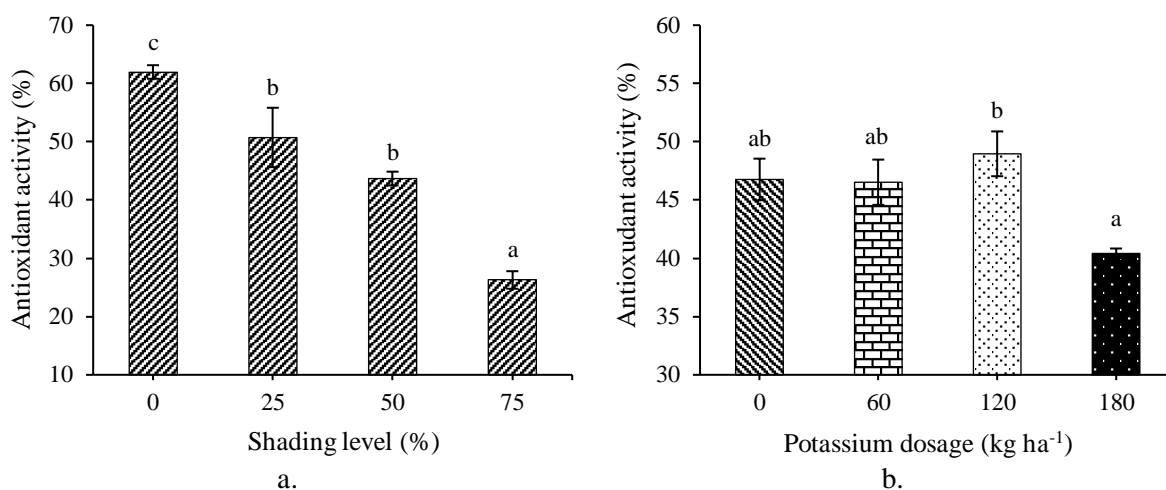


Figure 6. Antioxidant activity of fruit affected by (a) shading percentages, (b) potassium dosages

Note: Means followed by different letters on each bar indicated significant differences at HSD 5%

The full maturity of *P. angulata* fruits is yellow with a purple tinge (Sholehah et al., 2021). In shaded plants, fruit color when the fruit was fully ripening was not as yellow as fruit exposed to full sunlight. This echoes the study of Shezi et al. (2020) that found variability of a biochemical compound in fruit could be attributed to the effect of sunlight. Antioxidant activity is an essential constituent in the medicinal plant as its function for signifying the capacity of free radical scavenging (Kostecka-Gugala et al., 2015). The antioxidant activity of fruit was not affected by the interaction between shading and potassium level (Figure 6). The highest antioxidant activity was found in plants exposed to full sunlight, while the lowest was obtained from the plant under 75% shading. This finding confirmed that species of *P. angulata* yielded high-quality fruit when solar radiation was fully received. In another study, some physalis groups,

P. minima and *P. ixocarpa*, were reported to produce better fruit quality under full sunlight than the black net, while other species, *P. peruviana*, *P. pubescens*, were better under the black net (Da Silva et al., 2016). Regardless of the shading level, antioxidant activity even decreased under the high level of potassium applied (180 kg ha⁻¹) but was not different from no application under a lower potassium level. Potassium is expected to involve in secondary metabolic pathways with the role of coenzyme activation (Sonntag et al., 2020). However, the excessive potassium dosage tends to decrease the antioxidant activity of the fruit.

CONCLUSIONS

The high shading level reduced cutleaf groundcherry growth at all potassium dosages. Under full sunlight and low shading level (25%), high dosages of potassium (120 or 180 kg ha⁻¹)

were required to achieve a more significant leaf number and leaf area. Plants grown at full sunlight produced 27.31 fruits per plant in which the production reduced up to 30% under 75% shading. Under full sunlight, fruit weight was 48.35 g plant⁻¹ in which the reduction occurred at 50 to 75% shading for 50 to 80% yield losses. An adequate potassium fertilizer at 120 kg ha⁻¹ was required to obtain 35.56 g plant⁻¹ fruit weight, which was greater than without potassium fertilizer and performing 48.96% antioxidant activity. The results suggest that cutleaf groundcherry should be planted in the open field where no shading constrained the sunlight radiation or minimum shading (25%), which was still tolerated. In addition, 120 kg K₂O ha⁻¹ was recommended for potassium fertilizer.

ACKNOWLEDGEMENT

This study was supported by the Ministry of Research, Technology, and Higher Education through the Competitive Research Grant by contract number 439.38/UN10.C10/TU/2021.

REFERENCES

- Ahammed, G. J., Chen, Y., Liu, C., & Yang, Y. (2022). Light regulation of potassium in plants. *Plant Physiology and Biochemistry*, *170*, 316–324. <https://doi.org/10.1016/j.plaphy.2021.12.019>
- Ahmad, N., Sarfraz, M., Farooq, U., Arfan-ul-haq, M., Mushtaq, M. Z., & Ali, M. A. (2015). Effect of potassium and its time of application on yield and quality of tomato. *International Journal of Scientific and Research Publications*, *5*(9), 1–4. Retrieved from <https://www.ijsrp.org/research-paper-0915/ijsrp-p45120.pdf>
- Angmo, P., Phuntsog, N., & Namgail, D. (2021). Effect of shading and high temperature amplitude in greenhouse on growth, photosynthesis, yield and phenolic contents of tomato (*Lycopersicon esculentum* Mill.). *Physiology and Molecular Biology of Plants*, *27*(7), 1539–1546. <https://doi.org/10.1007/s12298-021-01032-z>
- Argade, M. B., Kadam, J. H., Garande, V. K., Patgaonkar, D. R., Patil, V. S., & Sonawane, P. N. (2018). Effect of different shading intensities on growth and yield of cherry tomato. *Journal of Applied and Natural Science*, *10*(1), 352–357. <https://doi.org/10.31018/jans.v10i1.1629>
- Biondi, F., Balducci, F., Capocasa, F., Visciglio, M., Mei, E., Vagnoni, M., Mezzetti, B., & Mazzoni, L. (2021). Environmental conditions and agronomical factors influencing the levels of phytochemicals in *Brassica* vegetables responsible for nutritional and sensorial properties. *Applied Sciences (Switzerland)*, *11*(4), 1927. <https://doi.org/10.3390/app11041927>
- Chen, J., Wu, S., Dong, F., Li, J., Zeng, L., Tang, J., & Gu, D. (2021). Mechanism underlying the shading-induced chlorophyll accumulation in tea leaves. *Frontiers in Plant Science*, *12*, 779819. <https://doi.org/10.3389/fpls.2021.779819>
- Çolpan, E., Zengin, M., & Özbahçe, A. (2013). The effects of potassium on the yield and fruit quality components of stick tomato. *Horticulture Environment and Biotechnology*, *54*, 20–28. <https://doi.org/10.1007/s13580-013-0080-4>
- Cui, J., & Tcherkez, G. (2021). Potassium dependency of enzymes in plant primary metabolism. *Plant Physiology and Biochemistry*, *166*, 522–530. <https://doi.org/10.1016/j.plaphy.2021.06.017>
- Da Silva, D. F., Pio, R., Soares, J. D. R., Elias, H. H. D. S., Villa, F., & Vilas Boas, E. V. D. B. (2016). Light spectrum on the quality of fruits of physalis species in subtropical area. *Bragantia*, *75*(3), 371–376. <https://doi.org/10.1590/1678-4499.463>
- Esmaeili, S., Aliniaiefard, S., Dianati Daylami, S., Karimi, S., Shomali, A., Didaran, F., Telesiński, A., Sierka, E., & Kalaji, H. M. (2022). Elevated light intensity compensates for nitrogen deficiency during chrysanthemum growth by improving water and nitrogen use efficiency. *Scientific Reports*, *12*, 10002. <https://doi.org/10.1038/s41598-022-14163-4>
- Ferreira, L. M. dos S., do Vale, A. E., de Souza, A. J., Leite, K. B., Sacramento, C., Moreno, M. L. V., Araujo, T. H., Soares, M. B. P., & Grassi, M. F. R. (2019). Anatomical and phytochemical characterization of *Physalis angulata* L: A plant with therapeutic potential. *Pharmacognosy Research*, *11*(2), 171–177. https://dx.doi.org/10.4103/pr.pr_97_18
- Firdaus, A., Ashari, S., Khoiriyah, L. L., & Waluyo, B. (2022). Phenological of cutleaf groundcherry (*Physalis angulata* L.) based on BBCH scale. *Jurnal Agronomi Tanaman*

- Tropika*, 4(2), 241–254. <https://doi.org/10.36378/juatika.v4i2.2063>
- Gaurav, A. K., Singh, B., Jain, R., Janakiram, T., Swaroop, K., Singh, B., Jain, R., & Gopalakrishnan, S. (2014). Microclimate modification under different shade levels and its effect on the growth of *Dracaena fragrans*. *Journal of Ornamental Horticulture*, 17(1&2), 12–17. <https://doi.org/10.5958/0974-0112.2016.00025.6>
- Gerardeaux, E., Jordan-Meille, L., Constantin, J., Pellerin, S., & Dingkuhn, M. (2010). Changes in plant morphology and dry matter partitioning caused by potassium deficiency in *Gossypium hirsutum* (L.). *Environmental and Experimental Botany*, 67(3), 451–459. <https://doi.org/10.1016/j.envexpbot.2009.09.008>
- Hasanuzzaman, M., Bhuyan, M. H. M. B., Nahar, K., Hossain, M. S., Al Mahmud, J., Hossen, M. S., Masud, A. A. C., Moumita, & Fujita, M. (2018). Potassium: A vital regulator of plant responses and tolerance to abiotic stresses. *Agronomy*, 8(3), 31. <https://doi.org/10.3390/agronomy8030031>
- Hemon, A. F., Sumarjan, & Hanafi, A. R. (2021). Shade stress in various growth phases of peanut genotypes and its effect on agronomic characters and chlorophyll content. *IOP Conference Series: Earth and Environmental Science*, 712, 012017. <https://doi.org/10.1088/1755-1315/712/1/012017>
- Ilić, Z. S., Milenković, L., Šunić, L., Barać, S., Mastilović, J., Kevrešan, Ž., & Fallik, E. (2017). Effect of shading by coloured nets on yield and fruit quality of sweet pepper. *Zemdirbyste-Agriculture*, 104(1), 53–62. <https://doi.org/10.13080/z-a.2017.104.008>
- Iwansyah, A. C., Julianti, W. P., & Luthfiyanti, R. (2019). Characterization of nutrition, antioxidant properties, and toxicity of *Physalis angulata* L. plant extract. *Asian Journal of Pharmaceutical and Clinical Research*, 12(11), 95–99. <https://doi.org/10.22159/ajpcr.2019.v12i11.35497>
- Javaria, S., Khan, M. Q., & Bakash, I. (2012). Effect of potassium on chemical and sensory attributes of tomato fruit. *The Journal of Animal & Plant Science*, 22(4), 1081–1085. Retrieved from <http://www.thejaps.org.pk/docs/V-22-4/44.pdf>
- Jiang, C. D., Wang, X., Gao, H. Y., Shi, L., & Chow, W. S. (2011). Systemic regulation of leaf anatomical structure, photosynthetic performance, and high-light tolerance in sorghum. *Plant Physiology*, 155(3), 1416–1424. <https://doi.org/10.1104/pp.111.172213>
- Jiang, C., Johkan, M., Hohjo, M., Tsukagoshi, S., & Maruo, T. (2017). A correlation analysis on chlorophyll content and SPAD value in tomato leaves. *HortResearch*, 71, 37–42. <https://doi.org/10.20776/S18808824-71-P37>
- Kapoor, L., Simkin, A. J., George Priya Doss, C., & Siva, R. (2022). Fruit ripening: Dynamics and integrated analysis of carotenoids and anthocyanins. *BMC Plant Biology*, 22, 27. <https://doi.org/10.1186/s12870-021-03411-w>
- Kesumawati, E., Apriyatna, D., & Rahmawati, M. (2020). The effect of shading levels and varieties on the growth and yield of chili plants (*Capsicum annum* L.). *IOP Conference Series: Earth and Environmental Science*, 425, 012080. <https://doi.org/10.1088/1755-1315/425/1/012080>
- Khalid, M. H. B., Raza, M. A., Yu, H. Q., Sun, F. A., Zhang, Y. Y., Lu, F. Z., Si, L., Iqbal, N., Khan, I., Fu, F. L., & Li, W. C. (2019). Effect of shade treatments on morphology, photosynthetic and chlorophyll fluorescence characteristic of soybean (*Glycine max* L. Merr.). *Applied Ecology and Environmental Research*, 17(2), 2551–2569. https://doi.org/10.15666/aeer/1702_25512569
- Kläring, H. P., & Krumbein, A. (2013). The effect of constraining the intensity of solar radiation on the photosynthesis, growth, yield and product quality of tomato. *Journal of Agronomy and Crop Science*, 199(5), 351–359. <https://doi.org/10.1111/jac.12018>
- Kostecka-Gugała, A., Ledwozyw-Smoleń, I., Augustynowicz, J., Wyzgolik, G., Kruczek, M., & Kaszycki, P. (2015). Antioxidant properties of fruits of raspberry and blackberry grown in central Europe. *Open Chemistry*, 13(1), 000010151520150143. <https://doi.org/10.1515/chem-2015-0143>
- Kusumaningtyas, R., Laily, N., & Limandha, P. (2015). Potential of ciplukan (*Physalis angulata* L.) as source of functional ingredient. *Procedia Chemistry*, 14, 367–372. <https://doi.org/10.1016/j.proche.2015.03.050>
- Li, A., Li, S., Wu, X., Zhang, J., He, A., Zhao,

- G., & Yang, X. (2016). Effect of light intensity on leaf photosynthetic characteristics and accumulation of flavonoids in *Lithocarpus litseifolius* (Hance) Chun. (Fagaceae). *Open Journal of Forestry*, 6, 445–459. <https://doi.org/10.4236/ojf.2016.65034>
- Lima, M. da S., Evangelista, A. F., dos Santos, G. G. L., Ribeiro, I. M., Tomassini, T. C. B., Pereira Soares, M. B., & Villarreal, C. F. (2014). Antinociceptive properties of physalin from *Physalis angulata*. *Journal of Natural Products*, 77(11), 2397–2403. <https://doi.org/10.1021/np5003093>
- Ma, Q., Cao, X., Wu, L., Mi, W., & Feng, Y. (2016). Light intensity affects the uptake and metabolism of glycine by pakchoi (*Brassica chinensis* L.). *Scientific Reports*, 6, 21200. <https://doi.org/10.1038/srep21200>
- Masabni, J., Sun, Y., Niu, G., & Del Valle, P. (2016). Shade effect on growth and productivity of tomato and chili pepper. *HortTechnology*, 26(3), 344–350. <https://doi.org/10.21273/horttech.26.3.344>
- Medina-Medrano, J. R., Almaraz-Abarca, N., Socorro González-Elizondo, M., Uribe-Soto, J. N., González-Valdez, L. S., & Herrera-Arrieta, Y. (2015). Phenolic constituents and antioxidant properties of five wild species of *Physalis* (Solanaceae). *Botanical Studies*, 56, 24. <https://doi.org/10.1186/s40529-015-0101-y>
- Morales, I., Martínez-Gutiérrez, G. A., Escamirosa-Tinoco, C., Nájera, C., da Cunha-Chiamolera, T. P. L., & Urrestarazu, M. (2018). Production and quality of *Physalis ixocarpa* Brot. Fruit under colored shade netting. *HortScience*, 53(6), 823–828. <https://doi.org/10.21273/HORTSCI113100-18>
- Muhidin, Syam'Un, E., Kaimuddin, Musa, Y., Sadimantara, G. R., Usman, Leomo, S., & Rakian, T. C. (2018). The effect of shade on chlorophyll and anthocyanin content of upland red rice. *IOP Conference Series: Earth and Environmental Science*, 122, 012030. <https://doi.org/10.1088/1755-1315/122/1/012030>
- Nguyen, G. N., Lantzke, N., & van Burgel, A. (2022). Effects of shade nets on microclimatic conditions, growth, fruit yield, and quality of eggplant (*Solanum melongena* L.): A case study in Carnarvon, Western Australia. *Horticulturae*, 8(8), 696. <https://doi.org/10.3390/horticulturae8080696>
- Oosterhuis, D. M., Loka, D. A., Kawakami, E. M., & Pettigrew, W. T. (2014). The physiology of potassium in crop production. *Advances in Agronomy*, 126, 203–233. <https://doi.org/10.1016/B978-0-12-800132-5.00003-1>
- Rezai, S., Etemadi, N., Nikbakht, A., Yousefi, M., & Majidi, M. M. (2018). Effect of light intensity on leaf morphology, photosynthetic capacity, and chlorophyll content in sage (*Salvia officinalis* L.). *Horticultural Science and Technology*, 36(1), 46–57. <https://doi.org/10.12972/kjst.20180006>
- Setiawati, T., Ayalla, A., Nurzaman, M., & Mutaqin, A. Z. (2018). Influence of light intensity on leaf photosynthetic traits and alkaloid content of kiasahan (*Tetracera scandens* L.). *IOP Conference Series: Earth and Environmental Science*, 166, 012025. <https://doi.org/10.1088/1755-1315/166/1/012025>
- Setyorini, D., Sugito, Y., Aini, N., & Tyasmoro, S. Y. (2018). Lycopene, beta-carotene and productivity of tomato varieties at different shade levels under medium land of Indonesia. *Journal of Applied Horticulture*, 20(2), 92–96. <https://doi.org/10.37855/JAH.2018.V20I02.17>
- Shah, P., & Bora, K. S. (2019). Phytochemical and therapeutic potential of physalis species: A review. *IOSR Journal of Pharmacy And Biological Sciences*, 14(4), 34–51. <https://doi.org/10.9790/3008-1404033451>
- Shao, Q., Wang, H., Guo, H., Zhou, A., Huang, Y., Sun, Y., & Li, M. (2014). Effects of shade treatments on photosynthetic characteristics, chloroplast ultrastructure, and physiology of *Anoectochilus roxburghii*. *PLoS ONE*, 9(2), e0085996. <https://doi.org/10.1371/journal.pone.0085996>
- Shezi, S., Magwaza, L. S., Tesfay, S. Z., & Mditshwa, A. (2020). Biochemical changes in response to canopy position of avocado fruit (cv. 'Carmen' and 'Hass') during growth and development and relationship with maturity. *Scientia Horticulturae*, 265, 109227. <https://doi.org/10.1016/j.scienta.2020.109227>
- Sholehah, D. N., Hariyanto, S., & Purnobasuki, H. (2021). Fruit development of groundcherry

- (*Physalis angulata* L.) in dryland. *Australian Journal of Crop Science*, 15(8), 1186–1191. <https://doi.org/10.21475/ajcs.21.15.08.p3318>
- Simkin, A. J., Kapoor, L., Doss, C. G. P., Hofmann, T. A., Lawson, T., & Ramamoorthy, S. (2022). The role of photosynthesis related pigments in light harvesting, photoprotection and enhancement of photosynthetic yield in planta. *Photosynthesis Research*, 152(1), 23–42. <https://doi.org/10.1007/s11120-021-00892-6>
- Singh, V. K., Dwivedi, B. S., & Rathore, S. S. (2021). Timing potassium applications to synchronize with plant demand. *Improving Potassium Recommendations for Agricultural Crops* (pp. 363–384). Springer. <https://doi.org/10.1007/978-3-030-59197-7>
- Sonntag, F., Bunzel, D., Kulling, S., Porath, I., Pach, F., Pawelzik, E., Smit, I., & Naumann, M. (2020). Effect of potassium fertilization on the concentration of antioxidants in two cocktail tomato cultivars. *Journal of Applied Botany and Food Quality*, 93, 34–43. <https://doi.org/10.5073/JABFQ.2020.093.005>
- Sulistiyowati, D., Chozin, M. A., Syukur, M., Melati, M., & Guntoro, D. (2016). Selection of shade-tolerant tomato genotypes. *Journal of Applied Horticulture*, 18(2), 154–159. <https://doi.org/10.37855/jah.2016.v18i02.27>
- Sun, C. P., Qiu, C. Y., Zhao, F., Kang, N., Chen, L. X., & Qiu, F. (2017). Physalins V-IX, 16,24-cyclo-13,14-seco withanolides from *Physalis angulata* and their antiproliferative and anti-inflammatory activities. *Scientific Reports*, 7, 4057. <https://doi.org/10.1038/s41598-017-03849-9>
- Tränkner, M., Tavakol, E., & Jákli, B. (2018). Functioning of potassium and magnesium in photosynthesis, photosynthate translocation and photoprotection. *Physiologia Plantarum*, 163(3), 414–431. <https://doi.org/10.1111/ppl.12747>
- Wan, Y., Zhang, Y., Zhang, M., Hong, A., Yang, H. Y., & Liu, Y. (2020). Shade effects on growth, photosynthesis and chlorophyll fluorescence parameters of three *Paeonia* species. *PeerJ*, 8, e9316. <https://doi.org/10.7717/peerj.9316>
- Woldemariam, S. H., Lal, S., Zelelew, D. Z., & Solomon, M. T. (2018). Effect of potassium levels on productivity and fruit quality of tomato (*Lycopersicon esculentum* L.). *Journal of Agricultural Studies*, 6(1), 104–117. <https://doi.org/10.5296/jas.v6i1.12262>
- Wu, S., Zhang, C., Li, M., Tan, Q., Sun, X., Pan, Z., Deng, X., & Hu, C. (2021). Effects of potassium on fruit soluble sugar and citrate accumulations in Cara Cara navel orange (*Citrus sinensis* L. Osbeck). *Scientia Horticulturae*, 283, 110057. <https://doi.org/10.1016/j.scienta.2021.110057>
- Wu, Y., Yang, H., Yang, H., Zhang, C., Lyu, L., Li, W., & Wu, W. (2022). A physiological and metabolomic analysis reveals the effect of shading intensity on blueberry fruit quality. *Food Chemistry: X*, 15, 100367. <https://doi.org/10.1016/j.fochx.2022.100367>
- Xu, J., Guo, Z., Jiang, X., Ahammed, G. J., & Zhou, Y. (2021). Light regulation of horticultural crop nutrient uptake and utilization. *Horticultural Plant Journal*, 7(5), 367–379. <https://doi.org/10.1016/J.HPJ.2021.01.005>
- Yasoda, P. G. C., Pradheeban, L., Nishanthan, K., & Sivachandiran, S. (2018). Effect of different shade levels on growth and yield performances of cauliflower. *International Journal of Environment, Agriculture and Biotechnology*, 3(3), 948–955. <https://doi.org/10.22161/ijeab/3.3.30>
- Yusof, F. F. M., Yaacob, J. S., Osman, N., Ibrahim, M. H., Wan-Mohtar, W. A. A. Q. I., Berahim, Z., & Zain, N. A. M. (2021). Shading effects on leaf gas exchange, leaf pigments and secondary metabolites of *Polygonum minus* Huds., an aromatic medicinal herb. *Plants*, 10(3), 608. <https://doi.org/10.3390/plants10030608>
- Zhang, N., Van Westreenen, A., Anten, N. P. R., Evers, J. B., & Marcelis, L. F. M. (2020). Disentangling the effects of photosynthetically active radiation and red to far-red ratio on plant photosynthesis under canopy shading: A simulation study using a functional-structural plant model. *Annals of Botany*, 126(4), 635–646. <https://doi.org/10.1093/aob/mcz197>
- Zhang, W., Zhang, X., Wang, Y., Zhang, N., Guo, Y., Ren, X., & Zhao, Z. (2018). Potassium fertilization arrests malate accumulation and alters soluble sugar metabolism in apple fruit. *Biology Open*, 7(12), bio024745. <https://doi.org/10.1242/bio.024745>

Zhou, T., Wang, L., Li, S., Gao, Y., Du, Y., Zhao, L., Liu, W., & Yang, W. (2019). Interactions between light intensity and phosphorus nutrition affect the p uptake capacity of maize

and soybean seedling in a low light intensity area. *Frontiers in Plant Science*, *10*, 395063. <https://doi.org/10.3389/fpls.2019.00183>