Diyala Agricultural Sciences Journal, 2025, Vol. (17) No. 1: 61-77
ISSN: 2073-9524
eISSN: 2310-8746

Growth, Physiological Response, and Phytochemical Composition of Mustard Plant as Affected by Light Intensity and Deficient Irrigation

Omar Ali Ahmed[1*], Husham A. Alqaderi[1], Walid M. Al-Busaidi[2]

[1]Department of Crop Science, Faculty of Agriculture, University of Diyala, Diyala, Iraq.
[2]Department of Plant Science, College of Agriculture and Marine Science, Sultan Qaboos University, Muscat, Sultanate of Oman.
*Corresponding author: omerahmed@uodiyala.edu.iq

Article history:
Received: 5 November 2024
Accepted: 10 February 2025
Published: 30 June 2025

Keywords: *Plant Physiology, Phytochemicals, Deficient Irrigation, sunlight, Brassica juncea.*

Abstract

Mustard is a medicinal plant known in various civilizations for its distinctive properties. Enhancing the production of primary and secondary metabolites in medicinal plants depends on light intensity and irrigation. This study evaluated the effects of two levels of light intensity full sun light (no shade) and 50% of sunlight (50% of shade) and four levels of irrigation (40, 60, 80, and 100 % of field capacity) on the growth, physiology, and phytochemical and antioxidant activity of mustard (*Brassica juncea*) using a randomized complete block design with three replications. Results showed a significant increase ($P \leq 0.05$) in plant height, chlorophyll pigments (ab - b - a), stem dry weight, and seed yield at 50% of light intensity. Meanwhile, the quantification of total phenolic and flavonoids content (TPC and TFC), and 1, 1-diphenyl-2-picrylhydrazyl (DPPH) significantly increased under low irrigation levels. Irrigation at 60% increased the TPC by 80.32% compared with 100% irrigation. High TPC and DPPH activity were observed at 40% irrigation. The RSR was significantly affected by high light intensity, increasing by 68.97% under full sunlight. Growth and chlorophyll pigments were more affected by light intensity than phytochemical compounds, which were more influenced by deficient irrigation. Under 50% of sunlight, the mustard plant allocated more biomass to the shoot system than to the root. In conclusion, the increase in seed yield is linked to optimal levels of lighting.

https://dx.doi.org/10.52951/dasj.25170105

Introduction

The water scarcity in Iraq requires substitute drought tolerant crops for food security and environment. Mustard (*Brassica juncea*) is an annual, edible herbaceous plant belonging to the cruciferous family, which is widely distributed in Africa, Asia, and Europe. It is cultivated in subtropical, semi-arid, and temperate regions due to its short life cycle and low water requirement (Li *et al*., 2022; Piri, 2012). It is widely consumed as food because it is rich in vitamins, minerals, fibers, and antioxidant properties and as spice due to its unique sharp hot pungent flavor (Park *et al*., 2019). The benefits of consuming mustard plants are related to their high concentration of bioactive components, such as phenols, flavonoids, carotenoids, and glucosinols (Sun *et al*., 2018).

Mustard extract possesses anti-inflammatory, antibacterial, and antiviral properties and is used to treat kidney disease, diabetes, and joint pain and reduce the risk of different types of cancer, such as breast cancer, stomach cancer, and lung cancer (Oh *et al*., 2017). The content of polyphenol compounds in mustard plants ranges from 3.26 mg GAE/g to 404.33 mg GAE/g (Sun *et al*., 2018). In particular, the polyphenol content is higher in the seeds and leaves than in the roots and stems, respectively (Harbaum *et al*., 2008a). The levels of these health-promoting compounds are greatly affected by the growth environment and cultural conditions (Tian and Deng, 2020; Li *et al*., 2022).

Light is the least stable (seasonally, diurnally, and spatially) environmental factor that affect plant growth, reproduction, survival, and distribution (Feng *et al*., 2002). Accordingly, light differentiation results in morphological adaptation and biomass distribution in plants to improve their flexibility and acclimation. The growth, physiology, and development of mustard plants are greatly influenced by light intensity (Paradiso and De-Pascale, 2014). Chen *et al*. (2022) reported that germination, photosynthesis rate, nutrient content, and hormones are light-dependent characteristics in lettuce and palmer amaranth. Mielke and Schaffer (2010) found a reduction in growth and photosynthesis rate under low light conditions. Meanwhile, *Myrica rubra* grows well under low irradiance. Compared with that under high-light environments, the content of leaf chlorophyll pigments in plants under low-light environments increases to promote light interception (Yang *et al*., 2007; Mielke and Schaffer, 2010).

Brazaitytė *et al*. (2015), Liu *et al*. (2022), and Xie et *al*. (2018) showed that the contents of carotenoids, anthocyanins, and polyphenols in mustard plants is significantly affected by light. The concentration of phenol and flavonoids are greatly influenced by abiotic and some biotic factors. The increase in phytochemical compounds under high irradiance has a direct effect on antioxidant activities due to the positive relationship between them (Ibrahim and Jaafar, 2012). Biomass production and phytochemicals are also affected by high or low light intensity. Water relations in plants are influenced by temperature, which is closely related to the levels of solar radiation.

The climatic change due to low rainfall in semi-arid regions increases the severity of drought and reduces the quality and quantity of crops (McKierna *et al.*, 2014). Under low moisture conditions, the primary physiological mechanism involves stomatal closure and reduced carbon exchange rate (Mittler, 2002). The increasing ROS under water deficiency is accompanied by a reduction in energy compounds, such as NADPH (Selmar *et al.,* 2013; Sehar *et al*., 2021; Seleima. *et al.,* 2021).

To resist water scarcity, plants increase the concentration of secondary metabolite compounds, such as phenols and flavonoids, to protect their photosynthetic organelles, cell membranes, and proteins and mitigate the inhibition of plant growth (Alinian *et al*., 2016). The concentration of genetically controlled secondary metabolites is affected by water deficiency (Mielke and Schaffer, 2010; Iqball *et al*., 2022). In addition, developing the regions affected by climate change is the suitable approach to enhance the production and productivity of mustard plants and minimize the risk associated with climate change (Rana, *et al*., 2020). This study was conducted to determine the effect of different levels of solar radiation on the growth, production, phenols, flavonoids, and antioxidant activity of mustard plants under deficient irrigation.

Materials and Methods

A field experiment was carried out at the research station of the College of Agriculture, Diyala University during the 2023 agricultural season to study the effect of four levels of irrigation (40, 60, 80, and 100% of field capacity) and two levels of solar radiation 100% sunlight, (0% shade) and 50% of sunlight, (50% shade), on the growth characteristics and yield of mustard plants. Lighting intensity was controlled using 50% shading net of Korean origin. The soil mixture was prepared at a ratio of (1 organic matter: 3 transported soil) volume/volume. NPK (20, 20, and 10) complex fertilizer was added when preparing the soil.

Study Parameters

The study parameters measured included growth and physiological parameters: chlorophyll pigments (a, b, and total chlorophyll a+b), plant height, total stem dry weight, number of branches and root-stem ratio (RSR). Leaf chlorophyll content was performed using the method of Lichtenthaler and Wellburn (1983). In brief, 0.2 g of leaves (fresh weight) were stored in glass vials containing 20 mL of acetone (80%), which were kept in dark for 3–7 days. The absorbance of chlorophyll *a* (A1) was measured at wavelength 662 nm, and that of chlorophyll *b* (B1) was measured at 645 nm. Absorbance was measured using a scanning spectrophotometer Model UV 3101 PC and calculated using the following formulae:

$$\text{Chlorophyll } a = 11.75 \text{ (A1)} - 2.350 \text{ (B1)}$$
$$\text{Chlorophyll b} = 18.61 \text{ (B1)} - 3.960 \text{ (A1)}.$$

Plant height was measured from the terminal bud of each plant to the top of the growing medium in each polybag using a measuring tape. The number of branches was calculated by counting the primary branches per plant. For total stem and root dry weight, six plants per treatment were harvested, and the stems and roots were dried under sunlight conditions until fully dried. The dry weights were determined using an electronic balance. The RSR was calculated using the formula:

Root–stem ratio (RSR) = total root dry weight / total stem dry weight

Phytochemical Constituents

Total Phenolic and Flavonoid Content

The quantification of total phenolic and flavonoids content (TPC and TFC) in mustard seed extracts were measured using the Folin–Ciocalteu reagent method (mg GAE/g DW) and aluminum chloride colorimetric method (mg CE/g DW), respectively (Kaewseejan and Siriamornpun, 2015).

Antioxidant Activities

1, 1-Diphenyl-2-Picrylhydrazyl (DPPH) Assay

The antioxidant activity of the ethanol extract was measured using the 1, 1-diphenyl-2-picrylhydrazyl (DPPH) radical (Wong *et al*., 2006). In brief, 40 µL of plant extract was added to 0.1 mM of ethanolic DPPH solution (195 µL). After 30 minutes of incubation in the dark at room temperature, the absorbance was measured using a spectrophotometer at a wavelength of (515 nm). The following formula was used to calculate the percentage of inhibition:

Percent inhibition (%) = [(A515 of control − A515 of sample)/A515 of control] × 100.

Statistical Analysis

The treatments were distributed randomly following a randomized complete block design. Data were analyzed using ANOVA, and the least significant difference was used for the means separated at significance level of 0.05 using SAS 9.4 software (2013). Pearson correlation analysis was performed between parameters.

Results and Discussion

Plant height (cm)

Figure 1 shows that the levels of solar radiation and irrigation had a significant effect on the height of mustard plants. The plant height recorded at the second level of solar radiation (50%) was higher than that at the first level with an increase of 24.7%. Although the highest average plant height of 95.22 cm was observed at the fourth level of irrigation, this value did not differ significantly from that at the third level. Figure 1 also shows no significant interaction between the two factors regarding plant height.

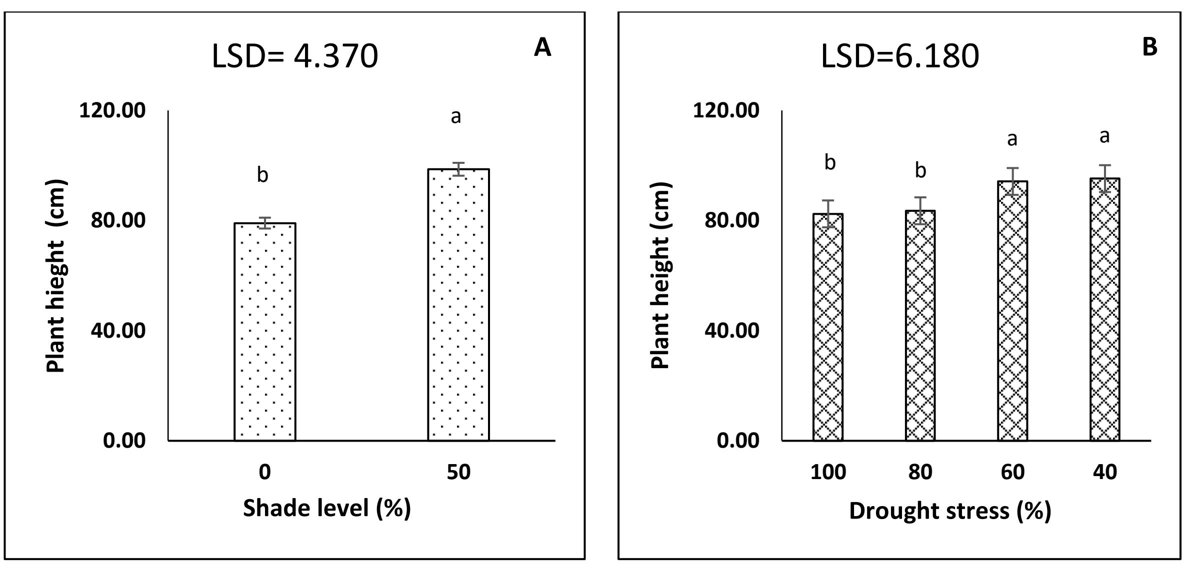

Figure 1. Effect of shade level (a) and drought stress on plant height (cm) of mustard

Chlorophyll a (mg g^{-1})

Table 1 shows that only solar radiation levels had a significant effect on the chlorophyll (a) content of mustard leaves. The lowest average chlorophyll (a) content (0.62) was recorded at the first level of solar radiation (full sunlight). This value decreased to 1.22 (49.2%) at the second level of solar radiation. Table 1 also shows no significant interaction between the two factors regarding this trait.

Chlorophyll b (mg g^{-1})

Table 1 demonstrates that only solar radiation levels had a significant effect on the chlorophyll b (mg) content of mustard leaves. Decreasing the level of solar radiation from 100% to 50% led to an increase in chlorophyll (b) content by 108.70%. Table 1 also shows no significant interaction between the two factors regarding this trait.

Total chlorophyll a+b (mg g^{-1})

Total chlorophyll (a+b) was more significantly affected by solar radiation than irrigation levels. In the mustard leaves, the total chlorophyll content increased by 97.67% when the level of solar radiation was reduced from 100% to 50%. No significant interaction was observed between the two factors regarding this trait (Table 1).

Table 1. Effects of shade levels and water deficiency on chlorophyll a, chlorophyll b and total chlorophyll a+b

Shade level (%)	Chlorophyll *a* (mg g^{-1})	Chlorophyll *b* (mg g^{-1})	Total chlorophyll *a+b* (mg g^{-1})
0	0.62± 0.01^{b}	0.23 ±0.008^{b}	0.86±0.02^{b}
50	1.22± 0.04^{a}	0.48 ±0.02^{a}	1.70± 0.06^{a}
Water deficiency (%)			
100	0.98 ± 0.16^{a}	0.39 ± 0.06^{a}	1.36 ± 0.22^{a}
80	0.96 ± 0.14^{a}	0.36 ± 0.06^{a}	1.32 ± 0.21^{a}
60	0.88 ± 0.12^{a}	0.34 ± 0.05^{a}	1.24 ± 0.17^{a}
40	0.88 ± 0.12^{a}	0.33 ± 0.04^{a}	1.21 ± 0.17^{a}
S x W	ns	ns	ns

Means with the same letters in same columns are not significantly different at $p<0.05$ (LSD).

Stem dry weight (g plant^{-1})

Figure 2 shows that only solar radiation levels had a significant effect on the average stem weight characteristic of mustard plants. The highest average stem dry weight was recorded at the second level of solar radiation (50% of sunlight). This value was 44.13% higher than that observed at 100% of sunlight. Figure 2 also shows no significant interaction between the two factors regarding this attribute.

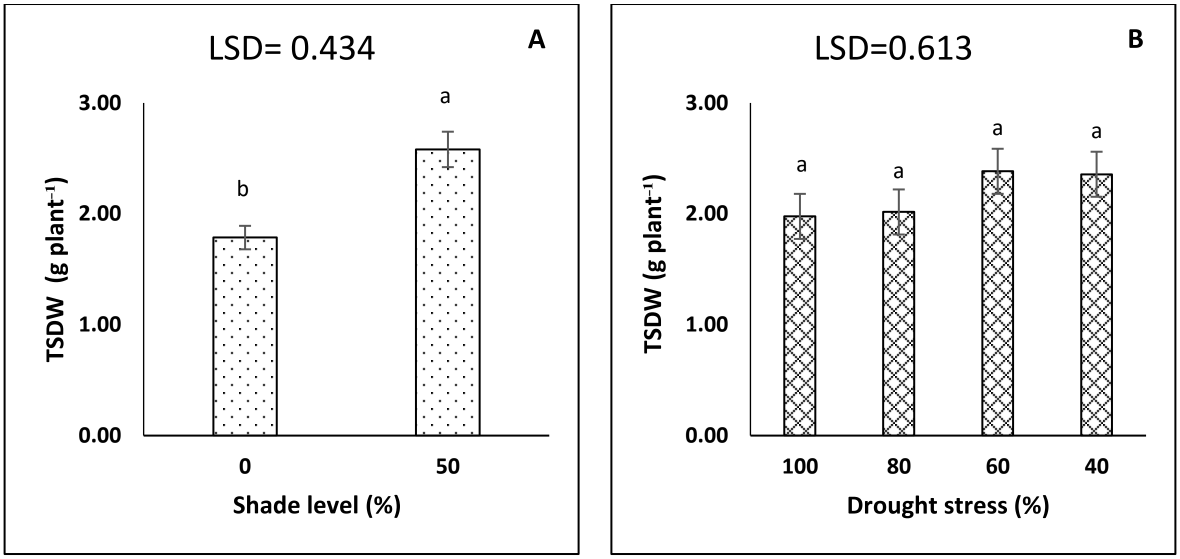

Figure 2. Effect of shade level (a) and drought stress on stem dry weight (g) of mustard

Number of branches per individual plant

Figure 3 shows that solar radiation, irrigation, and their interaction did not significantly affect the number of branches in mustard plants. The number of branches under the second level of solar radiation (50% sunlight) was higher than that under the first level, but the difference was not significant. Similarly, the average number of branches per plant (2.23) was the highest at the third level of irrigation and the lowest (1.56) at the first level. The difference was also not significant.

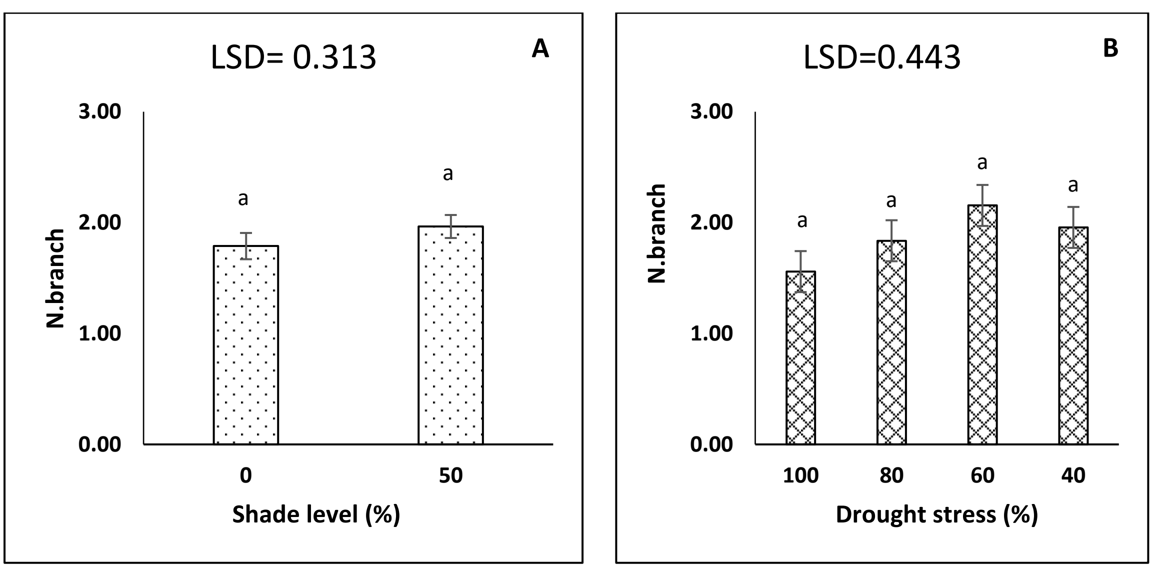

Figure 3. Effect of shade level (a) and drought stress on number of branches per plant of mustard

Seed yield (g plant^{-1})

Solar radiation and irrigation had significant effect on the seed yield (Figure 4) of mustard plants. The average seed yield per plant increased by 25.0% when the level of solar radiation was reduced from 100 to 50%. Meanwhile, the average seed yield per plant increased by 62.30% when the irrigation level decreased from 100% to 40%. No significant interaction was observed between the two factors regarding this trait.

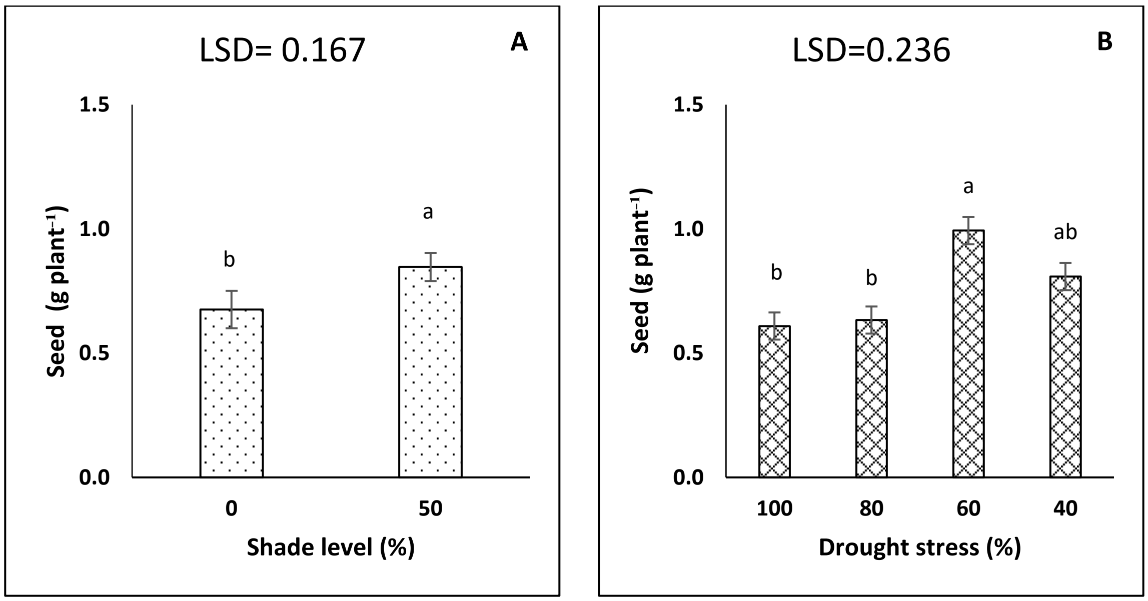

Figure 4. Effect of shade level (a) and drought stress on seed yield (g plant^{-1}) of mustard

Root-stem ratio (RSR)

Figure 5 shows that only solar radiation levels had a significant effect on the RSR of mustard plants. The highest average RSR (0.49) was recorded at the first level of solar radiation exceeded (100% sunlight). This value was 68.97% higher than that measured (0.29) at the second level. Figure 5 also shows no significant interaction between the two factors regarding this trait.

Oil content (%)

The oil content of mustard plants was affected by different levels of solar radiation and irrigation The oil content markedly increased with the increase in solar radiation from 50% to full sunlight as presented in Figure 6-A. The reduction in oil content under 100 and 80% of irrigation was more significant compared with that under 60 and 40% (Figure 6-B).

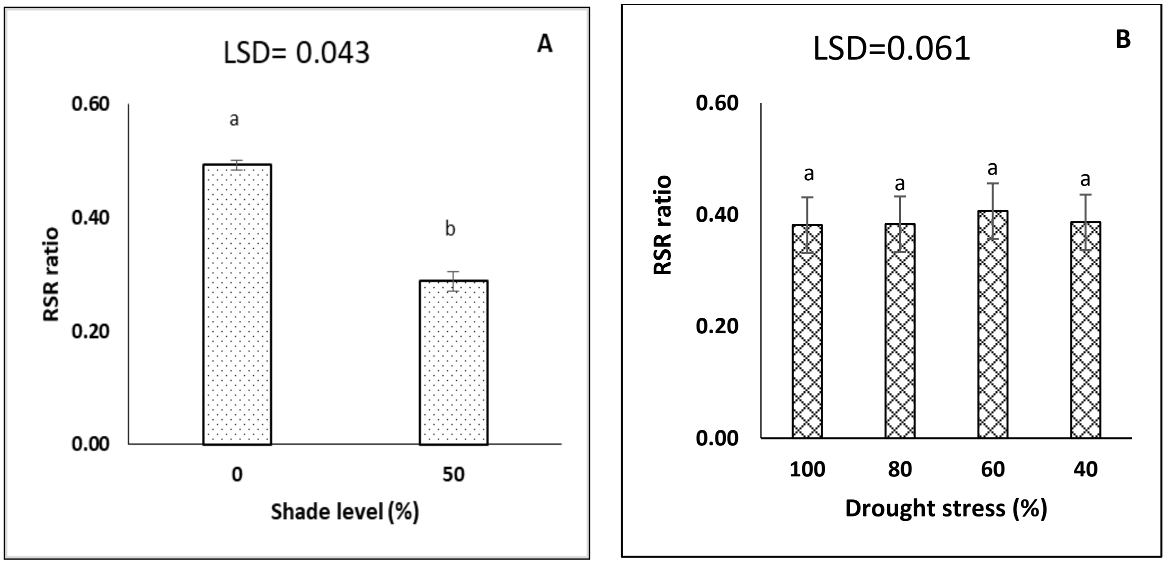

Figure 5. Effect of shade level (a) and drought stress on Root - stem ratio (RSR) of mustard

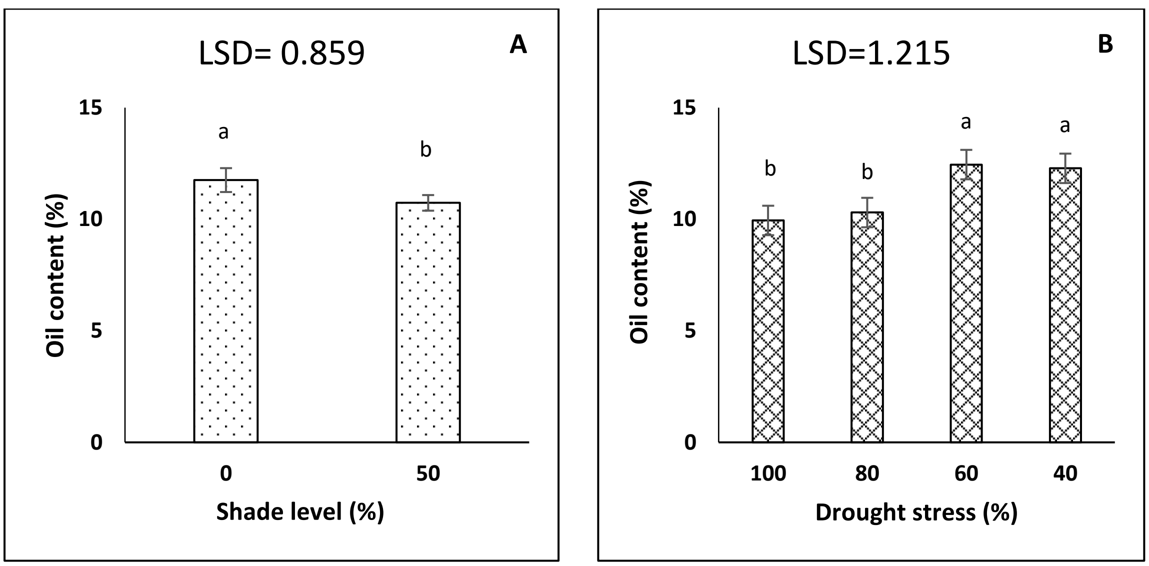

Figure 6. Effect of shade level (a) and drought stress on oil content (%) of mustard

Total phenolic content (TPC)

Only water deficiency had significant effects on the TPC of mustard plants. The results indicated that the TPC of the plant under 60% irrigation (30.06 mg GAE/g) increased by 80.32% compared with that of the plant grown under 100% irrigation. No differences in TPC were observed between 60% and 40% irrigation (Figures 7-A and B).

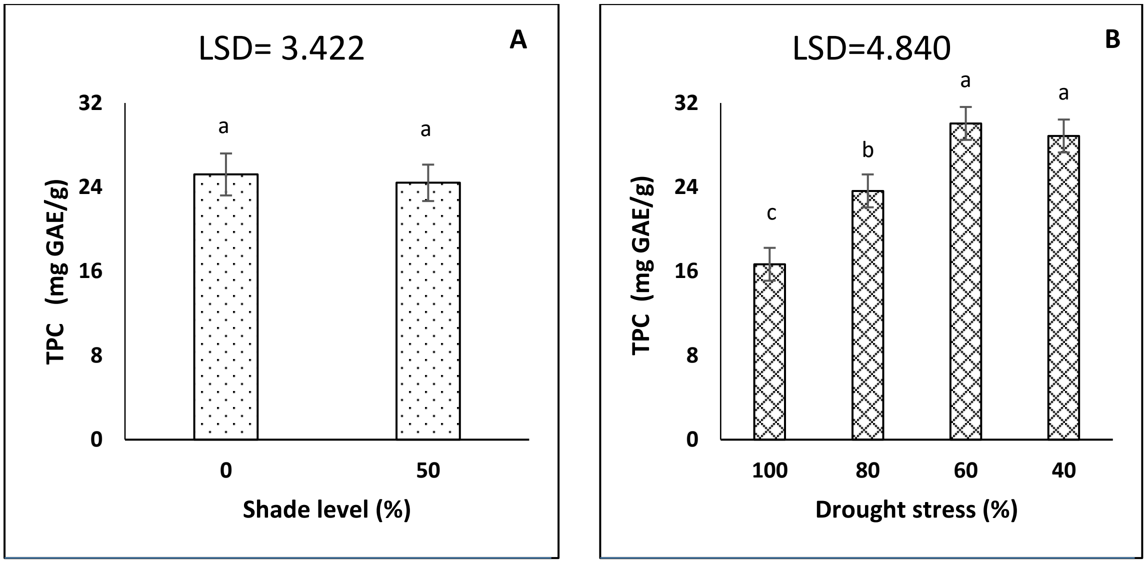

Figure 7: Effect of shade level (a) and drought stress on total phenolic content (TPC) of mustard

Total flavonoid content (TFC)

The TFC was not affected by solar radiation. Meanwhile, water deficiency had significant effects on the TFC of mustard plants. The TFC of the plant at 40% irrigation increased by 86.70% and 50.29% compared with that of the plants at 100% and 80% irrigation, respectively. No significant differences in TFC were observed under 40% and 60% irrigation (Figures 8-A and B).

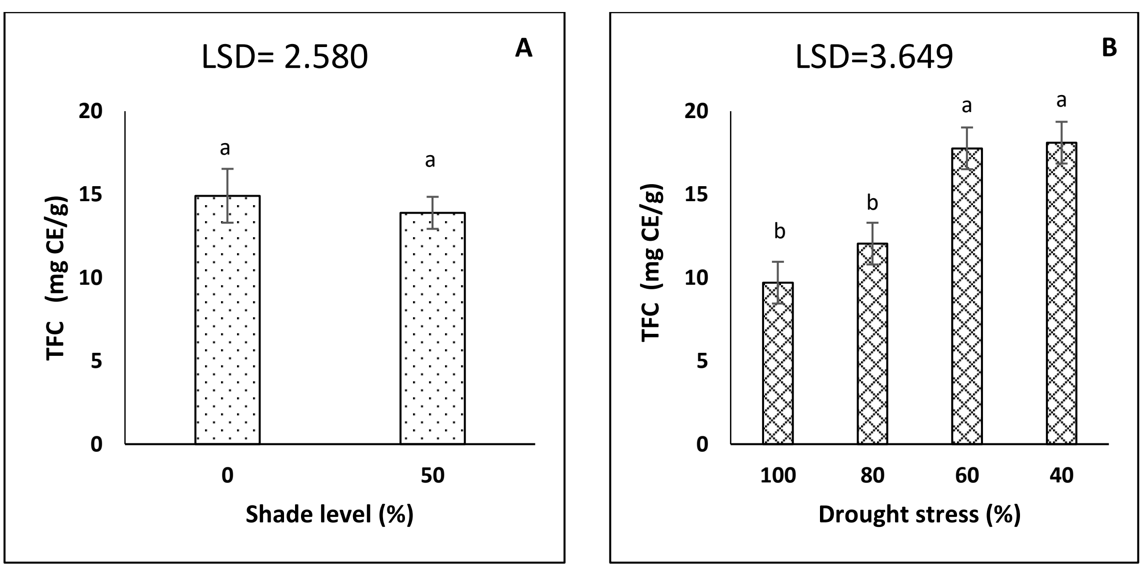

Figure 8. Effect of shade level (a) and drought stress on Total flavonoid content (TFC) of mustard

Antioxidant activity (DPPH) Assay

The 2,2- Diphenyl 1-1- picrylhydrazyl (DPPH) scavenging activity of mustard plants was significantly affected by shade levels and water drought stress. The DPPH scavenging activity was recorded at 48.29% under full sunlight and 41.88% at 50% of net shade. In addition, the highest DPPH scavenging activity was observed at 40% irrigation at 53.18% inhibition, which decreased to 23.05 and 23.24% at 100% and 80% irrigation, respectively (Figures 9-A and B).

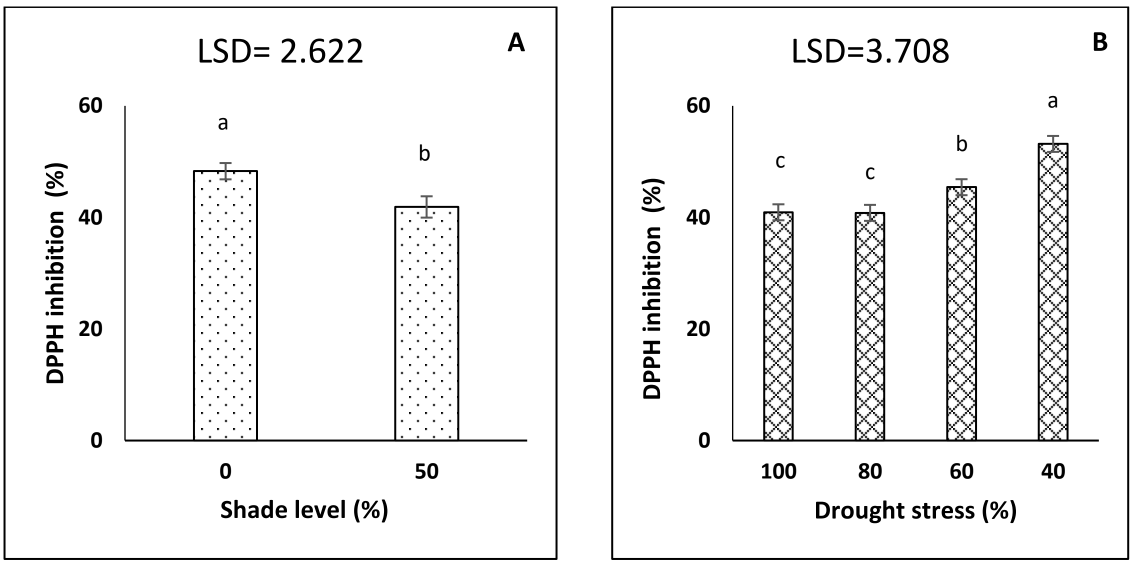

Figure 9. Effect of shade level (a) and drought stress on antioxidant activity (DPPH) assay of mustard

Table 2. Correlation coefficient (r) between chlorophyll-a (Chl-a), chlorophyll-b (Chl-b), total chlorophyll (Chl a+b), plant height (Phi), total stem dry weight (TSDW), number of branch (N.branch), number of boods (N. boods), seed yield (S. yield), root- stem ratio (RSR), Oil percentage (Oil %), total phenolic content (TPC), total flavonoid content (TFC), and 2,2-diphenyl-picrylhydrazyl (DPPH)

	Chl-a	Chl-b	Chl (a+b)	Phi	TSDW	N. branch	N. boods	S. yield	RSR	Oil	TPC	TFC	DPPH
Chl-a	-	0.91**	**0.**99**	0.71 **	0.61 **	0.13 ns	0.56 **	0.32 ns	-0.86 **	- 0.42 *	-0.17 ns	-0.27 ns	-0.54 ns
Chl-b		-	0.97 **	0.65 **	0.53 **	0.15 ns	0.44 *	0.22 ns	-0.84 **	- 0.47 *	-0.16 ns	-0.28 ns	-0.54 **
Chl (a+b)			-	0.72 **	0.61 **	0.14 ns	0.51 **	0.30 ns	- 0.86**	- .043 *	-0.15 ns	-0.27 ns	-0.53 **
PHi				-	0.82 **	0.46 *	0.79 **	0.69 **	- 0.71**	0.14 ns	0.33 ns	0.30 ns	-0.02 ns
TSDW					-	0.40 ns	0.76 **	0.72 **	- 0.62**	0.24 ns	0.15 ns	0.20 ns	-0.09 ns
N. branch						-	0.56 **	0.49 *	-0.18 ns	0.51 *	0.58 **	0.37 ns	0.18 ns
N. boods							-	0.75 **	-0.52 **	0.36 ns	0.38 ns	0.44 *	-0.09 ns
Seed yield								-	-0.29 ns	0.57 **	0.39 ns	0.62 **	0.10 ns
RSR									-	0.43 ns	0.9ns	0.20 ns	0.56 **
Oil										-	0.62 **	0.79 **	0.62 **
TPC											-	0.68 **	0.47 *
TFC												-	0.57 **
DPPH													-

**** Correlation is significant at the 0.01 level** *** Correlation is significant at the 0.05 level**

Figures 1–5 indicate that reducing solar radiation from full sunlight (0% shade) to 50% sunlight led to a significant increase in plant height, content of photosynthetic pigments (chlorophyll-a, chlorophyll-b, and total chlorophyll a+b), and stem dry weight. By contrast, decreasing irrigation from 100% to 40% had no significant effect on the above characteristics of mustard plants. As a physiological response to low light condition, the increase in plant height with the decreased solar radiation from full sunlight (no shade) to 50% sunlight aims to promote light interception. Meanwhile, the reduction in chlorophyll pigments under high irradiance in mustard plants could be due to excessive light. Under high light intensity, photosynthesis organs (such as chloroplast) absorb excessive light energy that deactivates or impairs chlorophyll (Labrooy *et al*., 2016). The reduction in stem dry weight under full sunlight may be related to the low growth caused by diminished chlorophyll pigments. The reduction in water evaporation and leaves temperature under 50% shade influences enzymes activities, carbon exchange rate and biomass accumulation (Ahmed *et al*., 2021). This result is in agreement with previous studies (Liu, *et al.,* 2022; Gerovac *et al*., 2016). Similarly, the highest content of chlorophyll pigments recorded under light deficiency led to an increase light absorption (Samuolienė *et al*., 2013; Weiguo *et al*., 2012).

In this study, solar radiation and water drought stress significantly affected the number of pods and seed yield per plant. Meanwhile, water drought stress showed no significant effect on the number of branches per plant. The value under high shade level (38.12%) increased by 25.0% compared with that under full sunlight, and the value at 60% irrigation increased by 62.30% and 57.14% compared with those under 100% and 80%, respectively. A positive correlation was observed between the number of pods and seed yield. This increment was related to the large amount of photosynthesis pigments, which enhance photosynthesis rate and biomass accumulation. These results are consistent with the findings of Bote *et al*. (2018), who found that high levels of solar radiation weaken or disrupt the photosynthesis systems in plants. In addition, the growth and physiological characteristics were more sensitive to light intensity than irrigation. The RSR at high light intensity (100% sunlight or no shade) was 68.97% higher than that under 50% shade. Under excessive light conditions, mustard plants reduce the size of aerial part (shoot system) or allocate more biomass to the root system than the shoot system for survival, thereby reducing the plant's yield. On the contrary, plants under low light intensity (50%) allocate more biomass to the shoot system than the root system, producing many photosynthesis pigments and improving plant growth and yield. These results are consistent with previous findings (Bote *et al*., 2018; Yang *et al*., 2018).

Figure 6 indicates that shade levels and water drought stress had significant effects on mustard seed oil content. The highest oil content was produced under 50% sunlight and 60% irrigation. This study also showed that water drought stress had a significant effect on the TPC and TFC of mustard plants. The TPC at 60% irrigation increased by 80.32% and 27.21% compared with those under 100% and 80% irrigation, respectively. Similarly, the TFC at 40% irrigation increased by 29.96% and 30.28% compared with those under 100% and 80% irrigation, respectively. Opposite to the growth and physiological characteristics, the phytochemical compounds (TPC and TFC) are more affected by water stress than light intensity. In addition, the antioxidant activity (DPPH) under full sunlight was 15.31% higher than that under 50% of sunlight. Meanwhile, the antioxidant activity under 40% irrigation was 86.70% and 50.29% higher than that under 100% and 80% irrigation, respectively. A positive correlation (r= 0.47 and 0.57) was found among DPPH, TPC, and TFC (Table 2). The increase in phytochemicals and antioxidants under abiotic stress aims to protect mustard plant tissues from ROS. This result is in line with previous findings (Park *et al*., 2019; Iqbal *et al*., 2021; Ahmed *et al*., 2021).

Shade levels and water drought stress had a significant effect on yield. Plant height and yield were significantly superior under irrigation at 40 and 60% of field capacity. These results are consistent with the findings of Xiong *et al*. (2019), who found that excessive irrigation or incomplete irrigation decreases yield compared with moderate irrigation. By contrast, Piri and Naserin (2020) proved that the mustard plant’s need for water is only one or two irrigations during the winter growing season, and some mustard varieties gave the highest yields under deficient irrigation. Another study showed no significant differences in onion yield at irrigation levels of 100 and 75%, and the 25% irrigation water that was saved can be used to increase the cultivated area and thus increase production (Piri and Naserin, 2020). The decrease in yield at 100% and 80% irrigation is due to the inability of mustard plants to benefit from moisture and nutrients dissolved in the soil solution, which negatively affects the exchange of carbon dioxide due to waterlogging. These results are consistent with the findings of Srivastava *et al*. (2022), who found a decrease in the exchange of carbon dioxide gas and the absorption of nutrients by mustard plants in waterlogged soils. No differences were observed between the mustard plants at 100% and 80% irrigation levels, as they experience the same conditions due to the plant’s inability to benefit from moisture at these levels of irrigation.

Conclusions

Identifying appropriate environmental conditions is crucial to improve the quantity and quality of mustard plants with high nutritional and medicinal value. Light intensity and irrigation significantly affected the growth, yield, phytochemicals, and antioxidant activity. The highest seed yield was recorded at 50% of sunlight (50% shade) and 60% irrigation, and the highest antioxidant activity was observed at full sunlight and 40% irrigation. These results showed the ability of mustard plants to produce a high yield under the lowest percentage of irrigation, allowing to save large amounts of water during seasons of water scarcity. Further study is warranted to investigate different agriculture practices, such as organic and inorganic fertilizer, swing data, and plant density to achieve high phytochemical content and biomass yield.

Conflict of interest

The authors have no conflicts of interest to disclose.

Acknowledgments

The authors would like to acknowledge the laboratory units in the Department of Crop Sciences, Faculty of Agriculture, University of Diyala, and Ardh Al-Sawad organization for agricultural development.

References

Ahmed, O. A., Yusoff, M. M., Misran, A., Wahab, P. E. M., and Zentou, H. (2021). Phytochemical content and antioxidant activity of'Gynura procumbens' in response to shade levels and rates of nitrogen fertilizer. *Australian Journal of Crop Science*, *15*(3), 445-454.

Alinian, S., Razmjoo, J., and Zeinali, H. (2016). Flavonoids, anthocynins, phenolics and essential oil produced in cumin (Cuminum cyminum L.) accessions under different irrigation regimes. *Industrial Crops and Products*, *81*, 49-55. https://doi.org/10.1016/j.indcrop.2015.11.040

Bote, A. D., Ayalew, B., Ocho, F. L., Anten, N. P., and Vos, J. (2018). Analysis of coffee (*Coffea arabica* L.) performance in relation to radiation levels and rates of nitrogen supply I. Vegetative growth, production and distribution of biomass and radiation use efficiency. *European Journal of Agronomy*, *92*, 115-122. https://doi.org/10.1016/j.eja.2017.10.007

Brazaitytė, A., Sakalauskienė, S., Samuolienė, G., Jankauskienė, J., Viršilė, A., Novičkovas, A., and Duchovskis, P. (2015). The effects of LED illumination spectra and intensity on carotenoid content in Brassicaceae microgreens. *Food Chemistry*, *173*, 600-606. https://doi.org/10.1016/j.foodchem.2014.10.077

Chen, X. L., Li, Y. L., Wang, L. C., Yang, Q. C., and Guo, W. Z. (2022). Responses of butter leaf lettuce to mixed red and blue light with extended light/dark cycle period. *Scientific Reports*, *12*(1), 6924. https://doi.org/10.1038/s41598-022-10681-3

Feng, X. P., Cha, Z. Y., and Wang, H. S. (2002). Study on the extractive technology of total flavones from foliage of Gingko. *Chem. Ind. Corros. Control Sichuan*, *138*(2), 23-26.

Gerovac, J. R., Craver, J. K., Boldt, J. K., and Lopez, R. G. (2016). Light intensity and quality from sole-source light-emitting diodes impact growth, morphology, and nutrient content of Brassica microgreens. *HortScience*, *51*(5), 497-503. https://doi.org/10.21273/HORTSCI.51.5.497

Harbaum, B., Hubbermann, E. M., Zhu, Z., and Schwarz, K. (2008). Impact of fermentation on phenolic compounds in leaves of pak choi (Brassica campestris L. ssp. chinensis var. communis) and Chinese leaf mustard (Brassica juncea Coss). *Journal of Agricultural and Food Chemistry*, *56*(1), 148-157. https://doi.org/10.1021/jf072428o

Ibrahim, M. H., and Jaafar, H. Z. (2012). Primary, secondary metabolites, H2O2, malondialdehyde and photosynthetic responses of Orthosiphon stimaneus Benth. to different irradiance levels. *Molecules*, *17*(2), 1159-1176. https://doi.org/10.3390/molecules17021159

Iqbal, N., Fatma, M., Gautam, H., Sehar, Z., Rasheed, F., Khan, M. I. R., and Khan, N. A. (2022). Salicylic acid increases photosynthesis of drought grown mustard plants effectively with sufficient-N via regulation of ethylene, abscisic acid, and nitrogen-use efficiency. *Journal of Plant Growth Regulation*, *41*(5), 1966-1977. https://doi.org/10.1007/s00344-021-10565-2

Iqbal, N., Umar, S., Khan, N. A., and Corpas, F. J. (2021). Nitric oxide and hydrogen sulfide coordinately reduce glucose sensitivity and decrease oxidative stress via ascorbate-glutathione cycle in heat-stressed wheat (*Triticum aestivum* L.) plants. *Antioxidants*, *10*(1), 1-20. https://doi.org/10.3390/antiox10010108

Kaewseejan, N., Siriamornpun, S. (2015). Bioactive components and properties of ethanolic extract and its fractions from *Gynura procumbens* leaves. *Industrial Crops and Products, 74*, 271–278. https://doi.org/10.1016/j.indcrop.2015.05.019

Labrooy, C. D., Abdullah, T. L., Abdullah, N. A. P., and Stanslas, J. (2016). Optimum shade enhances growth and 5, 7-dimethoxyflavone accumulation in Kaempferia parviflora Wall. ex-Baker cultivars. *Scientia Horticulturae*, *213*, 346-353. https://doi.org/10.1016/j.scienta.2016.10.042

Li, Z., Di, H., Cheng, W., Ren, G., Zhang, Y., Ma, J., and Sun, B. (2022). Effect of the Number of Dark Days and Planting Density on the Health-Promoting Phytochemicals and Antioxidant Capacity of Mustard (*Brassica juncea*) Sprouts. *Plants*, *11*(19), 1-15. https://doi.org/10.3390/plants11192515

Lichtenthaler, H. K., and Wellburn, A. R. (1983). Determinations of total carotenoids and chlorophylls *a* and *b* of leaf extracts in different solvents. *Portland Press Limited. Biochemical Society Transactions, 11*(5), 591-592. https://doi.org/10.1042/bst0110591

Liu, K., Gao, M., Jiang, H., Ou, S., Li, X., He, R., and Liu, H. (2022). Light intensity and photoperiod affect growth and nutritional quality of brassica microgreens. *Molecules*, *27*(3), 1-19. https://doi.org/10.3390/molecules27030883

McKiernan, A. B., Hovenden, M. J., Brodribb, T. J., Potts, B. M., Davies, N. W., and O'Reilly-Wapstra, J. M. (2014). Effect of limited water availability on foliar plant secondary metabolites of two Eucalyptus species. *Environmental and Experimental Botany*, *105*, 55-64. https://doi.org/10.1016/j.envexpbot.2014.04.008

Mielke, M. S., and Schaffer, B. (2010). Photosynthetic and growth responses of Eugenia uniflora L. seedlings to soil flooding and light intensity. *Environmental and Experimental Botany*, *68*(2), 113–121. https://doi.org/10.1016/j.envexpbot.2009.11.007

Mittler, R. (2002). Oxidative stress, antioxidants and stress tolerance. *Trends in Plant Science*, *7*(9), 405-410.

Oh, S., Tsukamoto, C., Kim, K., and Choi, M. (2017). Investigation of glucosinolates, and the antioxidant activity of D olsan leaf mustard kimchi extract using HPLC and LC-PDA-MS/MS. *Journal of Food Biochemistry*, *41*(3), 12366. https://doi.org/10.1111/jfbc.12366

Paradiso, R., and De Pascale, S. (2014). Effects of plant size, temperature, and light intensity on flowering of Phalaenopsis hybrids in Mediterranean greenhouses. *The Scientific World Journal*, *2014*(1), 1-9. https://doi.org/10.1155/2014/420807

Park, C. H., Kim, N. S., Park, J. S., Lee, S. Y., Lee, J. W., and Park, S. U. (2019). Effects of light-emitting diodes on the accumulation of glucosinolates and phenolic compounds in sprouting canola (*Brassica napus* L.). *Foods*, *8*(2), 1-9. https://doi.org/10.3390/foods8020076

Piri, H., and Naserin, A. (2020). Effect of different levels of water, applied nitrogen and irrigation methods on yield, yield components and IWUE of onion. *Scientia Horticulturae*, *268*, 109361. https://doi.org/10.1016/j.scienta.2020.109361

Rana, K., Parihar, M., Singh, J. P., and Singh, R. K. (2020). Effect of sulfur fertilization, varieties and irrigation scheduling on growth, yield, and heat utilization efficiency of indian mustard (Brassica Juncea L.). *Communications in soil science and plant analysis*, *51*(2), 265-275. https://doi.org/10.1080/00103624.2019.1705325

Samuolienė, G., Brazaitytė, A., Jankauskienė, J., Viršilė, A., Sirtautas, R., Novičkovas, A., and Duchovskis, P. (2013). LED irradiance level affects growth and nutritional quality of Brassica microgreens. *Central European Journal of Biology*, *8*, 1241-1249. https://doi.org/10.2478/s11535-013-0246-1

SAS, I. (2013). *Base SAS 9.4 procedures guide*: statistical procedures, Second Edition. Cary, USA: SAS Institute Inc.

Sehar, Z., Jahan, B., Masood, A., Anjum, N. A., and Khan, N. A. (2021). Hydrogen peroxide potentiates defense system in presence of sulfur to protect chloroplast damage and photosynthesis of wheat under drought stress. *Physiologia Plantarum*, *172*(2), 922-934. https://doi.org/10.1111/ppl.13225

Seleiman, M. F., Al-Suhaibani, N., Ali, N., Akmal, M., Alotaibi, M., Refay, Y., and Battaglia, M. L. (2021). Drought stress impacts on plants and different approaches to alleviate its adverse effects. *Plants*, *10*(2), 1-25. https://doi.org/10.3390/plants10020259

Selmar, D., and Kleinwächter, M. (2013). Stress enhances the synthesis of secondary plant products: the impact of stress-related over-reduction on the accumulation of natural products. *Plant and Cell Physiology*, *54*(6), 817-826. https://doi.org/10.1093/pcp/pct054

Srivastava, A., Sharma, V. K., Kaushik, P., El-Sheikh, M. A., Qadir, S., and Mansoor, S. (2022). Effect of silicon application with mycorrhizal inoculation on Brassica juncea cultivated under water stress. *Plos One*, *17*(4), 1-15. https://doi.org/10.1371/journal.pone.0261569

Sun, B., Tian, Y. X., Jiang, M., Yuan, Q., Chen, Q., Zhang, Y., and Tang, H. R. (2018). Variation in the main health-promoting compounds and antioxidant activity of whole and individual edible parts of baby mustard (*Brassica juncea var. gemmifera*). *RSC advances*, *8*(59), 33845-33854. https://doi.org/10.1039/C8RA05504A

Tian, Y., and Deng, F. (2020). Phytochemistry and biological activity of mustard (Brassica juncea): a review. *Cyta-journal of Food*, *18*(1), 704-718. https://doi.org/10.1080/19476337.2020.1833988

Weiguo, F., Pingping, L., Yanyou, W., and Jianjian, T. (2012). Effects of different light intensities on anti-oxidative enzyme activity, quality and biomass in lettuce. *Horticultural Science*, *39*(3), 129-134.

Wong, S. P., Leong, L. P., and Koh, J. H. W. (2006). Antioxidant activities of aqueous extracts of selected plants. *Food Chemistry*, *99*(4), 775-783. https://doi.org/10.1016/j.foodchem.2005.07.058

Xie, Q., Yan, F., Hu, Z., Wei, S., Lai, J., and Chen, G. (2018). Accumulation of anthocyanin and its associated gene expression in purple tumorous stem mustard (Brassica juncea var. tumida Tsen et Lee) sprouts when exposed to light, dark, sugar, and methyl jasmonate. *Journal of Agricultural and Food Chemistry*, *67*(3), 856-866. https://doi.org/10.1021/acs.jafc.8b04706

Xiong, Q. Q., Shen, T. H., Zhong, L., Zhu, C. L., Peng, X. S., He, X. P., and Chen, X. R. (2019). Comprehensive metabolomic, proteomic and physiological analyses of grain yield reduction in rice under abrupt drought–flood alternation stress. *Physiologia Plantarum*, *167*(4), 564-584. https://doi.org/10.1111/ppl.12901

Yang, X. Y., Ye, X. F., Liu, G. S., Wei, H. Q., and Wang, Y. (2007). Effects of light intensity on morphological and physiological characteristics of tobacco seedlings. *Ying Yong Sheng tai xue bao= The Journal of Applied Ecology*, *18*(11), 2642-2645.

Yang, Y., Dou, Y., An, S., and Zhu, Z. (2018). Abiotic and biotic factors modulate plant biomass and root/shoot (R/S) ratios in grassland on the Loess Plateau, China. *Science of The Total Environment*, *636*, 621-631. https://doi.org/10.1016/j.scitotenv.2018.04.260