RESEARCH ARTICLE

SABRAO Journal of Breeding and Genetics
56 (4) 1661-1668, 2024
http://doi.org/10.54910/sabrao2024.56.4.31
http://sabraojournal.org/
pISSN 1029-7073; eISSN 2224-8978

RESPONSE OF LOW NICKEL FERTILIZATION ON THE QUANTITATIVE PARAMETERS OF SHALLOT UNDER HYDROPONIC CONDITIONS

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SUMMARY

Nickel (Ni) is an essential micronutrient known for improving the growth and yield of various crops at low concentrations. However, the nickel's adequate information on shallots is insufficient. This study found out the effect of Ni fertilization with four concentrations (0.0, 0.025, 0.1, and 0.4 mg L^{-1} derived from NiSO4.6H2O) on plant and bulb weight, nutrient solution usage, and bulb nickel and nitrate content of two shallot cultivars (Lokananta and Sanren F1) using hydroponic condition, arranged in a split-plot design under field conditions. Increased Ni concentration (0.4 mg L^{-1}) negatively affected plant height, total plant weight, bulb weight per plant, and total nutrient solution usage, while it increased the bulb nickel and leaf carotenoid contents. The Ni concentration (0.025 mg L^{-1}) can be safer for shallot plant absorption with optimum growth and yield. Shallot cultivar Sanren F1 provides considerably better results in terms of yield components than cultivar Lokananta. Bulb weight per plant appeared positively correlated with the number of leaves, bulbs, total bulb diameter, and total volume of nutrient solution used per plant. The total bulb diameter per plant showed a better direct effect on the shallot bulb yield at various Ni levels.

Keywords: Shallot (*Allium cepa* L. Aggregatum group), cultivars, Ni nutrition, growth, physiological components, yield traits, path analysis, Pearson's correlation

Key findings: Ni at a low concentration (0.025 mg L^{-1}) stimulates the growth and physiological components of shallot plants, which, in turn, increases bulb yield. Leaf carotenoid content and water uptake can assess the response of shallot plants to heavy metal stress conditions.

Communicating Editor: Dr. Himmah Rustiami

Manuscript received: January 11, 2024; Accepted: June 20, 2024.

Citation: Kuse KG, Riadi M, Sjahril R (2024). Response of low nickel fertilization on the quantitative parameters of shallot under hydroponic conditions. *SABRAO J. Breed. Genet.* 56(4): 1661-1668. http://doi.org/10.54910/sabrao2024.56.4.31.

INTRODUCTION

Improvement in crop productivity has become an important goal in the agriculture sector. In Indonesia, the shallot's productivity is still below the potential yield compared with other producing countries (Tori *et al.,* 2023). Therefore, its improvement needs to progress through various components based on the cultivation technology and the used inputs (Saptana *et al.,* 2021; Afify and El-Nwehy, 2023). Planting materials like improved cultivars and hybrids are crucial components in crop production.

In Indonesia, the farming community still uses bulbs as planting materials; however, the seed quality does not meet agronomic standards (Syam'un *et al.,* 2017). Furthermore, seed bulbs also present a major challenge in logistics and distribution (Pangestuti and Sulistyaningsih, 2011; Al-Bayati *et al*., 2023). For now, the National Shallot Development Program sought to establish new areas for enhanced production (Indonesian Directorate General of Horticulture, 2021).

The use of shallot botanical seeds commonly known as 'True Seed of Shallots (TSS)' has several advantages, including disease-free, high-yield potential, ease of logistics and distribution, and long seed shelf life (Askari-Khorasgani and Pessarakli, 2019). In addition, it is crucial to select the cultivars that are more adaptive and have high-yield potential. Shallot cultivar Lokananta and hybrid Sanren F1 are new high-yielding genotypes that have officially come out from the Indonesian Ministry of Agriculture, Indonesia. Lokananta is a synthetic variety with medium bulb-splitting characteristics, while Sanren F1 is a hybrid variety with high bulb-splitting characteristics (Adin *et al.,* 2022). Both genotypes proved suitable for lowlands and their potential yields range between 13.25–23.03 t ha^{-1} (Annisa *et al*., 2022; Faried *et al*., 2023). However, nutrient management is also necessary to achieve the crop's better yield potential.

Nickel (Ni) is an essential micronutrient, which is significant for plant growth and development (Brown, 2006; Cakmak *et al*., 2023). Ni plays a primary role in Nitrogen metabolism and as a component of the enzyme urease (Freitas *et al.,* 2018). The specified species and even cultivars largely determine the Ni requirement of plants (Liu *et al.,* 2011). The addition of Ni (0.1 mg L^{-1}) to the nutrient solution can considerably enhance the nitrate ion (NO-3) content in tomato seedlings (Zhang *et al.,* 2022).

Adding Ni also affects the N metabolism, increasing further bulb yield in onions (Alibakhshi and Khoshgoftarmanesh, 2015, 2016). Soudek *et al.* (2009) analyzed the accumulation of Ni in several species of allium with concentrations of 0.05 and 0.25 μM hydroponically. However, Ni is also a heavy metal that can adversely affect plants and human health. Therefore, based on Government Regulation, Republic of Indonesia Number 22 of 2021, the safe limit of Ni for national water quality standards is 0.05 to 0.1 mg L^{-1}.

Information on the effects of Ni fertilization at low concentrations on plant growth, physiological, and yield-related traits, especially shallots, is still insufficient. Additionally, no safe limit and optimum concentration of Ni exists that provides a stimulant or toxic effect for shallots, especially in Indonesia. Therefore, this study sought to determine the effects of Ni fertilization on the growth, physiological, and bulb-yield components of two seed-origin shallot cultivars in hydroponic culture with a multi-analysis approach.

MATERIALS AND METHODS

Experimental material and procedure

The promising study commenced from May to August 2023 in Bombongi village, Maros District, South Sulawesi province, Indonesia. Nine seeds of the shallot cultivar Lokananta and hybrid Sanren F1 continued sowing on a Rockwool cube and grown for 40 days. Subsequently, seedlings transplanting into pots continued in containers with a mixture of cocopeat and pearlite (2:1; v/v) and measured 0.4 m × 0.32 m × 0.13 m with 10 cm × 12.5

cm spacing between plants filled with a nutrient solution with a conductivity of 1.5 mS cm^{-1} and pH 5.5 (Randle, 2000; Bugbee, 2004; Kratky, 2010). Nickel fertilization began from transplanting until one week before harvest by adding it to the nutrient solution. The application made by adding Ni stock solution ensued according to the different treatment levels (0, 0.25, 0.1, and 0.4 mg L^{-1}) mixed into the nutrient solution (N-total = 18.6%, P = 5.6%, K = 28.8%, Ca = 13%, Mg = 5.6%, S = 9.6%, Fe = 0.09%, B = 0.02%, Zn = 0.02%, Mn = 0.04%, Cu = 0.04%, and Mo = 0.001%). The hydroponic module arrangement had a split-plot design with cultivars as the main plots and Ni concentrations as the sub-plots repeated three times. The experiment progressed under field conditions with natural sunlight. The nutrient solution in the container maintained periodical renewals following the unit with the lowest volume of nutrient solution at the time of observation. The nutrient solution used had the same conductivity and pH values for all treatments. Harvesting of plants depended on physiological maturity criteria and when the top of the plant had fallen over.

Traits measured

Growth parameters included plant height and number of leaves per plant observed 60 days after planting. Physiological parameters comprised total leaf chlorophyll content (Porra *et al*., 1989) and leaf carotenoid content recorded 75 days after planting (Linchtenthaler and Wellburn, 1983). Yield parameters consisted of the number of bulbs per plant, total bulb diameter per plant, total plant weight (leaf and bulbs), and total bulb weight per plant measured after the plants' harvest. The recorded nutrient solution applied had calculations for the total volume of nutrient solution from transplanting to harvest. Measurement of nickel and nitrate levels of shallot bulbs progressed with the help of the Feed Chemistry Laboratory, Hasanuddin University, Makassar, Indonesia.

Statistical analysis

Analysis of variance ran on treatment effects, and if a significant effect exists, then further tests continued using the least significant difference (LSD) test at a 5% probability level. Further analyses through Pearson's correlation and Path analysis helped determine the effects among the various parameters and the outcome of independent parameters on plant yield components, respectively. Except for the parameters of nickel and nitrate content of bulbs, no analysis of variance occurred (Figures 1 and 2).

RESULTS AND DISCUSSION

Ni fertilization effect

Interactions between the shallot cultivars and Ni concentration treatments had nonsignificant effects on the growth, physiological, and bulb yield-related parameters (Table 1). It indicates that both cultivars had similar responses to low Ni fertilization. The influence of Ni fertilization was notable by the responsive genotypes, characterized by its N metabolism ability and the cultivation environment (Freitas *et al*., 2018). In addition, the nitrogen source used also affected the N metabolism of onion plants. Urea application as a source of N in hydroponic culture enhanced the activities of urease and glutamine synthase enzymes (Alibakhshi and Khoshgoftarmanesh, 2015).

In the presented study, the N sources used were $NH4^{+}$ and $NO3^{-}$, which were the N-available forms to plants without the hydrolysis process. The N source and plant species can determine the optimum Ni concentration favorably affecting plant growth and yield-related traits (Tan *et al*., 2000; Brown, 2006; Gheibi *et al*., 2009; Tabatabaei, 2009).

This study also found no significant yield-enhancing effect of adding Ni to the nutrient solution. Regardless of the cultivar, the addition of Ni to the nutrient solution, to some degree, significantly affects some shallot

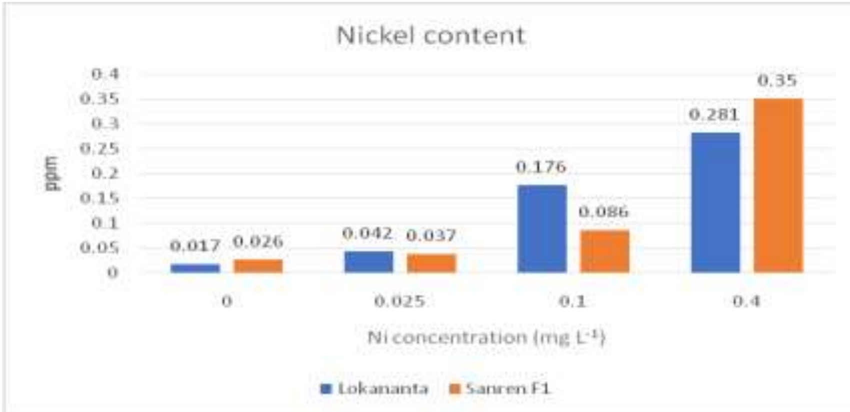

Figure 1. Effect of nickel concentrations on the accumulation of nickel content in the bulbs of shallots cultivars.

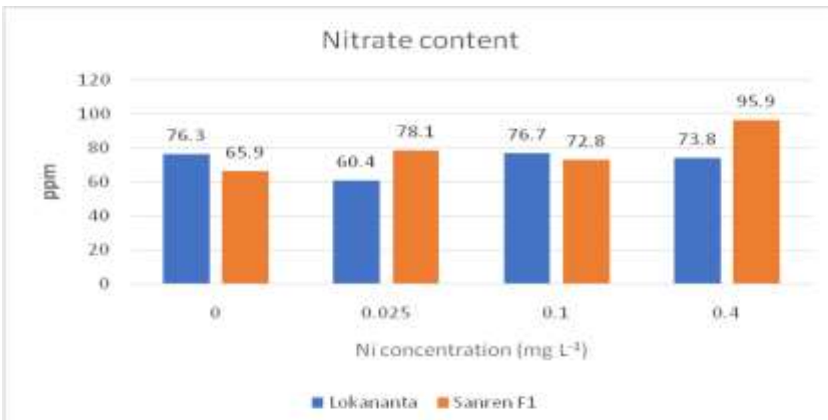

Figure 2. Effects of nickel concentrations on the accumulation of nitrate content in bulbs of shallot cultivars.

Table 1. Combined analysis of variance for growth, physiology, and yield components of two shallot cultivars under different nickel concentrations.

Source	d.f.	PH	LP	BP	BD	Chl	Crt	NSV	PW	BW
Cultivars (A)	1	ns	ns	**	ns	ns	ns	ns	ns	*
Error (a)	2									
Ni (B)	3	ns	ns	ns	ns	ns	ns	**	**	*
A × B	3	ns	ns	ns	ns	ns	ns	ns	ns	ns
Error (b)	12									
Total	23									
CV (a)		5.1%	27.5%	4.0%	18.9%	12.4%	3.4%	2.8%	7.4%	5.8%
CV (b)		5.4%	12.6%	14.5%	13.2%	9.3%	4.2%	3.0%	9.2%	10.4%

ns = not significant by F-test; * = significant by F-test ($P < 0.05$); ** = very significant by F-test ($P < 0.01$); d.f.= degrees of freedom; PH = plant height (cm); LP = number of leaves (blades plant^{-1}); BP = number of bulbs (bulb plant^{-1}); BD = bulb diameter (mm); Chl = leaf chlorophyll content (µg mL^{-1}); Crt = leaf carotenoid content (µg mL^{-1}); NSV = volume of nutrient solution used (L plant^{-1}); PW = plant weight (g plant^{-1}); BW = bulb weight per plant (g plant^{-1}); CV = coefficient of variation.

Table 2. Mean performance of shallot cultivars with Ni concentrations for various traits in shallot.

Treatments	PH	LP	BP	BD	PW	BW	NSV	Chl	Crt
Cultivars									
Lokananta	51.64	24.70	2.72b	93.05	52.65	45.29b	5.05	42.89	5.44
Sanren F1	51.51	36.76	4.30a	122.31	59.20	51.71a	5.22	38.88	5.56
$LSD_{0.05}$	ns	ns	0.25	ns	ns	4.94	ns	ns	ns
Ni supply (mg L^{-1})									
0.0	52.21	33.59	3.80	115.49	59.48a	51.78a	5.16a	39.00	5.37
0.025	52.46	30.87	3.56	107.15	59.28a	51.15a	5.31a	40.39	5.46
0.1	51.77	29.28	3.43	104.43	55.28a	47.69ab	5,16a	42.79	5.50
0.4	49.84	29.19	3.26	103.65	49.65b	43.38b	4.91b	41.36	5.67
$LSD_{0.05}$	ns	ns	ns	ns	6.51	6.32	0.12	ns	ns

Values with different letters in each row are significantly different according to the Least Significant Different test. PH = plant height (cm), LP = number of leaves (blades $plant^{-1}$), BP = number of bulbs (bulb $plant^{-1}$), BD = total bulb diameter per plant (mm), Chl = leaf chlorophyll content (µg mL^{-1}), Crt = leaf carotenoid content (µg mL^{-1}), NSV = volume of nutrient solution used (L $plant^{-1}$), PW = plant weight (g $plant^{-1}$), BW = bulb weight per plant (g $plant^{-1}$).

Table 3. Correlation between Ni supply on observed parameters and correlation among the parameters.

Traits	Ni-S	PH	LP	BP	BD	Chl	Crt	Ni-B	NO3-B	NSV	PW
PH	-0.896**	1									
LP	-0.185	0.098	1								
BP	-0.200	0.123	0.990**	1							
BD	-0.197	0.141	0.983**	0.981*	1						
Chl	0.218	-0.232	-0.830*	-0.843**	-0.873**	1					
Crt	0.785*	-0.576	0.204	0.232	0.245	-0.183	1				
Ni-B	0.963**	-0.907**	-0.186	-0.218	-0.225	0.364	0.704	1			
NO3-B	0.610	-0.498	0.203	0.134	0.223	0.049	0.661	0.685	1		
NSV	-0.709*	0.783*	0.434	0.497	0.507	-0.547	-0.141	-0.775*	-0.317	1	
PW	-0.742*	0.713*	0.748*	0.764*	0.773*	-0.748*	-0.257	-0.764*	-0.239	0.859**	1
BW	-0.671	0.670	0.754*	0.776*	0.806*	-0.809*	-0.147	-0.726*	-0.178	0.878**	0.984**

*, **: significant at ɑ 0.05 and ɑ 0.01, respectively, Ni-S = Nickel supply, PH = plant height, LP = number of leaves per plant, BP = number of bulbs per plant, BD = total bulb diameter per plant, Chl = total leaf chlorophyll content, Crt = leaf carotenoid content, Ni-B = bulb nickel content, NO3-B = bulb nitrate content, NSV = total nutrient solution usage per plant, PW = total plant weight, BW = bulb weight per plant.

attributes. Ni fertilization (0.025 mg L^{-1}) was not considerably different from the control in yield components. However, the higher Ni concentration (0.4 mg L^{-1}) remarkably reduced the total plant weight and bulb weight per plant (Table 2). With higher concentrations, Ni becomes toxic to shallot plants. The prevailing results are analogous to past findings in onions (Alibakhshi and Khoshgoftarmanesh, 2015) due to disrupting the enzymes involved in N metabolism, ultimately affecting plant yield (Rizwan *et al*., 2022).

The reduction in plant biomass can interlink with other traits, such as plant height, which tends to decrease with increasing Ni concentration (Table 3). Decreases in plant height can correlate with disruptions in plant metabolism and cell division (Patra *et al*., 2019; Pharmawati and Wrasiati, 2023). According to Manna *et al*. (2021), with high concentrations, Ni causes membrane damage due to an enhancement in reactive oxygen species (ROS), which, in turn, induces widespread physiological damage and cytotoxicity (Manna and Bandyopadhyay, 2023).

Furthermore, the increased Ni concentration enhanced the leaf carotenoid content (Table 3). Carotenoids typically have a positive role in increasing photosynthetic capacity and protecting plants under environmental stress conditions (Uarrota *et al*., 2018). Carotenoids function as antioxidants against reactive oxygen species (Havaux, 2014). However, this study observed a nonsignificant correlation between leaf carotenoid content and other parameters.

The Ni treatment significantly affected the nutrient usage volume (Table 1.). The higher Ni concentration significantly reduced plant uptake (Table 2), showing a positive correlation with the growth and yield attributes, such as plant height, plant weight, and bulb weight per plant (Table 3). A decrease in water uptake (volume of nutrient solution usage) can also inhibit plant growth and bulb yield due to disruptions in the plant's physiological processes. The Ni effect on water relation was highly concentration-dependent, and its higher concentration substantially decreased water, turgor, and osmotic potentials and relative water content (Jagetiya *et al*., 2013). Irrigation significantly affected the growth parameters of onion and subsequently influenced crop yield (Kumar *et al*., 2007). Furthermore, Kadayifci *et al*. (2005) findings revealed that onion plants were sensitive to a lack of soil water.

The increased Ni content positively correlated with Ni concentration in the nutrient solution in shallot bulbs (Table 3). The increased Ni content in the bulbs indicated that Ni is mobile in plant tissues. According to Brown (2006), plants can absorb Ni^{2+} using low and high-affinity transport systems at the higher and lower Ni concentrations in the solution, respectively. Ni has five valences, but only Ni^{2+} is available for plants (Liu *et al*., 2011). Plants can easily absorb Ni and translocate to different plant parts (Poulik, 1999). Furthermore, according to Soudek *et al*. (2009), transporting metals to other plant parts, especially bulbs, was lower in *Allium* species.

Correlation and path analyses

Selecting cultivars tolerant to heavy metal stress and high-yield potential is an essential component in crop production (Rabinowitch, 2021). High yield closely interlinked with the genetic potential of genotypes deal with environmental stress conditions. The shallot hybrid Sanren F1 produced significantly better yield attributes than Lokananta (Table 2). In previous research, Saidah *et al*. (2019) found similar results for the Sanren cultivar compared with Lokananta in shallots. Bulb weight per plant as a main component in shallot crop production revealed significant positive correlations with the number of leaves, bulbs, and total bulb diameter per plant (Table 3). The number of leaves per plant determines the photosynthetic capacity, while the number of bulbs determines the aggregation ability of the plant (Azis *et al*., 2017; Pangestuti *et al*., 2022). However, the total bulb diameter occurs from the amount of photosynthate translocated from the leaves to the storage organs.

The attributes of nutrient solution used meaningfully correlated positively to the shallot's yield components (Table 3). Higher yield can interlink with water usage of cultivars. Irrigation levels at 75% available soil moisture resulted in higher bulb yields and mean bulb weight of two local shallot cultivars compared with irrigation at 50% and 25% (Woldetsadik *et al*., 2003). Based on the path analysis, the total bulb diameter per plant attribute had the maximum direct effect on bulb weight per plant through an increase in the total nutrient solution use per plant (Table 4).

Table 4. Path analysis of shallot growth and yield traits with bulb yield per plant.

Traits	Direct effect	Indirect effects					Total effect
		PH	LP	BP	BD	NSV	
PH	0.326		0.016	-0.045	0.111	0.262	0.670
LP	0.165	0.032		-0.364	0.776	0.145	0.754
BP	-0.368	0.040	0.164		0.774	0.166	0.776
BD	0.789	0.046	0.163	-0.361		0.169	0.806
NSV	0.334	0.255	0.072	-0.183	0.400		0.878
Residual	0.114						
R2	0.89						

CONCLUSIONS

Increasing Ni concentration in the nutrient solution negatively affected the growth and yield in shallots. The Ni concentration at 0.025 mg L^{-1} appears as the best treatment without significantly reducing bulb size and can serve as a safe limit of Ni concentration in shallot production. Higher Ni concentration (0.4 mg L^{-1}) significantly reduced bulb weight and total plant weight.

REFERENCES

Adin A, Firdaus R, Haerudin H, Rokhman F, Harpenas A (2022). A review: TSS (true shallot seed) development in Indonesia and its health benefit. *Adv. Biol. Res.* 23: 208–223.

Afify RRM, El-Nwehy SS (2023). Nano fertilizers with algae extract as biostimulant affecting growth, bulb yield, and quality of onion. *SABRAO J. Breed. Genet*. 55(6): 2128-2139. http://doi.org/10.54910/ sabrao2023. 55.6.24.

Al-Bayati AS, Turk HAM, Al-Tufaili AKH, Aboohanah MA, Mohan RK, Qader HM (2023). Characterization of green onion with npk fertilization and foliar application of hornwort extract. *SABRAO J. Breed. Genet*. 55(6): 2140-2148. http://doi.org/10.54910/ sabrao2023.55.6.25.

Alibakhshi M, Khoshgoftarmanesh AH (2015). Effects of nickel nutrition in the mineral form and complexed with histidine in the nitrogen metabolism of onion bulb. *J. Plant Growth Regul.* 75: 733–740.

Alibakhshi M, Khoshgoftarmanesh AH (2016). The effect of nickel supply on bulb yield, urease and glutamine synthetase activity and concentrations of urea, amino acids and nitrogen of urea-fed onion plants. *Arch. Agron. Soil Sci.* 62(1): 37–51.

Annisa BA, Sulistyaningsih E, Pangestuti R (2022). Growth and yield of shallot (*Allium cepa* L. Aggregatum group) affected by transplanting age and varieties of TSS. *Adv. Biol. Res.* 23: 348–356.

Askari-Khorasgani O, Pessarakli M (2019). Agricultural management and environmental requirements for production of true shallot seeds – a review. *Adv. Plants Agric. Res.* 9(2): 318–322.

Azis FN, Budiono R, Zunaini SS (2017). Variation and traits relationship among yield component for shallot cv. super Philip in nine different soil fertilizer. *Agrin* 21(1): 11–16.

Brown PH (2006). Nickel. In: A.V. Barker and D.J. Pilbeam (Eds.). Plant Nutrition. 1st edition. Boca Raton: CRC Press, pp. 411–426.

Bugbee B (2004). Nutrient management in recirculating hydroponic culture. *Acta Hortic.* 648: 99–112.

Cakmak I, Brown P, Colmenero-Flores JM, Husted S, Kutman BY, Nikolic M, Rengel Z, Schmidt SB, Zhao FJ (2023). Micronutrients. In: Z. Rengel, I. Cakmak, P.J. White (Eds.). Marschner's Mineral Nutrition of Plants. 4th Ed., San Diego, Academic Press, pp. 283–385.

Faried M, Syam'un E, Mantja K (2023). Survival rate, disease incidence, and yield of shallots by seed priming and application of *Tithonia* compost enriched with *Gliocladium virens*. *Int. J. Life Sci. Agric. Res.* 2(5): 57–62.

Freitas DS, Rodak BW, dos Reis AR, Reis FD, de Carvalho TS, Schulze J, Carneiro MAC, Guilherme LRG (2018). Hidden nickel deficiency? nickel fertilization via soil improves nitrogen metabolism and grain yield in soybean genotypes. *Front. Plant Sci.* 9: 614. https://doi.org/10.3389/ fpls.2018.00614.

Gheibi MN, Malakouti MJ, Kholdebarin B, Ghanati F, Teimouri S, Sayadi R (2009). Significance of nickel supply for growth and chlorophyll content of wheat supplied with urea or ammonium nitrate. *J. Plant Nutr.* 32(9): 1440–1450.

Havaux M (2014). Carotenoid oxidation products as stress signals in plants. *Plant J.* 79: 597–606. https://doi.org/10.1111/tpj.12386.

Indonesian Directorate General of Horticulture (2021). Strategic Plan of the Directorate General of Horticulture 2020-2024. Available online: https://hortikultura. pertanian.go.id/rencana-strategis-2/ (Accessed on March 25, 2023).

Jagetiya B, Soni A, Yadav S (2013). Effect of nickel on plant water relations and growth in green gram. *Indian J. Plant Physiol.* 18: 372–376.

Kadayifci A, Tuylu Gİ, Ucar Y, Cakmak B (2005). Crop water use of onion (*Allium cepa* L.) in Turkey. *Agric. Water Manag.* 72(1): 59–68.

Kratky BA (2010). A suspended net-pot, non-circulating hydroponic method for commercial production of leafy, romaine, and semi-head lettuce. *Veg. Crops* 1: 1–19.

Linchtenthaler HK, Wellburn AR (1983). Determinations of total carotenoids and chlorophylls a and b of leaf extracts in different solvents. *Biochem. Soc. Trans.* 11(5): 591–592.

Liu G, Simonne EH, Li Y (2011). Nickel nutrition in plants. Available online: https://edis.ifas.ufl.edu/ publication/hs1191 (Accessed on March 25, 2023).

Manna I, Bandyopadhyay M (2023). Differential expression of nickel toxicity on *Allium cepa* L. seeds and seedlings. *Int. J. Environ. Sci. Technol*. 20(10): 11321–11340.

Manna I, Sahoo S, Bandyopadhyay M (2021). Effect of engineered nickel oxide nanoparticle on reactive oxygen species–nitric oxide interplay in the roots of *Allium cepa* L. *Front. Plant Sci*. 12: 586509.

Pangestuti R, Sulistyaningsih E (2011). Potential use of true seed shallot (TSS) as a source of shallot seed in Indonesia. *Proceed. Nat. Workshop* 14: 258--266.

Pangestuti R, Sulistyaningsih E, Kurniasih B, Murti RH (2022). Bulb aggregation and productivity of shallots (*Allium cepa* L. Aggregatum group) originating from seeds. Available online: https://etd.repository. ugm.ac.id/penelitian/detail/218787 (Accessed on January 10, 2024).

Patra A, Dutta A, Jatav SS, Choudhary S, Chattopadhyay A (2019). Horizon of nickel as essential to toxic element. *Int. J. Chem. Stud.* 7(2): 1185–1191.

Pharmawati M, Wrasiati LP (2023). Chromosomal and nuclear alteration induced by nickel nitrate in the root tips of *Allium cepa* var. Aggregatum. *Pollution* 9(2): 702–711.

Porra RJ, Thompson WAA, Kriedemann PE (1989). Determination of accurate extinction coefficients and simultaneous equations for assaying chlorophylls a and b extracted with four different solvents: Verification of the concentration of chlorophyll standards by atomic absorption spectroscopy. *Biochim. Biophys. Acta* 975(3): 384–394.

Poulik Z (1999). Influence of nickel contaminated soils on lettuce and tomatoes. *Sci. Hortic.* 81(3): 243–250.

Rabinowitch HD (2021). Shallot (*Allium cepa* L. Aggregatum group) Breeding. In: J.M. Al-Khayri, S.M. Jain, D.V. Johnson, (Eds.). Advances in Plant Breeding Strategies: Vegetable Crops. Cham: Springer, pp. 99–154.

Randle WM (2000). Increasing nitrogen concentration in hydroponic solutions affects onion flavor and bulb quality. *J. Am. Soc. Hortic. Sci.* 125(2): 254−259. https://doi.org/10.21273/JASHS.125.2.254.

Rizwan M, Usman K, Alsafran M, Jabri HA, Samreen T, Saleem MH, Tu S (2022). Nickel toxicity interferes with NO3−/NH4+ uptake and nitrogen metabolic enzyme activity in rice (*Oryza sativa* L.). *Plants* 11(11): 1401.

Saidah S, Muchtar M, Syafruddin S, Pangestuti R (2019). Growth and yield of two shallot varieties from true shallot seed in Sigi District, Central Sulawesi. *Pros. Sem. Nas. Masy. Biodiv. Indon.* 5(2): 213−216.

Saptana, Gunawan E, Perwita AD, Sukmaya SG, Darwis V, Ariningsih E, Ashari (2021). The competitiveness analysis of shallot in Indonesia: A policy analysis matrix. *PLoS One* 16(9): e0256832. https://doi.org/ 10.1371/journal.pone.0256832

Soudek P, Kotyza J, Lenikusová I, Petrová Š, Benešová D, Vaněk T (2009). Accumulation of heavy metals in hydroponically cultivated garlic (*Allium sativum* L.), onion (*Allium cepa* L.), leek (*Allium porrum* L.) and chive (*Allium schoenoprasum* L.). *J. Food Agric. Envion.* 7(3): 761–769.

Syam'un E, Yassi A, Jayadi M, Sjam S, Ulfa F (2017). Improving shallot productivity through the use of seeds as seedlings. *J. Din. Peng.* 2(2): 188–193.

Tabatabaei SJ (2009). Supplements of nickel affect yield, quality, and nitrogen metabolism when urea or nitrate is the sole nitrogen source for cucumber. *J. Plant Nutr.* 32(5): 713–724.

Tan XW, Ikeda H, Oda M (2000). Effects of nickel concentration in the nutrient solution on the nitrogen assimilation and growth of tomato seedlings in hydroponic culture supplied with urea or nitrate as the sole nitrogen source. *Sci. Hortic.* 84(3-4): 265–273.

Tori H, Dyanasari, Kholil AY (2023). Prospect analysis of onion (*Allium cepa* L.) production in Indonesia. *Int. J. Agric. Environ. Anal.* 2(1): 1–14. https://doi.org/10.55927/ ijaea.v2i1.2705.

Uarrota VG, Stefen DLV, Leolato LS, Gindri DM, Nerling D (2018). Revisiting carotenoids and their role in plant stress responses: From biosynthesis to plant signaling mechanisms during stress. In: D.K. Gupta, J.M. Palma, and F.J. Corpas (Eds.). Antioxidants and Antioxidant Enzymes in Higher Plants. Cham: Springer, pp. 207–232.

Woldetsadik K, Gertsson U, Ascard J (2003). Shallot yield, quality and storability as affected by irrigation and nitrogen. *J. Hortic.* 78(4): 549–553.

Zhang K, Li S, Xu Y, Zhou Y, Ran S, Zhao H, Huang W, Xu R, Zhong F (2022). Effect of nickel ions on the physiological and transcriptional responses to carbon and nitrogen metabolism in tomato roots under low nitrogen levels. *Int. J. Mol. Sci.* 23(19): 11398. https://doi.org/10.3390/ ijms231911398.