DOI: 10.47349/jbi/20012024/1 Jurnal Biologi Indonesia 20(1): 1-8 (2024)

Seed Germination and Evaluation of Vegetative Growth of Pak Choi (*Brassica rapa* subsp. chinenis L. Hanelts)

Perkecambahan Benih dan Evaluasi Pertumbuhan Vegetatif Pak Choi (*Brassica rapa* subsp. chinenis L. Hanelts)

Emyra Deska Rizki Utami[1], Reni Indrayanti[1*], Adisyahputra[1], & Ekaputri Azrai[2],

[1]Study Program of Biology, Universitas Negeri Jakarta.
[2]Study Program of Biology Education, Universitas Negeri Jakarta.
[*]Corresponding author: indrayantireni.unj@gmail.com

Received: January 2023, **Accepted:** January 2024

ABSTRACT

Pak choi is a group of plants in the mustard family. The production factors affecting pak choi cultivation are seeds, nutrients, and pesticides. This study aimed to (1) test the seed viability and vigor of two pak choi cultivars and (2) determine the effect of different cultivars on the growth and yield of pak choi plants. The plant cultivars used in this study are 'Brisk Green' and 'Nauli'. Viability and vigor testing of two pak choi cultivars showed no significant differences between pak choi cultivar 'Brisk Green' and cultivar 'Nauli' in the viability of seeds, with the percentage of Maximum Growth Potential (MGP) being 95.5 and 97.0%. Germination Potential (GP) was 86.5 and 84.0%. The vigor of seeds showed that the Seed Vigor Index (SVI) was 84.5 and 81.5%, and the Speed of Gemination (SG) was 12.4 and 12.0% at 5-7 days after sowing. Evaluation of plant growth showed that Pak choi cv. 'Nauli' has the highest number of leaves and fresh weights than 'Brisk Green', and it showed more resistance to watery soft rot due to the fungus of *Sclerotinia sclerotiorum*. This experiment also showed that growing plants in the indoor hydroponic planting system could be prospective for developing pak choi plants.

Keywords: 'brisk green' cultivar, nauli, viability testing, vigour testing

ABSTRAK

Pak choi adalah kelompok tumbuhan dalam keluarga sawi. Faktor produksi yang mempengaruhi budidaya pak choi adalah benih, nutrisi, dan pestisida. Tujuan penelitian ini adalah untuk (1) menguji viabilitas dan vigor benih dua kultivar pak choi; (2) mengetahui pengaruh perbedaan kultivar terhadap pertumbuhan dan hasil tanaman pak choi. Kultivar tanaman yang digunakan dalam penelitian ini adalah cv 'Brisk Green' dan 'Nauli'. Uji viabilitas dan vigor kedua kultivar pak choi menunjukkan bahwa tidak terdapat perbedaan yang nyata antara pak choi cv. 'Brisk Green' dan cv. 'Nauli' dalam viabilitas benih yang ditunjukkan pada Potensi Pertumbuhan Maksimum (PTM) sebesar 95,5 dan 97,0%, Daya Berkecambah (DB) sebesar 86,5 dan 84,0%. Uji vigor benih menunjukkan bahwa Indeks Vigor (VI) sebesar 84,5 dan 81,5%, dan Kecepatan Tumbuh (K_{CT}) sebesar 12,36 dan 12,00%. pada 5-7 hari setelah tanam. Evaluasi pertumbuhan tanaman menunjukkan bahwa cv. 'Nauli' memiliki jumlah daun dan bobot segar tertinggi dibandingkan 'Brisk Green', dan lebih tahan terhadap busuk lunak berair akibat jamur *Sclerotinia sclerotiorum*. Penelitian ini juga menunjukkan bahwa menanam tanaman dengan sistem tanam hidroponik dalam ruangan sangat prospektif untuk dikembangkan pada tanaman pak choi.

Kata Kunci: 'brisk green' cultivar, 'nauli', viabilitas, uji vigor

INTRODUCTION

Pak choi or Pak Choy (*Brassica rapa* subsp. Chinensis (L.) Hanelt) is an oriental vegetable widely consumed in Asia. Pak choi is a group of vegetable plants in the mustard family (Brassicaceae), consisting of various widely cultivated species, including mustard cabbage, celery cabbage, and Choi sum (Chinese flowering cabbage). This variety is headless and has green leaf blades with a lighter bulbous underside. In Indonesia, Chinese cabbage (mustard family) productivity are 727 467,00 ton (2021) and 760 608,00 ton (2022), with a growth rate from 2022 to 2021 is 4.55% (SI 2023). The availability of mustard greens per capita increased from 1.006 (kg/capita/year) in 2019 to 1.054 (kg/capita/year) in 2020 (SFC 2020).

Production factors that affect mustard cultivation are seeds, fertilizer or nutrients, and pesticides. Especially for cities, where crop production is far away from agricultural production centers, alternative agriculture systems, such as landless cultivation, can

help provide a food supply (Roulphael *et al.* 2017; Storck *et al.* 2019). One of the alternative systems is growing plants, typically in large indoor farms. It is such as hydroponic, aquaponic, or aeroponic systems, which are vertically stacked (Despommier 2013; Khan *et al.* 2018; Sharma *et al.* 2019; Storck *et al.* 2019). Vertical farming has several advantages, such as reduced agricultural land use and increased crop growth and yield. It also reduces pesticides and fertilizers, reducing water consumption because of water recirculation (Touliatos *et al.* 2016). Plants grown in hydroponic systems can reach 20–25% higher crop yields and 2-5 times higher productivity than in land-based systems (Gashgari *et al.* 2018). Many researchers have developed a hydroponic system in greenhouses to increase the production of vegetable crops, including pak choi plants (Istiqomah *et al.* 2016; Bahzar & Santosa 2018:), water spinach (Sholihat *et al.* 2018), and cucumbers (Gashgari *et al.* 2018).

Various pak choi cultivars are already on the commercial market in Indonesia. Some are registered in the Ministry of Agriculture, such as the 'Nauli' cultivar. The quality of the seed cultivar has passed seed certification. The 'Brisk Green' cultivar is sold commercially but not yet registered with the Ministry of Agriculture. Hydroponic planting systems consist of two techniques: (1) the solution culture method and (2) the media culture method (Khan *et al.* 2018). The solution culture method is known as the solution hydroponic method. The plant roots are soaked directly in the nutrient solution (Nguyen *et al.* 2016, Khan *et al.* 2018). The type of nutrient solution is another important factor in increasing vegetable production. AB mixed solution used in hydroponic cultivation as pak choi nutrition significantly produces more leaves than other nutrients such as NPK solution and complete compound nutrition (Sesanti & Sismanto 2016). Since open land in Indonesia is limited, indoor hydroponic systems are an alternative technique to increase pak choi productivity. The use of cultivars and the proper nutrition to support the vegetative growth of pak choi needs to be developed. This research aimed to determine the effect of the pak choi cultivar and types of nutrients on germination and plant growth and development of pak choi.

MATERIAL AND METHOD

The research method used in this study is the experimental method with a Completely Randomized Design (CRD). The treatments tested were seeds from pak choi cv. 'Brisk Green' and cv. 'Nauli'. The nutrients used are half-strength Murashige and Skoog medium (½ MS) and AB mixture. The seeds used in this experiment were 200 seeds for each treatment. Pak choi seeds are grown in a ½ MS nutrient solution, and then the seeds are grown in an AB mix solution. The material used in this study is Rockwool, hydroponic tools, a sprayer, a measuring cup, an aerator, digital analytics, pH meter, and a TDS meter. The material used is seed pak choi cv. 'Brisk Green' and cv. 'Nauli', nutrition ½ MS, nutrient AB mix Hydro J, aquadest, Sodium hypochlorite.

The viability and vigor seeds test of pak choi Cultivar was determined by germinating seeds on paper rice straw and using the top of the paper method. Each treatment used was 200 seeds (Rao *et al.* 2006). The seeds were sterilized in 10 % sodium hypochlorite 10% for 10 minutes, rinsed with distilled water 3 (three) times, and soaked in warm water for 15 minutes. The seed germinates on a wet sheet of paper rice straw and is placed in a dark room for 2 (2) weeks. Germination of seedlings was observed for abnormal and normal sprouts (Sajad 1993; Tefa 2017).

Sterilized seeds of pak choi cv. 'Brisk Green' and cv. 'Nauli' were germinating in a 2.5 x 2.5 cm Rockwool media. The seedling container is covered with black cloth and placed in a dark room for 1-4 days until the seeds germinate. Germinating seeds are then placed in a light room to prevent etiolation. After 14 days, the pak choi seedling was transferred to a hydroponic system containing ½ MS nutrition and to AB mix.

Preparation of stock solutions for half-strength Murashige and Skoog nutrition consists of macro and micronutrients, vitamins, and myoinositol. AB mix nutrition, stock A solution (Calcium Nitrate, Potassium nitrate, Fe EDTA) and stock B solution (Potassium dihydro phosphate, Ammonium sulfate, Potassium sulfate, Magnesium Sulphate, Cupri sulfate, Zinc Sulphate, Boric acid, Manganese Sulphate, Ammonium hepta molybdate) are dissolved in 500 mL distilled water (Istiqamah,

2016). The concentration of the two stock solutions, A and stock B, combined by mixing as much as 5 mL per stock solution in a 1-liter aquadest

Pak choi seedling is carried out in a solution of ½ MS until nine weeks after planting, and after that, the plants are transferred to AB mix solution up to 18 weeks after planting. Data parameters observed increased plant height and leaves at nine weeks after planting.

The plant growth of pak choi was evaluated in the vegetative phase at 8 to 18 weeks after planting. The plant was grown at a hydroponic system at room temp 20 ^{0}C – 25 ^{0}C with 24-hour LED.

The effects of type of cultivar and nutrients on germination percentages were analyzed by (Sajad 1993; Tefa 2017)

$$\text{MGP (\%)} = \frac{\sum germinated\ seeds}{\sum seeds\ planted} \text{ x } 100\%$$

Germinate Potensial (GP). Gemination potential are the ability of seeds to germinate. Germination potential is calculated based on the percentage of normal sprouts on the first to the last observation, calculated by:

$$\text{GP (\%)} = \frac{\sum NS\ day\ 5 + \sum NS\ day\ 6 + \sum NS\ day\ 7}{\sum seeds\ planted} \text{ x } 100\%$$

Vigor Index (VI). The vigor index is calculated based on the percentage of seeds that grow normally on the first observation (day 5):

$$\text{VI (\%)} = \frac{\sum\ normal\ sprouts\ day\ 5}{\sum seeds\ planted} \text{ x } 100\%$$

$$\text{PGR (\%)} = \sum_0^{tn} \frac{N}{t}$$

Notes:

N= % normal sprouts every day of observation; *t* = observation time; *tn* = final observation time

Quantitative and qualitative parameters observed in the vegetative phase are plant height, number of leaves, length, and width of leaves, and plant fresh weight. Mean values were compared using the Duncan Multiple Range Test (DMRT) of the 5% level significance to compare the treatment differences.

RESULT

Evaluation of Plant Growth of Pak Choi at Indoor Hydroponic Systems

Evaluation of plant growth of pak choi was observed on plant height and the number of leaves. The pak choi plant height observation showed a significant difference between the two cultivars 8-9 weeks after planting (Table 2). The average plant height of pak choi cv. 'Brisk Green' (12.73 cm ± 0.32) is markedly higher than cv. 'Nauli' (11.29 cm ± 0.20) at 9 weeks after planting, but there is no significant difference at 10 -12 weeks after planting. The observation of leaf numbers at both cultivars showed a significant difference at 8-12 weeks after planting. The average number of leaves is highest at pak choi cv. 'Nauli' (19.04 leaves ± 0.57) than cv. 'Brisk Green' (15.20 ± 0.44) at 12 weeks after planting (Table 3). According to Sarido & Junia (2017), the number of pak choi leaves at 6.5 weeks after planting ranges from 10.03 – to 11.09. In lettuce, the number of leaves per plant is related to either cultivar characteristics or the composition of the nutrition solution (Sapkota *et al.* 2019). The difference in the number of leaves between the two cultivars is related to differences in genetic information on each seed. Each plant variety will produce different proteins in quality and quantity and affect plant metabolism, resulting in plant growth and development diversity**.**

Evaluation of agronomic characters of pak choi at the harvest

Evaluation of the agronomic characteristics of the plant at 18 weeks after planting showed significant differences between the two different cultivars. Pak choi cv. 'Nauli' produced a higher number of leaves (26.83 leaves ± 0.98) and plant fresh weight (68.05 gr ± 5.19) but have a lower plant height (21.27 cm ± 0.56) compared to cv. 'Brisk Green' (Table 4). The number of leaves at pak choi cv. 'Nauli' is highest compared to pak choi cv. 'Green Fortune' (20.33 leaves), cv. 'Tai Sai' (13.67 leaves), cv 'Pak Choi Green' (20.67 leaves), and 'Dwarf Canton White' (19 leaves) are growing in the autumn season in the field of Turkey province (Balkaya *et al.* 2018).

Symptoms of Disease in Pak Choi Plants

Seeds sharing the same genotype can vary in the vigor related to the environment where they are developed and harvested, and each seed has its characteristics (Finch-Savage & Bassel 2016). In this research, pak choi was growing with an indoor hydroponic system to reduce plant risk of soil-borne diseases. However, 4 (four) of pak choi plants cv. 'Brisk Green' (8.1%) showed symptoms of the disease 16-18 weeks after planting. Symptoms appear in the form of white fungal mycelia at the basal of the stem.

DISSCUSSION

Germination of Pak choi cv. 'Brisk Green' and 'Nauli'

Seed germination is a process that commences with water absorption by quiescent dry seed and ends with the emergence of the embryonic axis (Bewley 1997). The germination of pak choi seeds was evaluated from the seed viability and vigor testing. Seed viability is the ability of seeds to germinate in suitable conditions (Bradbeer 1988). Seed viability is expressed as the percentage of germination seed and determined in the standard germination test. In this study, the germination percentage of the two cultivars tested was above the standard minimum of germination (95.5-97.0%) (Table 1). The International Standards for Genebanks define seeds as viable when germination reaches 90% (Rao *et al.* 2006).

Seed vigor is the sum of those properties that determine the activity and performance of seed lots of acceptable germination under various field conditions (ISTA 2015; Milosevic *et al.* 2010; Venter 2001). Seedling vigor is an index of how well a seed will establish seedlings (Finch-Savage & Bassel 2016). According to Basu & Groot (2023), larger seeds have higher seed vigor than smaller and lighter seeds. Pak choi cv. 'Brisk Green' and cv. 'Nauli' has a Vigor Indeks Index of 81.5 and 84.5%. Seeds with a higher percentage of seed vigor index are considered more vigor and can be stored well for a longer time without losing their germination ability compared to seeds with low vigor (Basu & Groot 2023). According to viability and vigor testing of pak choi, it is concluded that both cultivars have the same seed viability and vigor, although the phenotypic of pak choi seeds showed that pak choi seed of cv. 'Brisk Green' has a smaller seed size than cv. 'Nauli' (Figure 1).

Table 1. Viability and vigor testing (percentage) of pak choi cv. 'Brisk Green' and cv. 'Nauli' at 5 – 7 days after sowing.

Cultivar	MGP (%)	± SE	GP (%)	± SE	VI	± SE	SP	± SE
'Brisk Green'	95.50[a]	0.75	86.50[a]	1.25	84.50[a]	1.50	12.36[a]	0.18
'Nauli'	97.00[a]	0.75	84.00[a]	1.25	81.50[a]	1.50	12.00[a]	0.18

Notes: Mean with a different letter within each cultivar are significantly different at the 5% level significance according to the Duncan Multiple Range Test (DMRT). MGP = Maximum Groth Potential; GP = Germiination Potential, VI = Vigor Indez, SP = Speed of Germination.

Table 2. The average height of pak choi cv. 'Brisk Green' and 'Nauli' at 8 - 12 weeks grows in indoor hydroponyc system.

Cultivar	The average plant height (cm) at age (weeks after planting)									
	8 weeks		9 weeks		10 weeks		11 weeks		12 weeks	
	Average	±SE	Average	±SE	Average	±SE	Average	±SE	Average	±SE
'Brisk Green'	11.08[a]	0.32	12.73[a]	0.32	14.72[a]	0.38	15.36[a]	0.36	17.52[a]	0.60
'Nauli'	9.13[b]	0.26	11.28[b]	0.29	13.94[a]	0.40	15.02[a]	0.37	17.19[a]	0.40

Notes: Mean with a different letter within each treatment (cultivars) are significantly different at the 5% level according to the Duncan Multiple Range Test (DMRT)

Evaluation of Plant Growth of Pak Choi at Indoor Hydroponic Systems

Plant growth is evaluated on pak choi sprouts 8 to 12 weeks after planting. These are equal to the period time of harvest of pak choi plants (Figure 2). According to Tuquero *et al.* (2018), harvesting standards in pak choi range from 5 to 8 weeks after planting. Plant growth increases the size, volume, or mass of cells or organs, irreversible cell division, and cell expansion (Brukhin & Morozova 2011).

Figure 1. Seed of pak choi cv. 'Brisk Green' (a) and cv. 'Nauli' (b)

Observation of plant height of cv. 'Brisk Green' (17.52 cm) and cv. 'Nauli' (17.19 cm) at 12 weeks after planting showed no significant difference between the two cultivars (Table 2), but this result was relatively lower than pak choi cv. Flamingos grown in AB mixed with a hydroponic system in a greenhouse produced an average plant height of 13.89 cm five weeks after planting (Bahzar and Santosa 2018).

According to Finch-Savage & Bassel (2016), seedlings are sensitive to the availability of water measured as water potential (MPa) and the influence of solutes (osmotic potential). If the concentration of the solution exceeds the concentration scale, then the nutrient solution will have a more negative osmotic potential. Cells become plasmolysis due to the nutrients in the media being higher than an inside cell. In this study, transferring plants from half-strength Murashige and Skoog (MS) to AB mix are suitable nutrients for indoor hydroponic

Table 3. The average number of leaves of pak choi cv. 'Brisk Green' and 'Nauli' at grows in indoor hydroponyc system.

Cultivar	The number of leaves at age (weeks after planting):									
	8 weeks		9 weeks		10 weeks		11 weeks		12 weeks	
	Average	±SE	Average	±SE	Average	±SE	Average	±SE	Average	±SE
'Brisk Green'	8.92[a]	0.26	10.20[a]	0.29	12.24[a]	0.28	13.60[a]	0.32	15.20[a]	0.44
'Nauli'	11.84[b]	0.28	13.76[b]	0.36	16.16[b]	0.44	17.44[b]	0.64	19.04[b]	0.57

Note: Mean with a different letter within each treatment (cultivars) are significantly different at the 5% level according to the Duncan Multiple Range Test (DMRT)

Table 4. Characteristics of pak choi cv. 'Brisk Green' and cv. 'Nauli' at the harvest 18 weeks after planting.

Pak choi Cultivar	Number of leaves		Plant height (cm)		Leaf length (cm)		Leaf Width (cm)		Plant fresh weight (gr)	
	Average	±SE	Average	±SE	Average	±SE	Average	±SE	Average	±SE
Bisk Green	20.72[a]	0,052778	24.31[b]	01.06	12.65[a]	0,06	8.86[a]	00.54	45.50[a]	06.50
'Nauli'	26.83[b]	0,068056	21.27[a]	00.56	13.48[a]	00.43	8.14[a]	00.26	68.05[b]	05.19

Note: Mean with a different letter within each treatment (cultivars) are significantly different at the 5% level according to the Duncan Multiple Range Test (DMRT)

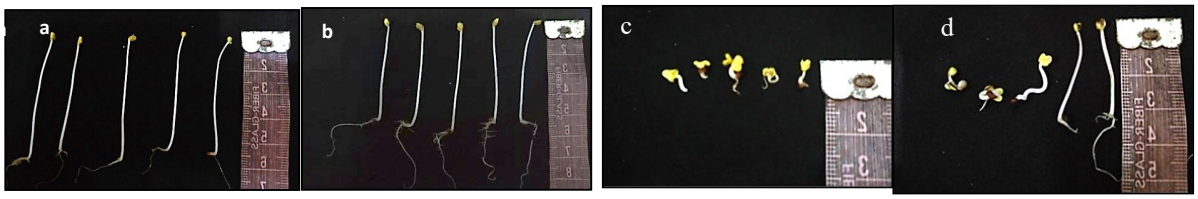

Figure 2. Germination of pak choi seed at 4 days after sowing (a) a normal sprouts in cv. 'Brisk Green', (b) cv. 'Nauli', and (c) an abnormal sprouts in cv. 'Brisk Green', (d) abnormal sprouts in cv. 'Nauli'

cultivation systems. According to Sublett *et al.* (2018), hydroponic nutrients are the main factors that affect plant growth and biomass production.

Evaluation of agronomic characters of pak choi at the harvest

Evaluation of the agronomic characteristics of the plant at 18 weeks after planting showed (Figure 3). Pak choi cv. 'Nauli' produced more leaves and plant fresh weight but had a lower plant height than cv. 'Brisk Green' (Table 4). Plant cultivars that can absorb and have more efficient nutrient metabolism can produce more leaves. Pak choi cv. 'Nauli' has larger seeds than cv. 'Brisk Green' (Figure. 1). Vegetable plants with smaller seeds are often unpredictable in the emergence of seed radicles, which can interfere with planning production schedule (Fince-Savage and Bassel 2016). Shoot apical meristem (SAM) is also responsible for plant cell extension (Crang *et al.* 2018; Brukhin & Morozova 2011).

Water uptake, nutrients, and photosynthate products affect the plant's fresh weight. It also increases the mass and size of plant cells (Souza & Fargundes 2014). Photosynthesis occurs in the leaf, producing carbohydrates that translocate throughout the plant. The number of leaves, length, and width of the leaves also play a role in the photosynthate product. In this research, there were significant differences in the number of leaves and fresh plant weight, but there were no significant differences in the leaf length and width of the leaves of both cultivars (Table 4). Pak choi cv. 'Nauli' has a higher number of leaves and plant fresh weight; this cultivar is predicted to have more efficient nutrient metabolism. However, these cultivars' leaf length and width are shorter than in cultivars Green Fortune, Dwarf Cantoon White, Pak Choi Green, and Tai Sai (Balkaya *et al.* 2018). According to Weraduwage *et al.* (2015), the growth in leaf area and its relationship to biomass accumulation depend on how carbon is distributed between the new leaf area, leaf mass, root mass, reproductive organs, and respiration processes. In the vegetative phase, there is an increasing mass and volume of plant organs such as roots, stems, and leaves (Huijser & Schmid 2011). According to Fraile *et al.* (2017), the growth and quality of lettuce in a hydroponic system conclude that leaf size is highly dependent on nutrient composition, water availability, and temperature.

Symptoms of Disease in Pak choi Plants.

Observation of plant growth on an indoor hydroponic system showed that 8.1% of plants die because of pathogens. Symptoms appear 16 weeks after planting. Plant stems infected showed rot, which seems to inhibit nutrient translocation, so that the pak choi stems dry out, necrosis, and experience death. Based on the visible symptoms, the fungus that infects the base of the Pak choi stem is suspected to be *Sclerotinia sclerotiorum* (soft, watery rot). *Sclerotinia sclerotiorum* is a fungal plant pathogen that causes necrosis in Brassica species (Rahmanpour *et al.* 2011). It shows that even though plants are growing in indoor hydroponic systems, plants being infected by pathogens is still possible**.**

CONCLUSION

Seed germination of Pak Choi (*Brassica rapa* subsp. Chinensis (L.) Hanelt) showed that pak choi cv. 'Brisk Green' and cv. 'Nauli' has the same seed viability and vigor according to the percentage of Maximum Growth Potential,

Figure 3 a. Representative figure characteristics of pak choi cv. 'Brisk Green' (a); and cv. 'Nauli' (b) at 18 weeks after planting

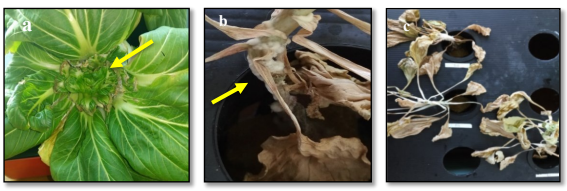

Figure 3b. Symptoms on pak choi cv. 'Brisk Green' at the age of 16 weeks after planting: (a) fungus infection in young leaves, (b) necrosis of the base of the fungus pak choi infected with fungus, (c) pak choi died at 16 weeks after planting.

Germination Potential, Vigor Index, and Speed of Germination. Evaluation on plant growth of pak choi cv. 'Nauli' produces a higher number of leaves and fresh weights. This experiment also shows that plants grown in indoor hydroponic growing systems are prospective to be developed for pak choi cultivars.

AUTHOR CONTRIBUTOR

EDRU collected and analized the data, wrote draft the manuscript, RI. designed the research, wrote the manuscrip and supervised all the process, A., EP. supervised the process

REFERENCES

Bahzar, MA., & M. Santosa. 2018. Pengaruh nutrisi dan media tanam terhadap pertumbuhan dan hasil tanaman pak choi (*Brassica rapa* L. var. *Chinensis*) dengan Sistem Hidroponik Sumbu, *Jurnal Produksi Tan*anaman 6(7), 1273-1281. ISSN: 2527-845.

Balkaya, A., O. Aydin, & SM. Dogru. 2018. The adaptation of pak choi (*Brassica rapa* var. *Chinensis*) cultivars in Samsun Province, Turkey. ISHS. *Acta Horticulture*. 1202. 55-61. http://dx.doi.org/10.17660/ActaHortic.2018.1202.8

Basu, S., & S.P.C Groot. 2023. Seed Vigour and Invigoration. *In*: Dadlani, M., Yadava, D.K. (eds) Seed Science and Technology. Springer, Singapore. https://doi.org/10.1007/978-981-19-5888-5_4.

Bewley, JD. 1997. Seed Germination and Dormancy. *The Plant Cell*. 9, 7, 1055-1066.

Bradbeer, JW. 1988. Seed Dormancy and Germination © Blackie and Son Ltd 1988

Brukhin, V. N., & Morozova. 2011. Plant Growth and Development - Basic Knowledge and Current Views. *Mathemathic Modell. of Natural. Phenom.* 6(02), 1-53 https://doi.org/10.1051/mmnp/20116201.

Crang, R., S.L-Sobaski, & R. Wise. 2018. Plant Anatomy A Concept-Based Approach to the Structure of Seed Plants. Springer Nature Switzerland.

Despommier, D. 2013. Farming up the city: the rise of urban vertical farms. *Trends in Biotechnology*, 31(7): 388–389. https://doi.org/10.1016/j.tibtech.2013.03.008.

Finch-Savage, WE., & GW. Bassel. 2016. Seed vigor and crop establishment: Extending performance beyond adaptation. *Journal of Experimental Botany*, 67 (3), 567–591 https://doi.org/10.1093/jxb/erv490

Fraile-Robayo, RD., JG. álvarez-Herrera, MA. Reyes, OF. Álvarez-Herrera, & AL. Fraile-Robayo. 2017. Evaluation of the growth and quality of lettuce (*Lactuca sativa* L.) in a closed recirculating hydroponic system. *Agronomía Colombiana* 35(2), 216-222. https://doi.org/10.15446/AGRON.COLOMB.V35N2.63439.

Gashgari, R., K. Alharbi, K. Mughrbil, A. Jan. & A. Glolam. 2018. Comparison between Growing Plants in Hydroponic System and Soil Based System. Proc. of the 4th World Congress on Mechanical, Chemical, and Material Engineering (MCM'18) Madrid, Spain.http://dx.doi.org/10.11159/icmie18.131.

Huijser, P., & M. Schmid. 2011. The control of developmental phase transitions in plants. *Development*, *138*(19), 4117–4129. https://doi.org/10.1242/dev.063511.

Khan, FA., A. Kurklu, A. Ghafoor, Q. Ali, M. Umair, & Shahzaib. 2018. A review on hydroponic greenhouse cultivation for sustainable agriculture. *International Journal of Agriculture Environment and Food Sciences*. 2 (2), 59-66. http://dx.doi.org/10.31015/jaefs.18010.

International Seed Testing Association [ISTA]. 2015. International rules for seed testing. Basserdorf, Switzerland .

Istiqamah, A., A. Rauf, & A. Aiyen. 2016. Respon Varietas Tanaman Sawi (*Brassica juncea* L.) Terhadap Larutan Hara (AB Mix) Pada Sistem Hidroponik. *Agrotekbis : E-Jurnal Ilmu Pertanian*, *4*(4), 374–383. http://jurnal.faperta.untad.ac.id/index.php/agrotekbis/ article/view/35.

Nguyen, NT., SA. McInturf, & DG. Mendoza-Cózatl. 2016. Hydroponics: A Versatile System to Study Nutrient Allocation and Plant Responses to Nutrient Availability and Exposure to Toxic Elements. *Journal of visualized experiments: JoVE*, (113), 54317.

https://doi.org/10.3791/54317.

Milošević, N., DM. Vujaković, & D. Karagić. 2010. Vigour Tests as Indicators of Seed Viability. *Genetika,* 42 (1), 103-118. https://doi.org/10.2298/GENSR1001103M

Rahmanpour, S., D. Backhouse, & HM. Nonhebelc. 2011. The reaction of Brassica species to *Sclerotinia sclerotiorum* applying inoculation techniques under controlled conditions. *Crop Breeding Journal.* 1 (2): 143-149.https://dx.doi.org/10.22092/cbj.2011. 100364.

Rao, NK., J. Hanson, ME. Dulloo, K. Ghosh, D. Nowell, & M. Larinde. 2006. *Manual of Seed Handling in Genebanks*. Handbooks for Genebanks No. 8. Bioversity Inter-national. Italy. 163 pp. ISBN 13: 978-92-9043-740-6.

Sadjad, S. 1993. Dari Benih Kepada Benih. Jakarta: Gramedia.

Sarido L., & Junia. 2017. Uji Pertumbuhan Dan Hasil Tanaman Pakcoy (*Brassica rapa* L.) dengan Pemberian Pupuk Organik Cair pada System Hidroponik." *Agrifor*, 16(1): 65-74.https://dx.doi.org/10.31293/af.v16i1. 2591

Sapkota, S., S. Sapkota, & Z. Liu, Z. 2019. Effects of Nutrient Composition and Lettuce Cultivar on Crop Production in Hydroponic Culture. *Horticulturae. 5*(4): 72, 1-8 https://doi.org/10.3390/horticulturae 5040072.

Sesanti, RN., & Sismanto. 2016. Pertumbuhan dan Hasil Pakchoi (*Brasicca rapa* L.) pada Dua Sistem Hidroponik dan Empat Jenis Nutrisi. *Jurnal Kelitbangan*. 4 (1):1-9.

Sharma, N., S. Acharya, K. Kumar, NP. Singh & OP. Chaurasia. 2018. Hydroponics as an advanced technique for vegetable production: An overview. *Journal of Soil and Water Conservation.* 17: 364-371. https://doi.org/10.5958/2455-7145.2018.00056.5.

Sholihat, SN., MR. Kirom, & IW. Fathonah. 2018. Pengaruh kontrol nutrisi pada pertumbuhan kangkung dengan metode hidroponik Nutrient Film Technique (NFT). *e-Proceeding of Engineering*. 5 (1): 910-915. ISSN: 2355-9365.

Souza, ML., & M. Fagundes. 2014. Seed Size as Key Factor in Germination and Seedling Development of Copaifera langsdorffii (Fabaceae). *American Journal of Plant Sciences.* 5: 2566-2573. https://doi.org/10.4236/AJPS.2014.517270.

Statistics Indonesia [SI]. 2023. *Production of vegetables 1997-2022. https://www.bps.go.id/indicator/55/61/1/production-of-vegetables.html.*

Statistics of Food Consumption [SFC]. 2020. Center for Agricultural Data and Information System. Secretariate General - Ministry of Agriculture https://satudata.pertanian.go.id/assets/docs/publikasi/Statistik_Konsumsi_Pangan_Tahun_2020.pdf.

Storck, JL., R. Böttjer, R., D. Vahle, B. Brockhagen, T. Grothe, K.-J. Dietz, A. Rattenholl, F. Gudermann, & A. Ehrmann. 2019. Seed Germination and Seedling Growth on Knitted Fabrics as New Substrates for Hydroponic Systems. *Horticulturae*. 5(4): 73, 3-9. https://doi.org/10.3390/horticulturae 5040073.

Sublett, W., T. Barickman, & C. Sams. 2018. The Effect of Environment and Nutrients on Hydroponic Lettuce Yield, Quality, and Phytonutrients. *Horticulturae*, *4*(4), 48. MDPI AG. Retrieved from http://dx.doi.org/10.3390/horticulturae4040048e.

Tefa, A. 2017. Uji viabilitas dan vigor benih padi (*Oryza sativa* L.) selama penyimpanan pada tingkat kadar air yang berbeda. *Savana Cendana* 2 (3): 48-50 .

Touliatos, D., IC. Dodd, & McAinsh, M. 2016. Vertical farming increases lettuce yield per unit area compared to conventional horizontal hydroponics. *Food and energy security.* 5(3): 184–191. https://doi.org/10.1002/fes3.83.

Tuquero, J., RG. Chargualaf, & M. Marutani, 2018. Growing Bok Choy (*Brassica rapa* Chinensis Group) Varieties for Guam. Food Plant Product. https://www.uog.edu/resources/files/wptrc/BokChoy.pdf.

Venter, AV. (2001). What Is Seed Vigour. *Journal of New Seeds. 2*: 67-72. https://doi.org/10.1300/J153V02N03_06.

Weraduwage, SM., J. Chen, FC. Anozie, A. Morales, SE. Weise, & TD. Sharkey. 2015. The relationship between leaf area growth and biomass accumulation in Arabidopsis thaliana. *Frontiers in plant science*, *6*, 167. https://doi.org/10.3389/fpls.2015.00167.