Seed Germination and Evaluation of Vegetative Growth of Pak Choi 
(\textit{Brassica rapa} subsp. \textit{chinensis} L. \textit{Hanelts})

Perkecambahan Benih dan Evaluasi Pertumbuhan Vegetatif Pak Choi
\textit{(Brassica rapa} subsp. \textit{chinensis} L. \textit{Hanelts})

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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 Germination (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 \textit{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

INTRODUCTION

Pak choi or Pak Choy (\textit{Brassica rapa} subsp. \textit{Chinensis} (L.) \textit{Hanelt}) is an oriental vegetable widely consumed in Asia. Pak choi is a group of vegetable plants in the mustard family (\textit{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 727467.00 ton (2021) and 760608.00 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 (Istiqamah 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 & Sismananto 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; Tefi 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,
Seed Germination and Evaluation of Vegetative Growth of Pak Choi 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 °C – 25 °C with 24-hour LED.

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

\[
\text{MGP} (\%) = \frac{\sum \text{germinated seeds}}{\sum \text{seeds planted}} \times 100\%
\]

Germinated Potential (GP). Germination 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:

\[
\text{GP} (\%) = \frac{\sum NS_{\text{day 5}} + \sum NS_{\text{day 6}} + \sum NS_{\text{day 7}}}{\sum \text{seeds planted}} \times 100\%
\]

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

\[
\text{VI} (\%) = \frac{\sum \text{normal sprouts day 5}}{\sum \text{seeds planted}} \times 100\%
\]

PGR(%)=\[\sum_{0}^{m} \frac{N}{t}\]

Notes:

\(N\) = % normal sprouts every day of observation; \(t\) = observation time; \(m\) = 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.

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>MGP (%) ± SE</th>
<th>GP (%) ± SE</th>
<th>VI ± SE</th>
<th>SP ± SE</th>
</tr>
</thead>
<tbody>
<tr>
<td>‘Brisk Green’</td>
<td>95.50a 0.75</td>
<td>86.50a 1.25</td>
<td>84.50a 1.50</td>
<td>12.36a 0.18</td>
</tr>
<tr>
<td>‘Nauli’</td>
<td>97.00a 0.75</td>
<td>84.00a 1.25</td>
<td>81.50a 1.50</td>
<td>12.00a 0.18</td>
</tr>
</tbody>
</table>

**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 = Germination 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 hydroponic system.

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>The average plant height (cm) at age (weeks after planting)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>8 weeks Average ±SE</td>
</tr>
<tr>
<td>‘Brisk Green’</td>
<td>11.08a 0.32</td>
</tr>
<tr>
<td>‘Nauli’</td>
<td>9.13b 0.26</td>
</tr>
</tbody>
</table>

**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 pakchoi 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)

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

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>8 weeks Average ±SE</th>
<th>9 weeks Average ±SE</th>
<th>10 weeks Average ±SE</th>
<th>11 weeks Average ±SE</th>
<th>12 weeks Average ±SE</th>
</tr>
</thead>
<tbody>
<tr>
<td>‘Brisk Green’</td>
<td>8.92±0.26</td>
<td>10.20±0.29</td>
<td>12.24±0.28</td>
<td>13.60±0.32</td>
<td>15.20±0.44</td>
</tr>
<tr>
<td>‘Nauli’</td>
<td>11.84±0.28</td>
<td>13.76±0.36</td>
<td>16.16±0.44</td>
<td>17.44±0.64</td>
<td>19.04±0.57</td>
</tr>
</tbody>
</table>

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.

<table>
<thead>
<tr>
<th>Pak choi Cultivar</th>
<th>Number of leaves Average ±SE</th>
<th>Plant height (cm) Average ±SE</th>
<th>Leaf length (cm) Average ±SE</th>
<th>Leaf Width (cm) Average ±SE</th>
<th>Plant fresh weight (gr) Average ±SE</th>
</tr>
</thead>
<tbody>
<tr>
<td>‘Brisk Green’</td>
<td>20.72±0.052778</td>
<td>24.31±0.0106</td>
<td>12.65±0.006</td>
<td>8.86±0.0050</td>
<td>45.50±0.0650</td>
</tr>
<tr>
<td>‘Nauli’</td>
<td>26.83±0.068056</td>
<td>21.27±0.0056</td>
<td>13.48±0.0043</td>
<td>8.14±0.0026</td>
<td>68.05±0.0519</td>
</tr>
</tbody>
</table>

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’
carnation 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 photosynthetic 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 photosynthetic 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,
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 analyzed the data, wrote draft the manuscript, RI. designed the research, wrote the manuscript and supervised all the process, A., EP. supervised the process

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