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Seed Germination and Adaptation of Several National and Introduced Varieties of Spinach Plants (*Spinacia oleracea* L.) in Tropical Lowlands

Perkecambahan Benih dan Adaptasi Beberapa Varietas Nasional dan Introduksi Tanaman Horenso (Spinacia oleracea L.) di Dataran Rendah Tropis

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ABSTRAK

Studi ini bertujuan mempelajari perkecambahan dan adaptasi beberapa varietas nasional dan introduksi tanaman horenso yang ditanam di dataran rendah tropis. Penelitian dilaksanakan pada September–November 2023 di lahan percobaan Fakultas Pertanian, Universitas Muhammadiyah Jakarta. Penelitian terdiri atas dua percobaan: percobaan pertama adalah uji perkecambahan dan daya adaptasi empat varietas tanaman pada *tray* semai menggunakan media tanam organik. Percobaan ini menggunakan Rancangan Kelompok Lengkap Teracak (RKLT) dengan perlakuan varietas yang terdiri atas empat varietas horenso, masing-masing terdiri dari enam ulangan. Percobaan kedua adalah uji perkecambahan pada dua media perkecambahan yang berbeda, yaitu tanah organik dan tisu basah. Kedua percobaan menggunakan empat varietas yang sama, yakni dua varietas nasional (Kiara F1 dan Okezo 009) dan dua varietas introduksi (Mozart F1 dan Autumn Big-Leaf). Parameter yang diamati adalah persentase perkecambahan biji dan waktu kematian bibit setelah berkecambah. Pengamatan dilakukan pada 0–21 hari setelah semai. Hasil studi ini menunjukkan bahwa semua genotipe tanaman horenso yang digunakan tidak mampu beradaptasi dengan iklim tropis dataran rendah. Semua varietas tanaman memiliki persentase perkecambahan yang rendah, berkisar 0–38%, dan semua benih yang berkecambah mengalami kematian di usia 0–14 hari setelah semai.

Kata kunci: Benih, Horenso, Pemuliaan tanaman, Pertumbuhan.

ABSTRACT

The study aims to examine the germination and adaptation of several national and introduced varieties of spinach plant in tropical lowlands. This study was carried out on September to November 2023 at the experimental field of Faculty of Agriculture, Jakarta Muhammadiyah University. This study consisted of two experiments: the first experiment was a test of germination and adaptability of four spinach varieties on seedling trays using organic growing media. The experiment used a Randomized Complete Block Design (RCBD) with the treatments of spinach verieties consisted of four varieties, each with six replications. The second experiment was a germination test in two different germination media, namely organic soil and moistened tissue. Both experiments used the same four varieties, namely two national varieties (Kiara F1 and Okezo 009) and two introduced varieties (Mozart F1 and Autumn Big-Leaf). The parameters observed were seeds germination percentage and seedlings death time after germination. The observation was carried out at 0 to 21 days after sowing. The results show that all spinach plant genotypes used could not adapt to the climate conditions of tropical lowlands. All four varieties produced low germination percentages, ranging from 0–38%, and all seeds that germinated died within 0–14 days after sowing.

Keywords: *Spinach, Growth, Seed, Crop breeding.*

INTRODUCTION

Horenso or Spinach (*Spinacia oleracea* L.) is a subtropical vegetable crop that has been gaining popularity in Indonesia. Spinach is one of the newly introduced species in Indonesia (Suwardike et al., 2019). Plant introduction is a plant breeding method that can contribute to generate variation and diversity in genetic material, also create superior plant varieties. Introduced plants can be developed into new varieties in several ways, namely 1) directly from the introduced plants after the adaptation process; 2) through selection methods; and 3) through hybridization or genetic engineering (Syukur et al., 2015).

Spinach has many benefits and high nutritional content. Spinach is rich in fiber, vitamins A, C, E, K, B6, and B12, and contains several minerals and other nutrients, such as Mg, Mn, Fe, Ca, K, Cu, P, Zn, Se, folate, betaine, folic acid, niacin, omega-3 fatty acids, beta-carotene, lutein, and several flavonoid compounds (Roughani & Miri, 2019). The high nutritional content also makes spinach is quite beneficial for human health, such as by improving the digestive system; reducing the risk of diabetes; reducing the symptoms of fever, colds, and heart disease; alleviating urinary and biliary tract disorders, malaria, eye pain, skin diseases (scabies and leucoderma), and joint pain; as an antioxidant, antipyretic, anti-inflammatory, anti-bacterial, anti-cancer, diuretic; improving blood circulation; and good for child growth and development (Nurtjahyani & Iskandar, 2016; Roughani & Miri, 2019).

Spinach has high prospects to be developed because it has high economic value. In several subtropical countries, such as the United States, Japan, and Turkey, spinach is one of the horticultural crops that is seriously developed due to its high economic value, increasing public demand, good nutritional value, and relatively easy cultivation process (Koike et al., 2011; Brandenberger et al., 2015; Türkmen, 2016; Fauziah, 2021). Based on FAO data in 2020, China had the highest production of spinach worldwide (28,520,698 tons/year), followed by the United States (367,433 tons/year), Kenya (243,336 tons/year), Turkey (231,515 tons/year), and Japan (217,238 tons/year) (FAO, 2020).

Spinach cultivation in Indonesia is relatively new so that it has not been widely practiced and information related to its good cultivation practices is also still limited. These conditions cause spinach productivity in Indonesia to remain very low, at around 3.82 tons/ha, which is much lower than that of in Jordan (50.82 tons/ha), China (39.50 tons/ha), Kuwait (31.44 tons/ha), the United Arab Emirates (28.20 tons/ha), and Kenya (24.86 tons/ha). In Southeast Asia, spinach productivity in Indonesia is still much lower than that of Singapore (20.73 tons/ha) and Malaysia (12.51 tons/ha) (FAO, 2020).

The low production of spinach in Indonesia is thought to be due to the limited production areas. As an introduced crop from subtropical regions, spinach production in tropical countries, such as Indonesia, is still limited to highlands with an altitude of > 700 meter above sea level (masl) (Suwardike et al., 2019). Cultivation of horenso at altitudes below 700 masl can cause the plant to grow less optimally due to higher temperature. Spinach can grow in a temperature range of 5–30^{o}C, in which 15–18^{o}C is considered the optimal range (Koike et al., 2011). The most important factor in a plant introduction process is the adaptability of the introduced plants to the environmental conditions of the new place where the plants are introduced. This adaptability allows the introduced plants to survive, grow, and develop optimally.

Spinach cultivation practices in the highlands of Indonesia had been reported in several studies, such as in the Cianjur area (Ekaningtias, 2011; Lubis & Fitrianti, 2016; Lestary, 2020), Batu (Prawira, 2018), Mojokerto (Simanjuntak & Heddy, 2018), and Lembang (Rasmikayati et al., 2020). All of these studies showed that spinach can grow well in these areas. Nonetheless, studies related to spinach cultivation in tropical lowlands in Indonesia have not yet been conducted. As a result, there is no adequate information so far related to this topic.

Based on the aforementioned background, it is necessary to study the extent to which several varieties of spinach plant can adapt to the environmental conditions of tropical lowlands in Indonesia. Therefore, this study aims to investigate the germination and adaptation of several national and introduced varieties of spinach plant grown in the tropical lowlands in Indonesia.

METHODS

The study was conducted in September–November 2023 at the experimental field of the Faculty of Agriculture, Universitas Muhammadiyah Jakarta, Cirendeu, East Ciputat, South Tangerang City, which is located at a coordinate of 6°17'58" South Latitude and 106°46'02"East Longitude with an altitude of about 15 masl (Central Bureau of Statistics of South Tangerang City, 2019). The average climate conditions during the study are presented in Table 1.

Table 1. Climate data on September–November 2023

Month	Daily Temperature (°C)		
	Minimum	**Maximum**	**Average**
September	24.51	35.10	29.03
October	25.83	36.00	30.36
November	25.34	34.33	30.80

Source: MCGA (2023)/ BMKG (2023)

In this study, two experiments were conducted. The first experiment was a growth comparison experiment on four spinach varieties using randomized complete block design (RCBD) with six replications. The spinach varieties used were two national varieties (Kiara F1 and Okezo 09) and two introduced varieties (Mozart F1 from Japan and Autumn Big-Leaf from China). In this study, the seedling tray method of germination was chosen using ready-made commercial organic planting media purchased from agricultural stores. One seed was planted in each hole of seedling tray. The number of seeds in each variety and replication varies, ranging from 35–70 seeds, depending on the availability of seeds. Data obtained in this experiment were analyzed using the F-test (analysis of variance) and continued with the Duncan multiple range test (DMRT) at the 5% significance level.

In the second experiment, germination test was conducted using two different germination media, namely organic soil medium on seedling trays and moistened tissue medium on plastic trays (Figure 1). The four varieties used were the same as those of the first experiment, namely two national varieties (Kiara F1 and Okezo 09) and two introduced varieties (Mozart F1 and Autumn Big-Leaf). However, in this experiment, data analysis was not carried out because the number of replications used did not meet the data analysis requirements. The observation parameters were seeds germination percentage and seedlings death time. The observation was performed at 0–21 days after sowing (DAS). Germination percentage was calculated using the following formula (Sutopo, 2002):

$$Germination\ percentage\ (\%) = \frac{n}{N}\ x\ 100\%$$

Description: *n* = Number of seeds that germinate
N = Number of seeds tested (germinated)

Figure 1. Germination of spinach seeds in organic soil medium (left) and moistened tissue medium (right)

RESULTS AND DISCUSSION

Table 2 shows that Okezo 09 variety could not germinate at all (zero germination percentage), while the other three varieties were able to germinate, although at quite low percentage, namely at an average of 30.65, 24.05, and 27.18%, respectively. Kiara F1 variety produced the highest germination percentage, although it was not significantly different from that of Mozart F1 and Autumn Big-Leaf varieties. All varieties tested produced germination percentages that were much lower than the potential growth capacity of all varieties. Table 2 also shows that all seeds that successfully germinated died at relatively the same time. Kiara F1 and Autumn Big-Leaf varieties died at 7.50 and 7.17 days after sowing (DAS), respectively, while Mozart F1 variety died at 3 DAS.

Based on the results obtained, it can be seen that the spinach varieties tested were not able to adapt to the climate conditions of tropical lowlands. Kiara F1 and Okezo 09 are spinach varieties that have undergone adaptation testing in Indonesia's tropical climate and had been registered as national varieties, while Mozart F1 and Autumn Big-Leaf are introduced spinach varieties from Japan and China. However, based on the results obtained, all four varieties, both national and introduced varieties, have not been able to adapt to the climate conditions of tropical lowlands.

Table 2. Seed germination percentage and seedlings death time of four spinach varieties

Variety	Germination Percentage (%)	Seedlings Death Time (DAS)
Kiara F1	30.65 a	7.50 a
Mozart F1	24.05 a	3.00 ab
Autumn Big-Leaf	27.18 a	7.17 a
Okezo 09	0.00 b	0.00 b

Description: Numbers followed by the same letter in the same column indicate no significant difference based on the results of DMRT test at the 5% level

In the second experiment, seed germination of four spinach varieties was tested using two different germination media. The first medium used was moistened tissue and then transferred to the planting medium after the radicle emerged. The second medium was organic soil. The results show that spinach seeds germinated in moistened tissue medium produced higher germination percentage compared to seeds germinated directly in organic soil medium, except for Autumn Big-Leaf variety, which produced higher germination percentage in organic soil medium than that in moistened tissue medium (Table 3).

Table 3. Seed germination percentage of four spinach varieties in two kinds of germination media

Variety	Germination Percentage (%)	
	Moistened Tissue	Organic Soil
Kiara F1	32.11	22.86
Mozart F1	38.46	14.15
Autumn Big-Leaf	20.83	33.33
Okezo 09	33.33	0.00

In moistened tissue medium, Mozart F1 variety produced the highest germination percentage (38.46%), followed by Okezo 09 (33.33%), Kiara F1 (32.11%), and Autumn Big-Leaf (20.83%) in order. Meanwhile, in organic soil medium, Autumn Big-Leaf variety produced the highest germination percentage (33.33%), followed by Kiara F1 (22.86%), Mozart F1 (14.15%), and Okezo 09 (0%) in order. Table 3 implies in general that all spinach seeds tested were not able to germinate optimally using organic soil or moistened tissue media under the climate conditions of tropical lowlands.

The same experiment also observed the seedlings death time of each variety in each germination medium. Table 4 shows that all seedlings of spinach varieties in moistened tissue medium began to die at the same time, namely at 14 DAS, while in organic soil medium, Kiara F1, Mozart F1, and Autumn Big-Leaf varieties began to die at faster time, namely at 10, 6, and 9 DAS, respectively.

Spinach is a plant native to subtropical climates that has been introduced to Indonesia in recent years. As a subtropical plant, spinach has very distinctive growing requirements that make it naturally unsuitable to grow in tropical climate conditions. Temperature is one of the main obstacles in the introduction process of subtropical plants to tropical areas. Thus, several modifications are needed in order to achieve the suitable climate conditions, one of which is by adjusting the latitude of origin of the plant to the altitude of the new place (Lumingkewas & Koesmaryono, 2023). Therefore, the process of introducing plants from the subtropics to tropics is usually carried out in the tropical highlands, whose temperature conditions are more in line with subtropical climate conditions. Wahyu et al. (2013) emphasized that the main obstacle faced in the growth and development of subtropical crops in tropical lowlands is high temperature stress.

Table 4. Seedlings death time of four spinach varieties in two kinds of germination media

Variety	Seedling Death Time (DAS)	
	Moistened Tissue	Organic Soil
Kiara F1	14	10
Mozart F1	14	6
Autumn Big-Leaf	14	9
Okezo 09	14	0

Spinach is a type of plant that requires low temperature for its growth (Rai, 2014). Spinach is able to grow at temperature range of 5–30°C, in which 15–18°C is considered the optimal range for rapid growth. During the germination phase, spinach requires a temperature range of 2–30°C, in which 7–24°C is considered the optimal range (Koike et al., 2011). During this study, the daily air temperatures for three months were similar in average (Table 1). These temperature conditions were above the optimal conditions for spinach germination and growth. The overall results show that all spinach varieties tested in this study were not able to adapt to high temperature stress conditions.

Several previous studies are also in line with the results of this study. Masuda and Konishi (1993) reported that spinach has a suitable temperature for germination in the range of 10–20°C, in which 20°C is considered the most optimal. Germination was inhibited at 25°C with an average germination percentage of only 34%. The seed germination percentage of several spinach varieties, such as King of Denmark, TG-1, Jiroumaru, and Houyou, decreased significantly at 30°C, with germination percentages of 9, 21, 13, and 0%, respectively. Furthermore, Chitwood et al. (2016) reported that nine spinach varieties (Ozarka II, Fallgreen, F88-310, Donkey, Tyee, Marabu, F88-354, Raccoon, and Samish) had optimal temperature range for germination at 10–20°C. The germination percentage decreased at 30°C, with a drastic decrease occurred at 35°C. At 35°C, only Ozarka II variety produced a fairly high germination percentage (63.0%), while the other eight varieties, namely Fallgreen, F88-310, Donkey, Tyee, Marabu, F88-354, Raccoon, and Samish produced a very low germination percentage, namely 27.3, 23.3, 20.7, 19.3, 13.3, 9.7, 8.7, and 6.7%, respectively.

Temperature is the most important environmental factor in the dormancy process and seed germination time (Chahtane et al., 2017; Yan & Chen, 2020). Temperature plays an important role in the germination phase as it affects various chemical reactions that occur during the seed germination process. Temperature functions to activate the work of enzymes that play a role in the germination process, such as amylase, lipase, and proteinase (Rusmin et al., 2014). High temperature conditions above optimal limit during the seed germination process can cause a reduction in the number of proteins directly involved in the process of methionine metabolism, amino acid biosynthesis, protein folding, energy metabolism, and degradation of food reserves (Liu et al., 2015).

As a consequence, the seeds are unable to germinate, and even if they germinate, they will die in a short time. These conditions are often referred to as thermo-dormancy or thermo-inhibition, namely the failure of seeds germination due to high temperatures (Odabas & Mut, 2007; Yan & Chen, 2020).

Every plant requires an optimal temperature to germinate. Temperatures higher than the optimal range will reduce the seed germination percentage. A study by Kurtar (2010) showed that seeds of watermelon, melon, cucumber, and several types of pumpkin experienced a drastic decrease in germination percentage when they were exposed to temperatures higher than the optimal range. Several previous studies have also shown that subtropical plants require lower temperatures to germinate optimally. Lee and Yang (1999) reported that lily seeds from high altitudes (2,000 masl) require temperature range of 10–20°C to reach germination percentage of more than 90%. At 25°C, germination dropped to 8%, and at 30°C, the seeds were completely unable to germinate. Lee and Goodwin (2006) also reported that *Actinotus helianthi* (Apiaceae family) seeds produced the highest germination percentage at 15°C, both for freshly harvested and stored seeds, then the germination percentage decreased drastically as the temperature increased.

Taiz et al. (2014) stated that temperature affects all biochemical reactions in plants, including photo-respiration and photosynthesis. Rai (2014) explained that temperature higher than the optimal range will cause an imbalance, such as indicated by the respiration rate higher than the photosynthesis rate. Andriani and Karmila (2019) added that increasing temperature can elevate the molecules' energy and rate of movement, meaning the increasing temperature can naturally elevate the speed of reactions in metabolic activities. An increase in temperature will affect the process of denaturation and influence the production and balance of enzyme activity involved in all metabolic activities. Salisbury and Ross (1995) further explained that when the temperature is above the maximum limit, plants' growth will be inhibited and eventually experience death if they cannot adapt to this stress condition. In the germination phase, plants are still in a growth process so that they have not yet been able to perform photosynthesis optimally. In this phase, it is possible that the high respiration rate that occurs may cause the plants to experience an energy deficit and slowly die.

Several studies on different introduced crops have also shown that plants' growth is inhibited in environmental conditions with temperatures both below and above the optimal range. Asri (2016) reported that wheat plants, which are introduced plants from subtropical regions, experienced a lot of deaths when planted in lowlands (higher temperatures) and experienced much lower growth and production compared to the ones grown in highlands. Andriani and Karmila (2019) also reported that the growth of tolo bean (*Vigna* sp.) plants decreased significantly at temperatures below and above the optimal range.

CONCLUSIONS

Based on the results of this study, it was revealed that all spinach varieties tested were not able to adapt to the climate conditions of tropical lowlands. This is based on the germination percentage produced, which only ranged from 0–38%. The seeds that successfully germinated were not able to survive and died within 0–14 days after sowing (DAS). The results also show that differences in germination media were not able to increase spinach plant's adaptability to the existing climate conditions. This study generally confirms that spinach is actually not adaptive enough to the environmental conditions of tropical lowlands. In future study, observations can be performed using more detailed variables so that the data obtained can be more comprehensive to understand the adaptation of spinach plants in tropical lowlands.

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