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Research

Broccoli (*Brassica oleraceae* var. italica) Growth Performance in Lowland Using Fertigation Under Protected Rain Shelter: The Influence of Spacings and Accessions

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ABSTRACT

Broccoli (*Brassica oleraceae* var. *italica*) is traditionally grown in the highlands using an open system with 60 cm × 60 cm spacing. However, insect pests and disease infestation are limiting factors that cause major produce damage. Efforts have been made to increase the supply by cultivating them in protected rain shelters in lowlands to meet consumers' high demand. Consequently, the initial construction costs of infrastructures are substantial. Optimizing the rain shelter's space to increase yield and cover production costs is necessary. The performance of Broccoli accessions grown at various spacings in a closed rain shelter fertigation system in the lowland was evaluated. The treatments consisted of two plant spacings: S1- 30 cm × 30 cm and S2 - 60 cm × 60 cm, with five hot summer hybrid broccoli accessions: V1-accession BC114 (Chef 1856), V2-accession BC120 (Green Jade 2034), V3-accession BC123 (Royal Green), V4-accession BC124 (Green Magic), and V5-accession BC126 (V-075). Treatments were arranged in a Split Plot Randomized Design with three replications. Data on each spacing, accession & interaction's vegetative growth, and yield performance were collected. The findings indicated that different spacing treatments did not significantly affect plant height, number of leaves, leaf length, leaf width, curd height, curd diameter, curd weight, or curd compactness. In comparison, when compared to other accessions, V4 and V5 generated noticeably greater curd yield, curd size, and growth. Only V5 significantly interacts with spacing treatments on days to curd initiation and days to curd maturity. The spacing treatment did not affect the yield of the accession V5. Very low (1%) pest incidence and no known disease infestation recorded. The findings suggest that the V4 and V5 accessions can be commercialized with 30 cm × 30 cm plant spacing to achieve optimal production yield in protected rain shelters in lowlands.

Key words: Accessions, broccoli, growth, spacing, yield

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INTRODUCTION

Broccoli (*Brassica oleracea* var. *italica*) is a popular vegetable crop in many countries due to its nutritionally rich benefits, favorable tastes, and high organoleptic qualities (Dhillon *et al*., 2005). It is cultivated worldwide but only in relatively temperate climates since vegetative and curd development is poor in hot conditions (Pornsuriya *et al*., 1997). Broccoli is grown in cool limited areas in Malaysia (Cameron Highlands, Pahang, & Ranau, Sabah) with an annual production of 1,457.04 metric tonnes in 2021 (Jabatan Pertanian Malaysia, 2021). Numerous tropical regions have high rainfall, which is not conducive to open-system vegetable cultivation. Heavy rainfall leads to increased disease incidence, reduced pesticide effectiveness, decreased fertilizer effectiveness resulting from nutrient leaching, and lowered labor productivity (Kratky, 2006). This scenario results in low yield and high market prices for these vegetables. The importation of broccoli was vigorously urged to meet consumer demand in Malaysia.

Broccoli is typically grown in an open field, where it is susceptible to head rot and soft rot disease due to the impact of raindrops or humid conditions (Vodhivanich, 2006).

Insect pests and disease infestation are limiting factors causing the severe destruction of vegetables. *Helulla undalis, Spodoptera litura, Phyllotreta* sp., *Plutella xylostella*, Aphis sp., and *Crocidolomia* sp. are among the typical pests of broccoli in Malaysia (Jabatan Pertanian Malaysia, 1999). Arternaria leaf spot (fungus Arternaria brassicae), soft/black rot (Bacteria *Xanthomonas campestris*), powdery mildew (Erysiphe cruciferarum) downy mildew (*Hyaloperonospora parasitica*), damping off (*Rhizoctonia solani*, *Phytium* sp., *Fusarium* sp. and fusarium wilt (*Fusarium oxysporum f.sp. conglutinans*) are among the common diseases infecting broccoli. Therefore, the genetic traits of the cultivar, tolerance to disease, adaptability to climatic and soil conditions, and the application of nutrients significantly impact the success of its cultivation. The hot and humid tropics are not an ideal environment for the cultivation of broccoli in most cultivars. Diverse genetic improvement programs have produced heat-tolerant broccoli cultivars that can grow well in high temperatures, enabling year-round production (Nooprom *et al*., 2013). There are two types of broccoli: heading and sprouting. The heading variety, which grows closely linked to cauliflower and produces a large central curd in high demand on the market, is the most popular form of broccoli. Sprouting broccoli generates several little curds or florets but not a large curd (Tejaswini *et al*., 2018).

It is claimed that switching from a soil-based growing system to a soilless media cultivation using a fertigation system in lowlands reduces the incidence of soil-borne diseases and is advantageous for plant development. This is in response to the rising demand for imported vegetables in Malaysia (Yaseer, 2016). Using fertigation has enhanced crop yield and quality, decreased soil-borne disease, and improved fertilizer utilization efficiency (Romic *et al*., 2003). Despite this, the initial cost of setting up the infrastructure can be relatively high. It is crucial to optimize the capacity of the rain shelter to increase yield and cover production costs. According to Bhangre *et al*. (2011), plants grown conventionally at a distance greater than 60 cm × 60 cm had the significantly highest values for various traits, with days needed for harvesting at 50% (59.83 days), while those grown at 30 cm × 45 cm had the lowest values for the same traits (64.5 days). Plant spacing is essential for crop development and growth and improving farmers' yield, quality, and profitability. Broader spacing results in bigger plants with more robust growth and better-quality produce, while closer spacing may cause competition between the plants for nutrients, air, and light. Therefore, there must be a balance in the number of cultivated plants per unit area (Sharma *et al*., 2001). In Sarawak, Malaysia, there are no recommendations on the suitability of specific cultivars or plant spacing for broccoli production in the lowland using a rain shelter fertigation system.

The study was conducted to evaluate the most acceptable accessions and optimum plant spacing under a protected rain shelter fertigation system in the lowland to produce high-value broccoli in Sarawak. Pest and disease incidences were also monitored in this study for better control management, as severe infestation causes yield loss.

MATERIALS AND METHODS

Treatment & experimental design

The present study was executed in the Agriculture Research Centre Semongok in Sarawak, Malaysia, for 2020-2021, with temperatures ranging from 26 to 35 °C. The experiment was laid out in a split-plot randomized complete block design (RCBD) with three replications. The study was carried out with two plant spacings as a main plot: S1 - 30 cm × 30 cm and S2 - 60 cm × 60 cm, with sub-plots consisting of heat tolerant broccoli accessions: V1-accession BC114 (Chef 1856), V2-accession BC120 (Green Jade 2034), V3-accession BC123 (Royal Green), V4-accession BC124 (Green Magic), and V5-accession BC 126 (V-075).

Germination, field planting & management

Broccoli seeds were sown individually in 51-hole germination trays loaded with peat moss as a germination medium. Foliar fertilizers were applied once a week to germinated seedlings after the first two leaves had emerged. Disease and pest management were handled as necessary, and seedlings were watered twice daily (in the morning and evening). The 25 days old of healthy seedlings were transplanted into polybags filled with coco peat and arranged inside the rain shelter with two different plant spacings (S1 & S2) (double row planting). Plants were automatically fertilized with EC doses of 1.5 to 2.0 mS/cm and irrigation dosages of 1 to 1.5 L per day. The plant maintenance was conducted following the recommended package of cultivation practices.

Data collection & analysis

On ten plants randomly selected from each experimental plot, the following growth variables were assessed and recorded: days to curd initiation from days after transplanting (DAT), days to marketable curd maturity from DAT, number of leaves, leaf length (cm), leaf width (cm) and plant height at maturity. Pest and disease assessments were carried out four times at age 15, 25, 35, and 45 DAT. A total of five plants were selected randomly from each treatment per replicate. The assessment was

conducted via visual scoring based on the damage symptoms of each pest and disease infection and inspection of the presence of insect pests. Sample collection for identification of the causal agent(s) in the laboratory was carried out (if any). Broccoli curds from each plot was harvested at a marketable stage, and the following characteristics were measured: curd weight (g/plant), curd diameter (cm), curd height (cm), and curd compactness (yield/diameter, g/cm).

The data obtained were subjected to analysis of variance (ANOVA) using the statistical program SPSS version 26. The means were compared using Tukey's multiple range test at the significance level (P<0.05) to assess the performance differences among broccoli accessions and spacings.

RESULTS AND DISCUSSION

Effect of accessions on broccoli growth and yield

Vegetative growth

The findings reported in Table 1 demonstrated that the shortest plant heights were recorded in accessions V1 (45.54 cm) and V5 (46.10 cm), while the tallest plant height was notably measured in V4 (50.28 cm). The table shows no significant variations between accessions in the number of leaves. The accession with the longest leaf (52.63 cm) was V4, whereas the accession with the shortest leaf (44.00 cm) was V1. Maximum days to curd initiation (51.13 days & 50.87 days) and days to curd maturity (60.20 days & 63.00 days) were recorded in accessions V4 and V5 during two consecutive years, whereas minimum values were recorded in V1, V2 and V5 resulted in significantly the highest leaf width among the accessions.

Production yield

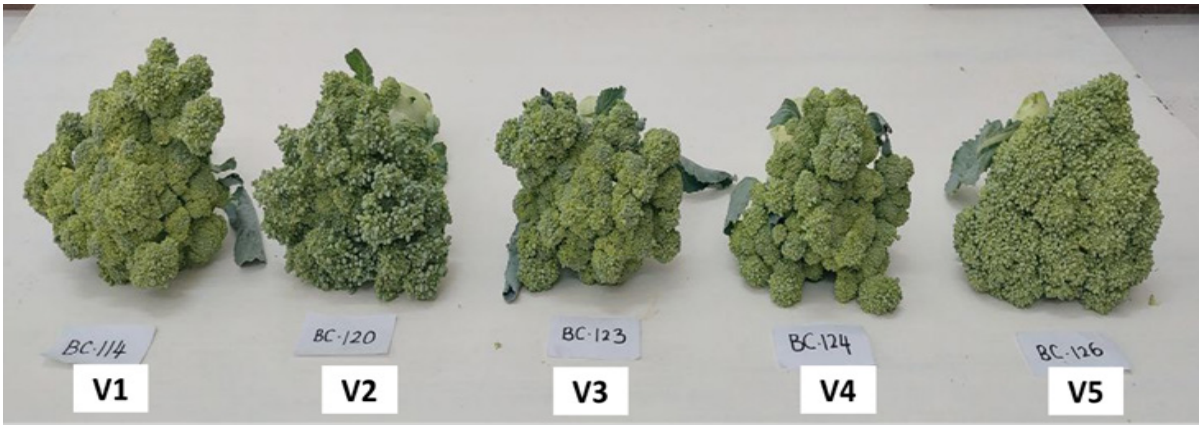
The highest curd height (50.28 cm) was observed in V4, while the lowest height (45.54 cm) was in V1 (Table 2). No significant difference was recorded in curd diameter among accessions (Table 2). V4 and V5 resulted in the highest curd weights (164.23 g & 166.27 g) and curd compactness (14.65 g/cm & 14.45 g/cm) among the accessions (Table 2). As a result, these five accessions had significantly different growth characteristics. V4 and V5 are the most outstanding yield-producing accessions. It proves that the genetic variability, nutritional absorption capability, and adaptability to agroclimatic conditions of accessions V4 and V5 influenced their performance (Marschner, 1990). Both accessions V4 and V5 generate significantly more compact curd, showing that both have a firm central head and are in demand on the market (Figure 1). It is supported by Tejaswini *et al*. (2018), which suggests that accessions V4 and V5 were of the heading type, whereas the other accessions are of the sprouting type.

Effect of spacing on broccoli growth and yield

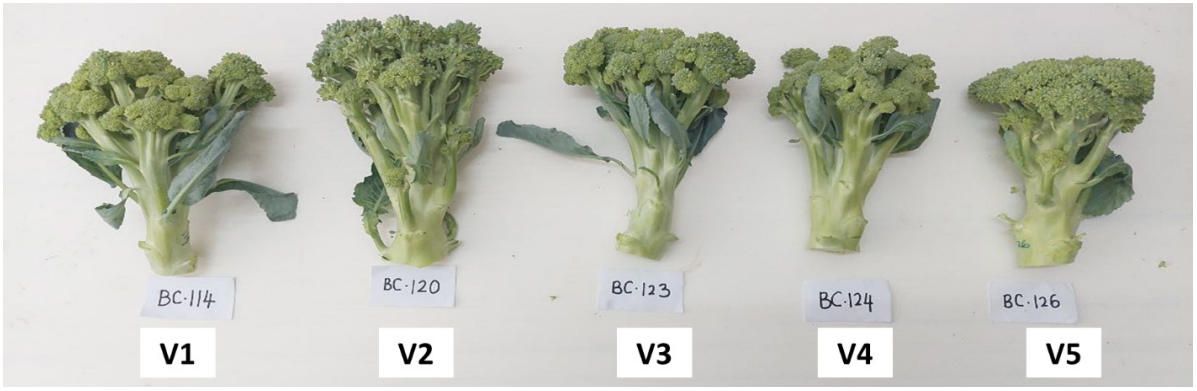
Tables 1 and 2 revealed that the parameters of the vegetative growth (plant height, number of leaves, leaf length, leaf width) and yield (curd height, curd diameter, curd weight, and curd compactness) were not significantly affected by different spacings. These findings are consistent with Tejaswini *et al*. (2018), who discovered that closer plant spacing led to a higher plant population per unit area, resulting in an increased yield per area. However, the effect of different plant spacings concerning days to curd initiation and days to curd maturity from DAT was significant. The significant minimum days to curd initiation from DAT (51.13 days) and days to curd maturity from DAT (60.20 days) were recorded with S2 spacing (60 cm × 60 cm). Days taken to curd maturity by different plant spacing might be due to early curd initiation and development of small curd. The shorter days required for growth at wider plant spacing might be due to reduced plant competition for light, moisture, nutrients, and other environmental resources (Sanjay *et al*., 2020). It is supported by Cheema *et al*. (2004), who observed that cultivating off-season vegetable crops under shade net could produce higher yield and advance maturity.

Interaction effect of spacing and accessions on broccoli growth and yield.

There were no significant differences in growth parameters among interaction between accessions and spacings, except with treatment S1V5 (Table 1). The maximum days to curd initiation (61.13 days) and days to curd maturity (70.40 days) from DAT were recorded under S1V5 treatment. However, the interaction effect of accessions and spacing treatment did not affect the curd yield quality of Broccoli (Table 2). Considering this, the growth duration for treatment S1V5 was still acceptable by using a fertigation system in a protected rain shelter in the lowland. Protected rain shelters provide a microclimate conducive to plant development (Sindhu & Ranjit, 2020). Fertigation delivers precise nutrition to the plant root zone, thus optimizing production and quality (Solaimalai *et al*., 2005; Biswas, 2010; Agostini *et al*., 2010).



(a)



(b)

Fig. 1. Variable characteristics of broccoli accessions, (a) curd and (b) stalk.

Pest & disease incidence

Based on field observations, accessions, and spacing treatments had very low pest incidence (1%), and no disease infestation was observed throughout the assessment. Plant accessions that showed insect pest damage symptoms were BC114 (Chef 1856), BC123 (Royal Green), BC124 (Green Magic, BC126 (V-075), and plant in control treatment, with spacing treatment 60 cm × 60 cm. Feeding damage was found on broccoli leaves at age 15 and 25 days. No damage was found on all plants with planting spacing 30 cm × 30 cm and at age 35 and 45 days. Based on the feeding damage symptom, it is suspected that the damage was caused by grasshoppers. The damage on the leaves was very low and not severe and presumably did not affect the head size and quality. The primary pest of broccoli, such as *Plutella xylostella*, *Phyllotreta* sp., and *Crocidolomia* sp. were not present in this experiment. Rain shelter with netting used in this experiment effectively reduced pest and disease infestation and contributed to low/no pest and disease incidences. It is supported by Takashi (1985), who claimed that rain shelters prevent disease spread in vegetables and reduce insect pest control measures, leading to safe produce for consumers.

Table 1. Vegetative growth performance of broccoli accessions at different spacings

Treatment	Plant Height (cm)	Number of Leaves	Leaf Length (cm)	Leaf Width (cm)	Days to Curd Initiation (from DAT)	Days to Curd Maturity (from DAT)
Accession (V)						
V1 (BC 114)	45.54 ± 3.15[a]	16.60 ± 1.92[a]	44.00 ± 2.75[a]	23.01 ± 1.59[a]	45.27 ± 2.37[a]	55.80 ± 3.26[a]
V2 (BC 120)	48.82 ± 2.98[bc]	16.47 ± 1.01[a]	47.42 ± 2.20[b]	26.02 ± 1.39[b]	45.53 ±2.07[a]	57.13 ± 2.26[ab]
V3 (BC 123)	46.74 ± 2.66[ab]	16.77 ± 2.98[a]	45.10 ± 1.85[a]	23.75 ± 1.40[a]	45.80 ± 3.10[a]	56.40 ± 3.11[ab]
V4 (BC 124)	50.28 ± 3.48[c]	17.40 ± 1.52[a]	52.63 ± 2.62[c]	23.17 ± 1.42[a]	50.87 ± 5.57[b]	63.00 ± 6.36[c]
V5 (BC 126)	46.10 ± 2.25[a]	17.33 ± 1.95[a]	47.30 ± 2.49[b]	26.25 ± 2.54[b]	51.13 ±7.54[b]	60.20 ± 6.55[bc]
Spacing (S)						
S1 (30 cm × 30 cm)	47.60 ± 3.55[a]	16.67 ± 1.83[a]	47.43 ± 4.10[a]	24.37 ± 1.98[a]	61.13 ± 7.42[b]	70.40 ± 7.30[b]
S2 (60 cm × 60 cm)	47.39 ± 3.27[a]	17.16 ± 2.13[a]	47.15 ± 3.52[a]	24.51 ± 2.43[a]	51.13 ±7.54[a]	60.20 ± 6.55[a]
Interaction (V × S)						
S1V1	NS	NS	NS	NS	45.00 ± 1.68[a]	56.53 ± 1.68[a]
S1V2	NS	NS	NS	NS	46.60 ± 3.31[a]	58.73 ± 2.26[a]
S1V3	NS	NS	NS	NS	46.07 ± 2.81[a]	58.73 ± 2.26[a]
S1V4	NS	NS	NS	NS	53.40 ± 1.06[a]	62.47 ± 2.77[a]
S1V5	NS	NS	NS	NS	61.13 ± 7.26[b]	70.40 ± 7.26[b]
S2V1	NS	NS	NS	NS	45.27 ± 2.37[a]	55.80 ± 3.26[a]
S2V2	NS	NS	NS	NS	45.53 ± 2.07[a]	57.13 ± 2.87[a]
S2V3	NS	NS	NS	NS	45.80 ± 3.09[a]	57.13 ± 2.87[a]
S2V4	NS	NS	NS	NS	50.87 ± 5.59[a]	63.00 ± 6.36[a]
S2V5	NS	NS	NS	NS	51.13 ± 7.54[a]	60.20 ± 6.55[a]

[a]Mean values in the same row with different alphabets (a>b>c) are significantly different at $p<0.05$ (ANOVA, Tukey's test).

[b]Values are given in means ± standard error.

[c]NS- not significant.

[d]DAT-Day after Transplanting

Table 2. Yield performance of broccoli accessions at different spacings

Treatment	Curd Height (cm)	Curd Diameter (cm)	Curd Weight (g/plant)	Curd Compactness (g/cm)
Accession (V)				
V1 (BC 114)	45.54 ± 3.15[a]	12.28 ± 1.65[a]	137.23 ± 18.88[a]	11.27 ± 1.57[ab]
V2 (BC 120)	48.82 ± 2.98[bc]	11.75 ± 1.57[a]	147.97 ± 29.41[ab]	12.58 ± 1.77[b]
V3 (BC 123)	46.74 ± 2.66[ab]	16.79 ± 19.58[a]	133.37 ± 20.57[a]	9.93 ± 2.30[a]
V4 (BC 124)	50.28 ± 3.48[c]	11.22 ± 1.06[a]	164.23 ± 21.23[b]	14.65 ± 1.38[c]
V5 (BC 126)	46.10 ± 2.25[a]	11.48 ± 1.19[a]	166.97 ± 39.36[b]	14.45 ± 2.40[c]
Spacing (S)				
S1 (30 cm × 30 cm)	47.60 ± 3.55[a]	13.33±2.59[a]	147.53±31.36[a]	12.38±2.77[a]
S2 (60 cm × 60 cm)	47.39 ± 3.27[a]	12.07±1.65[a]	132.37±28.49[a]	12.76±2.46[a]
Interaction				
V × S	ns	ns	ns	ns

[a]Mean values in the same row with different alphabets (a>b>c) are significantly different at $p<0.05$ (ANOVA, Tukey's test).

[b]Values are given in means ± standard error.

[c]NS- not significant.

CONCLUSION

The findings indicate that accessions V4-accession BC124 (Green Magic) and V5-accession BC126 (V-075) have the potential to be commercialized in the lowlands with S1:30 cm × 30 cm plant spacing to achieve higher broccoli value and yield under fertigation system. Further study on how broccoli responds to recommended doses of fertilizer formulas is required to optimize curd size, yield, and quality.

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ETHICAL STATEMENT

Not applicable.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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