Transactions on Science and Technology Vol. 7, No. 4, 178 - 188, 2020

Optimal Plant Density, Nutrient Concentration and Rootzone Temperature for Higher Growth and Yield of *Brassica rapa* L. 'Curly Dwarf Pak Choy' in Raft Hydroponic System Under Tropical Climate

Andrea Joyce Maludin#, Mok Sam Lum, Mohammad Mohd Lassim, Januarius Gobilik

Faculty of Sustainable Agriculture, Universiti Malaysia Sabah, Locked Bag No. 3, 90509 Sandakan, Sabah, MALAYSIA.
#Corresponding author. E-Mail: andreajmaludin@gmail.com.

ABSTRACT Little is known on the optimal plant densities, nutrient concentrations, and rootzone temperatures for Curly Dwarf Pak Choy' (CDP) production in raft hydroponic system in tropical climate. In this study, five experiments were carried out to assess the growth and yield of CDP at 40, 50 and 61 plants/m^2 × 1.7, 2.2 and 2.8 mS/cm nutrient concentrations (EC). This experiment was followed with single plant experiments in EC 2.2 mS/cm at 25°C/25°C - 27°C versus not-controlled/25°C - 38°C (rootzone °C/ambient °C). The highest growth and yield were achieved at 50 plants/m^2, EC 2.2 mS/cm, and 25°C rootzone temperature. Marketable size was also achieved in less than 30 days at the lower temperature. Growth and yield, however, were not depending on plant density × nutrient concentration. These three factors need to be optimized to achieve a higher Pak Choy yield in raft hydroponic system in tropical climate.

KEYWORDS: *Brassica* rapa L.; raft hydroponic system; plant density; electrical conductivity; rootzone temperature.
Received 07 November 2020 **Revised** 30 November **Accepted** 10 December 2020 **Online** 10 December 2020

Original Article

INTRODUCTION

Pak Choy or *Brassica rapa* L. (Brassicaceae) is one of the popular leafy vegetables in Asia (Cartea *et* al., 2010). Apart from its economic importance, it is also known for its health benefits. Pak Choy contains beneficial phytochemicals, provitamin A, vitamin C, minerals and fiber (Fahey, 2003; Acikgoz, 2016). The demand and awareness about the importance of vegetable for a healthy diet are increasing. However, the vegetable productions in Southeast Asia are still insufficient to meet the recommended minimum intake, which are at least 146 kg vegetables and fruits per capita (WHO & FAO, 2005). This need can be attained with the use of modern farming technologies that allows farmers to provide the condition for the crops to achieve its genetic growth potential. In that direction, the soilless farming could represent the effective crop management to enhance crop yield.

In a soilless production of Pak Choy, plant density, nutrient supply and rootzone temperature are some of the controllable factors that determine growth and yield. Plant density is the number of plants per area. A suitable plant density can lead to optimum marketable yields, as it affects the plants leaf area index (LAI) and light use efficiency (LUE) (Lee *et al*., 2003). Increment in plant spacing increased plant height, canopy width, leaf number, leaf length, and leaf fresh and dry mass per plant (Moniruzzaman, 2006). Cho *et al*. (2015) showed a linear relationship between shoot weights (dry and fresh) per area and plant density. At high plant density, shoot dry weight per plant decreases because inter-plant competition for light and nutrients increases. In commercial practices, plant densities are usually decided based on the mature size of the Pak Choy which can be as low as 20–30 plants/m^2 in floating system (Silva *et al*., 2015; Bailey & Ferrarezi, 2017). Cho and Son (2005) suggested a much higher density of 67 plants/m^2 to achieve the best yield of hydroponic Pak Choy. Wiangsamut and Koolpluksee (2020) recommended an even higher density with 167 plants/m^2. As there is a high variation in the current recommendations, it is certainly important to reassess plant density in soilless farming on a case-to-case basis to help farmers to decide on this factor.

A proper and balanced supply of nutrients will boost the growth and yield of hydroponic Pak Choy. Nevertheless, an optimal EC is crop specific and depends on the environmental condition (Sonneveld & Voog, 2009; Le Bot *et al*., 1998). For Pak Choy cultivation in a controlled-environment condition, the EC is suggested from 1.5 to 2.5 mS/cm (Parks & Murray, 2011; Ding *et al*., 2018; Lee *et al*., 2012). For open-system Pak Choy cultivation in tropical condition, however, reports on the suitable EC are scarce. This information is vital because the air temperature in a greenhouse in tropical climate can reach up to 38°C during midday. This promotes high rate of transpiration in plants. In this condition, the nutrient supply, as indicated by the solution's EC, will strongly determine the balance between water and nutrient uptake. A combination of high EC with high surrounding temperature will cause nutrient build up at the root surface, leading to osmotic drought or fertiliser toxicity. Although interaction between plant density and nitrogen supply has a significant effect on Chinese vegetable yield in conventional farming (Hill, 1990), the effect of these two factors on the growth and yield Pak Choy in hydroponic system is yet to be known. There is a possibility of maximizing the growth and yield of high-density hydroponic Pak Choy in tropical region by supplying more nutrients, but this has to be tested first because it could also be detrimental to the plants.

Rootzone temperature affects plant growth and the balance between water and nutrient uptake (Mozafar *et al*., 1993; Marschner *et al*., 1996; Bode Stoltzfus *et al*., 1998). In tropical climate, the temperature of the surrounding area is high. This condition may increase the hydroponic solution temperature. As a result, osmotic concentration in the rootzone also increases. Water and nutrient uptake balance are disordered and interrupted the photosynthesis. A severe situation occurs when the ambient temperature is also high, as temperatures above 35°C will halt the primary photosynthetic process in green plants (Al-Khatib & Paulsen, 1989). Lettuce, on the other hand, can be grown in tropical ambient temperature by lowering the rootzone temperature (He & Lee, 1998; Cometti *et al*., 2013). Lowering the rootzone temperature minimizes the effects of high EC and increases the concentration of dissolved oxygen. Hence, it facilitates plant water and nutrient uptake at higher ambient temperature. Pak Choy has a better tolerance to high ambient temperatures than lettuce, and thus controlling the rootzone temperature may be less critical. From another perspective, however, the need to control the rootzone temperature for Pak Choy stands on economic factor where a few previous studies indicate a remarkable yield of these vegetables in hot weather due to the lower rootzone temperature.

Based on the above review, little is reported in the literature about the optimal plant density, nutrient concentration and rootzone temperature for hydroponic production of leafy vegetables in tropical regions. Hence, this study was carried out to determine those values to achieve a higher growth and yield of *Brassica rapa* L. 'Curly Dwarf Pak Choy' (CDP) in raft hydroponic system in tropical climate. The data will fill up the relevant knowledge gaps for the benefits of the local farmers.

METHODOLOGY

This study was carried out in the Faculty of Sustainable Agriculture, Universiti Malaysia Sabah, Sandakan campus. The experiments on density and nutrient concentration were carried out in an insect proof rain shelter (IR). The ambient temperature and relative humidity in the IR were 25°C – 38°C and 50% – 91% respectively; it is an open-air rain shelter of 24m × 6m – the roof is UV plastic and the wall is an insect net. The experiments on rootzone temperature were carried out in a controlled-environment house (CE). The CE is an 8 m × 4 m greenhouse with corrugated polycarbonate wall and roof. The temperature, humidity and CO_2 levels inside the CE can be programmed to certain values using a computer. During this study, the temperature and relative humidity in the CE was controlled at 25°C – 27°C and 65% – 96%, respectively.

Plant Materials and General Cultural Method

The seeds of *Brassica rapa* L. 'Curly Dwarf Pak Choy' (CDP) were purchased from authorised local seed supplier. The CDP was first germinated in 1,536 4-cm-diameter hydroponic cups placed in eight 88cm × 56cm × 5cm trays filled each with 13L of 1 mS/cm nutrient solution. Cotton yarns were placed in the cups as the media and about 4-5 seeds were germinated directly on the yarn. The solution level in the trays were maintained by adding 3L filtered tap water every 2-3 days, or when necessary, to maintain the EC and pH of the solution. These seedlings were all established in the IR. On day 10 after sowing (DAS), the seedlings were thinned to retain two healthy seedlings per cup. The cups with the best seedlings were then selected and transplanted to the experiments (i) on density and nutrient concentration and (ii) on rootzone temperature. On day 10 after transplanting (DAT), a second thinning was carried out to retain only one seedling per cup until harvest. The plants were harvested at 27 DAT (37 (DAS). Monitoring of pest and disease were carried out daily throughout the study. Detected pests were removed by hands.

The composition of stock solution was 186.3 mg/L NO_3-N, 20.7 mg/L NH_4-N, 207 mg/L K, 69 mg/L Ca and 4.14 mg/L Fe for Stock A, 41.4 mg/L P, 41.4 mg/L Mg, 0.45 mg/L B, 0.12 mg/L Cu, 2.07 mg/L Mn, 0.02 mg/L Mo, and 0.28 mg/L Zn for Stock B; nutrient composition and concentration were rationalised based on the nutrient content in dry plant tissue as reported in Resh (2013). The nutrient solution was prepared by diluting the stocks with filtered tap water accordingly to the targeted ECs (1.7, 2.2 and 2.8 mS/cm). The pH was adjusted by adding 20% nitric acid to a favourable range of 5.5-6.5. The EC, pH and dissolved oxygen (DO) of the nutrient solutions in all experiments were measured and recorded every 3 days using EC/TDS tester (HI98318, Hanna Instrument), Eutech pH6+, and Eutech DO 6+ (Eutech Instruments, Thermo Fisher Scientific). An external data logger (HOBO® Pro v2 U23-002; www.onsetcomp.com) was placed 30cm above the ponds or the mini raft systems to record the temperature and relative humidity of the environment inside the IR and CE every hour throughout the study.

Effect of Plant Density and Nutrient Concentration

The experiments were carried out in the IR. Twelve 2.44m × 1.22m ponds were constructed and placed in 9m × 5m area in the shelter to collectively become semi-commercial raft hydroponic system. Each pond had four pieces of 0.6m × 1.2m Styrofoam-rafts and a capacity of 220L nutrient solution. A 1800L/h submersible water pump was placed in each pond to stir the nutrient solution in order to avoid sedimentation and to maintain the DO in the solution above 2ppm. The power of the water pump was controlled with a digital timer; it was set to work every 1 hour, with 2-hour rest in between throughout the day. The growth and yield of the CDP were assessed in a 3 × 3 factorial experiment with three levels of plant densities (PD) and nutrient concentration (EC) (Table 1). Nine units (ponds) of the semi-commercial raft hydroponic system were used in the experiment per production cycle. The experiment was laid out in a completely randomized design with five replications, or five production cycles.

Table 1. List of factors and treatment levels in Experiment 1.

Factors	PD (plants/m²)	EC (mS/cm)
	40 (15 x 15 cm) †	1.7
Treatments	50 (12 x 15 cm)	2.2
	61 (12 x 12 cm)	2.8

Note: PD = plant density; EC = nutrient concentration.
† plant spacing: distance between and within the rows of two hydroponic cups.

Effect of Rootzone Temperature

The experiments were carried out in 10 mini raft systems following the suspended raft and non-circulating method by Kratky (2010). Each mini raft system made of 24 cm (L) × 17 cm (W) × 14 cm (H) plastic container. Each system had one Styrofoam-raft; 4-cm hole was drilled at the centre of the Styrofoam to accommodate one hydroponic cup. The seedlings raised in the IR were selected and grown in EC 2.2 mS/cm nutrient solution as a single plant in each of the mini raft systems. Five systems were placed in the IR and CE, respectively, following a completely randomized design. The replicates in the IR represented not-controlled/ 25°C – 38°C (rootzone °C/ ambient °C: T1). The rootzone temperature was not controlled; it depended on the ambient temperature. The replicates in the CE represented 25°C/ 25°C – 27°C (rootzone °C/ ambient °C: T2). The rootzone temperature was controlled at 25°C using a 70W thermostat. The mini raft systems were placed in an 88cm × 56cm × 5cm tray that were filled with water and the water was run through the thermostat where the temperature was set to chill the water to 25°C. A thermometer was used to confirm that the rootzone temperature in the mini raft systems was 25°C.

Growth and Yield Assessments

Growth was evaluated as the height (H), number of leaves (LN), leaf area (LA), fresh root weight (FWR) and root to shoot ratio (R:S) of the CDP. Before harvesting, H was measured using a 30cm long standard scale as the length from the surface of hydroponic media to the highest free-standing point of the CDP crown. LN was counted including leaves that were just beginning to unfold, or once the leaf has expanded to 1cm² or greater. After harvesting, CDP were rinsed with water to remove dust or debris, and excess water was dried using laboratory grade tissue. LA was measured using leaf area meter (LI-3100 Area Meter, LI-COR Biosciences). Roots were separated from the shoots by cutting the stem just above the hydroponic media. FWR was weighed using a top balance (Model TLE3002E, Mettler Toledo). The shoots and roots of CDP were dried in oven (Model FD 23 – 20L, Binder) at 80°C until constant weight was attained (42 hours), and weighed immediately using a top balance. The R:S per plant sample was calculated based on the root and shoot dry matter weights.

Yield was measured as the fresh (FWS) and dry (DWS) shoot weights of the harvested CDP. Fresh weight was measured just after harvesting using the top balance. DWS was extracted from the R:S assessment explained above. Productivity per area (PV) was measured as the total yield of CDP per 1m² of area grown.

Plant Nutrient Uptake

Concentrations of N, P and K in dry plant tissue were measured as nutrient uptake of CDP. Sample was pre-treated, dried at 70°C for 42 hours (Sonneveld & van Dijk, 1982) and ground before analysis. Total N was determined using dry combustion-based analyser (CHN-600, LECO Corporation, St. Joseph, MI). Analyses of dry plant tissue for determination of total P and K were carried out using dry ashing method (Isaac & Johnson, 1975) with some minor modifications. Approximately 0.5g of the ground sample of dry plant tissue was weighed into a porcelain crucible. The sample was placed in a muffle furnace and ash at 300°C for 1 hour. The temperature was raised to 520°C and continued ashing for 5 hours until sample turns white. The sample was left to cool before inspection. Then, a few drops of distilled water were added to moisten sample, followed by 1mL of concentrated HCl. Sample was evaporated to dryness on a hotplate. Then 5mL of 20% HNO_3 was added and placed in a water bath 1 hour. All digestion was conducted in the fume hood following standard practices. After the digestion process has completed, the solution was filtered into a 50mL volumetric flask through a filter paper (Whatman No. 2). The volume of the solution was then made to the mark by adding deionized water. The concentration of K was determined by Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES Optima 5300 DV, Perkin Elmer). Total P was estimated using a benchtop photometer (HI83099, Hanna Instrument).

Statistical Analysis

Growth and yield of the CDP in the different PDs and ECs were statistically analysed by performing a two-way ANOVA on the data obtained. Normality and variance homogeneity test on the data were carried out prior to analysis; the tests showed that the data were normally distributed and had homogenic variances. The means were separated using Tukey HSD test. A T-test was performed to determine the effects of rootzone temperature on growth performance and yield of the CDP. All statistical analyses were carried out using SAS Version 9.4 (SAS Institute Inc., 2002) at alpha = 0.05.

RESULT

Effects of Plant Density and Nutrient Concentration

There was no significant effect of interaction between PD and EC on the growth and yield of the CDP either on H, LN, LA, FWR, R:S, FWS, DWS, or PV (Table 2). The effect of PD on H, LN and LA was not significant. Root growth as root weight was significantly lower at PD 60 plants/m^2. Hence, root to shoot ratio was higher at the highest PD treatment. Fresh and dry yield and productivity per area were significantly lower at PD 60 plants/m^2. EC had no effect on the growth parameters. Fresh yield was significantly higher at EC 2.8 mS/cm. Total yield per area significantly increased at EC 2.2 mS/cm, and it further increased at EC 2.8 mS/cm.

There was no significant effect of interaction between PD and EC on the nutrient uptake of the CDP either on N, P or K (Table 3). Plant density had no significant effect on the accumulation of N, P and K in the plants. However, increment in nutrient concentration increased the uptake of N and K. N and K significantly accumulated in EC 2.8 mS/cm. Based on the growth, yield and nutrient accumulation response of CDP, the best PD and EC are 50 plants/m^2 and 2.2 mS/cm, respectively.

Table 2. Growth and yield responses of CDP in different PD and EC.

Treatment	H (cm)	LN	LA (cm^2)	FWR (g)	R:S	FWS (g)	DWS (g)	PV (kg/m^2)
PD ($plants/m^2$)								
40	13.67±0.26a†	14.39±0.26a	56.21±2.63a	5.04±0.29a	0.10±0.004b	87.96±3.99a†	4.46±0.18a	4.49±0.36a
50	13.93±0.19a	14.27±0.25a	54.49±2.71a	4.37±0.27ab	0.11±0.003ab	83.20±2.96a	4.02±0.69ab	4.21±0.27ab
61	14.15±0.22a	13.69±0.22a	52.58±2.43a	3.84±0.18b	0.12±0.005a	72.03±2.85b	3.53±0.38b	3.69±0.29b
EC (mS/cm)								
1.7	13.73±0.23a	13.86±0.24a	51.50±2.10a	4.51±0.24a	0.11±0.005a	73.16±3.25b	3.77±0.15a	2.93±0.13c
2.2	14.09±0.23a	14.15±0.25a	52.58±2.20a	4.54±0.32a	0.11±0.005a	82.58±3.18ab	3.95±0.17a	4.13±0.16b
2.8	13.93±0.23a	14.35±0.26a	59.21±2.98a	4.20±0.27a	0.11±0.005a	87.44±3.76a	4.29±0.20a	5.33±0.23a
PD	NS	NS	NS	*	**	**	***	**
EC	NS	NS	NS	NS	NS	**	NS	***
PD × EC	NS	NS	NS	NS	NS	NS	NS	NS

† Data are means ± SE (n = 5). Values in each column followed by a different lower-case letter indicate significant difference by the Tukey's multiple range test ($P \leq 0.05$).
* = significant at 5% level of probability; ** = significant at 1% level of probability; *** = significant at 0.1% level of probability; NS = not significant

Table 3. N, P and K accumulation in dry tissue of CDP in different PD and EC.

Treatment	N (ppm)	P (ppm)	K (ppm)
PD ($plants/m^2$)			
40	59516±3460.0a†	94.81±3.97a	461.93±43.75a
50	58507±4039.88a	90.00±2.08a	428.77±41.91a
61	58890±3294.13a	91.11±4.41a	405.94±31.44a
EC (mS/cm)			
1.7	50253±2390.62b	91.11±1.67a	337.86±25.55b
2.2	58418±3360.49b	90.74±4.37a	416.69±27.58b
2.8	68243±1383.86a	94.07±4.30a	542.09±28.13a
PD	NS	NS	NS
EC	***	NS	***
PD × EC	NS	NS	NS

† Data are means ± SE (n = 3). Values in each column followed by a different lower-case letter indicate significant difference by the Tukey's multiple range test ($P \leq 0.05$).
*** = significant at 0.1% level of probability; NS = not significant

Effect of Rootzone Temperature

Controlling rootzone temperature at 25°C showed positive effects on CDP growth and yield (Table 4). H and LN of CDP was not significantly affected by rootzone temperatures. Root growth increased by 77% and leaf expansion by 58% compared to those of CDP in T1. Visual observation of size revealed that CDP in T2 was much larger where 20 DAT of T2 was similar in size to 27 DAT of T1 (Figure 1). For yield, fresh and dry yield per plant increased by 88% and 47% respectively, compared to those of CDP in T1. Controlling the rootzone temperature, however, did not affect accumulation pf N, P and K in dry tissue of CDP; concentration of these elements were not significantly different between T1 and T2 (Table 5).

Table 4. Growth and yield parameters of CDP in different rootzone temperatures.

T (°C)	H (cm)	LN	LA (cm²)	FWR (g)	R:S	FWS (g)	DWS (g)
T1	13.4±0.54a[†]	14.5±0.34a	71.03±5.84 b	7.31±0.70 b	0.12±0.009 a	85.28±5.02 b	5.44±0.17 b
T2	13.5±0.64a	17.0±0.73a	111.90±8.45 a	12.93±1.21 a	0.12±0.004 a	160.08±10.13 a	8.01±0.46 a

Note: T1 = uncontrolled temperature; T2 = 25°C.
[†] Data are means ± SE (n = 5). Values in each column followed by a different lower-case letter indicate significant difference by the Tukey's multiple range test ($P \leq 0.05$).

Table 5. N, P and K accumulation in dry tissue of CDP in different rootzone temperatures.

T (°C)	N (ppm)	P (ppm)	K (ppm)
T1	60127 ± 2721[†]	248±26.34	471.17 ± 33.2
T2	58284 ± 2361	265±19.45	425.89 ± 18.71

Note: T1 = uncontrolled temperature; T2 = 25°C.
[†] Data are means ± SE (n = 3).

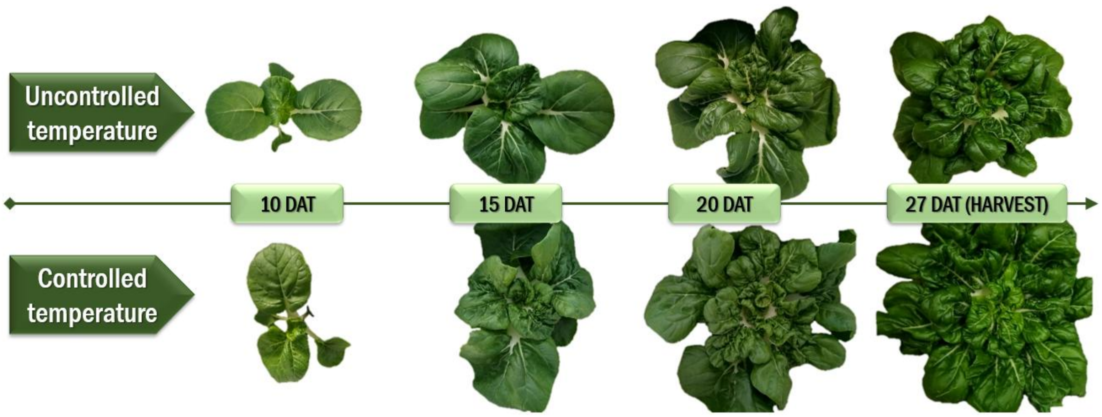

Figure 1. Growth stages of CDP in uncontrolled and controlled solution temperature. (scale: 1cm = 5cm)

DISCUSSION

Effect of Plant Density

CDP in PD 40 and 50 plants/m² achieved the highest growth and yield compared to that in 60 plants/m² (Table 2). Plants are known to develop adaptation strategy as a response to unfavourable growing conditions. Plant root system would expand in the presence of lower-ground competition especially water and nutrients, or decrease due to above-ground light competitions (Le Bot *et al.*, 1998). In this study, the root mass was significantly lower at PD 60 plants/m². This trend was also observed in R:S of the CDP. This could be the respond of plants in the highest PD to light competition, as when density increased many more leaves overlapped and adjacent plants shaded one another. Light is insufficient, leading to poor energy biosynthesis for shoot and root developments.

Planting density could determine the crop productivity as increased yield is the result of higher number of plants in an area. Cho and Son (2005) reported that the best marketable yield of Pak Choy was obtained at plant density 67 plants/m². Surprisingly, in this study, the yield of the CDP was significantly lower at PD 60 plants/m², which is still lower than the recommended density. This opposing finding could be a varietal factor where the Pak Choy variety used in this study is a semierect with leaves expanding horizontally rather than semi-vertically. In other words, shading effect is much severe. Cho *et al.* (2015) reported that productivity per area of Pak Choy increased with increasing plant density but at the same time shoot dry weight per plant decreased due to competition for light and nutrients. In this study, however, both yield per area and shoot dry weight per plant decreased as PD increased. This trend was well explained by Cho and Son (2005) where above the ideal density, both total yield and marketable yield (judged from individual yield) will significantly drop. It is known that accumulation of N and K was not affected by PD as nutrients are continuously available in the system. Hence, even a smaller root system is sufficient to absorb adequate amount of nutrients (Greenwood, 1983). In other words, the poor yield at PD 60 plants/m^2 is purely resulted from light competition, poor photosynthetic activity and low energy biosynthesis for growth rather than because of low nutrient availability.

Effect of Nutrient Concentration

EC affects growth performance of Pak Choy. Ding *et al.* (2018) reported that leaf area of Pak Choy was small when the plants were grown in EC 0 to 1.2 mS/cm, but it expanded when the nutrient concentration was increased to EC 1.8 to 4.8 mS/cm; however, it decreased once the nutrient concentration was increased to EC 9.6mS/cm. Leaf area and stomatal conductance decrease once the plants are grown in high nutrient concentration (Albornoz & Lieth, 2015). In this study, the leaf area size was reasonable irrespective of EC, as the ECs tested were all in the range suggested by Ding *et al.* (2018). The fresh yield per plant was significantly higher at EC 2.8mS/cm, while fresh yield per area was significantly increased at EC 2.2mS/cm. Yield continued to increase as EC increased. This increment is the result of increased macronutrients (NPK) supply at higher EC. Nitrogen is essential in chlorophyll synthesis, the primary light harvesting compound of photosynthesis. Phosphorus is essential in energy metabolism while, potassium functions in protein synthesis, activation of enzymes, and photosynthesis. Supplying these elements at the right amount increases photosynthetic rate and leads to increment in fresh yield, such as, the case for the CDP in this study. This trend was also reported by Albornoz and Lieth (2015) in their study on the effects of macronutrient content increment on photosynthetic rates in lettuce.

A proper and balanced supply of nutrients to hydroponic Pak Choy is important for maximizing growth and yield. Based on the data of this study, EC 2.2 mS/cm is proposed as the appropriate nutrient concentration. It satisfies both the EC and the acceptable nitrogen limit in vegetables recommended in the literature. EC of 1.5 to 2.5 mS/cm have been suggested as the best EC for higher-yield hydroponic Pak Choy farming in controlled-environment conditions (Parks & Murray, 2011; Ding *et al.*, 2018; Lee *et al.*, 2012). In this study, the yield of the CDP, however, was still increasing even after the EC was increased beyond the range suggested above (Table 2). Hence, if it is not because of the concern about nitrogen limit in vegetable for safer consumption, the higher EC used in this study would rightly be suitable for hydroponic Pak Choy cultivation in tropical condition. The acceptable daily intake (ADI) of nitrate as determined by the Scientific Committee on Food (SCF) was 0 to 3.7 mg/kg body weight/day (Santamaria, 2006). This amount is equivalent to the intake of 222 mg nitrate/day for and adult weighing 60kg, which was also found to be more-or-less the concentration of nitrate in 96g plant tissue of Pak Choy grown in EC 2.2 mS/cm. In Malaysia, the average consumption of green leafy vegetables among 40% of adults was 96g/day (Norimah *et al.*, 2008), meaning EC 2.2. mS/cm offers the safest limit of nitrogen concentration in vegetable. It is indeed considered to be safe, as the total recommendation of leafy greens consumption by WHO is 240g per day (Striegel-Moore *et al.*, 2006).

Effect of Rootzone Temperature

A lower rootzone temperature resulted in higher growth and yield of the CDP (Table 4). This was because root mass was higher at a lower solution temperature (Table 4). At a higher solution temperature, root death and bolting would be common as a result of reduced dissolved oxygen (DO) concentration and limited cellular respiration (Cometti *et al.*, 2013). With a higher root volume, CDP in T2 had higher water and nutrient uptake, resulting in a significantly higher yield. Crop growth accelerates when exposed to a lower temperature (Dodd *et al.*, 2000). Controlling the rootzone temperature at 25°C was also found to have shortened the time to achieve the marketable size to 30 days (Figure 1). In another perspective, this advantage could also reduce fertilizer use and increase production cycle a year.

CDP in T2 had higher water content of 95.0% compared to 93.6% in T1. It was reported that the average water content in hydroponic lettuce increased from 94.6% to 95.2% once the temperature was controlled at 26°C (Cometti *et al.*, 2013). A low solution temperature speeds up the metabolic processes, inducing water and nutrient uptake, and promotes the increase in shoot growth (Moorby & Graves, 1980). Nutrient accumulation, however, was not affected by solution temperature (Table 5), meaning the increment in the growth and yield (Table 4) is thought to be the result of a more balanced water and nutrient uptake of the plants at 25°C rootzone temperature.

CONCLUSION

Based on the data obtained, the optimal plant density, nutrient concentration and rootzone temperature for CDP production in raft hydroponic system in tropical climate are 50 plants/m^2, 2.2 mS/cm EC, and 25°C, respectively. There is also no significant effect of interactions between plant densities and nutrient concentrations on growth and yield of CDP. Controlling the rootzone also shortens the growing period of this Pak Choy. It has to be noted that the optimal density recommended is lower than the rate recommended in the literature, because for CDP, higher plant spacing is required to reduce light competition. Optimal plant density and nutrient requirement differ for different types of leafy vegetables, meaning optimizing the three factors are crucial for a higher leafy vegetable production in raft hydroponic system under tropical climate.

ACKNOWLEDGEMENTS

This research is supported by UMS Research Grant Scheme (GUG0260-2/2018).

REFERENCES

[1] Acikgoz, F. E. 2016. Seasonal variations on quality parameters of pak choi (Brassica rapa L. subsp. chinensis L.). *Advances in Crop Science and Technology*, 4, 233.

[2] Albornoz, F. & Lieth, J. H. 2015. Over fertilization limits lettuce productivity because of osmotic stress. *Chilean Journal of Agricultural Research*, 75, 284-290.

[3] Al-Khatib, K., & Paulsen, G. M. 1989. Enhancement of thermal injury to photosynthesis in wheat plants and thylakoids by high light intensity. *Plant Physiology*, 90, 1041-1048.

[4] Bailey, D. S. & Ferrarezi, R. S. 2017. Valuation of vegetable crops produced in the UVI Commercial Aquaponic System. *Aquaculture Reports*, 7, 77-82.

[5] Bode Stoltzfus, R. M., Taber, H. G. & Aiello, A. S. 1998. Effect of increasing root-zone temperature on growth and nutrient uptake by 'Gold Star' muskmelon. *Journal of Plant Nutrition*, 21, 321-328.

[6] Cartea, M. E., Francisco, M., Soengas, P. & Velasco, P. 2010. Phenolic compounds in Brassica vegetables. *Molecules*, 16, 251-280.

[7] Cho, Y. C. & Son, J. E. 2005. Effect of planting density on growth and yield of hydroponically-grown Pak-choi. *Horticulture, Environment and Biotechnology*, 46(5), 291-294.

[8] Cho, Y. Y, Lee, J. H., Shin, J. H. & Son, J. E. 2015. Development of an expolinear growth model for Pak-choi using the radiation intergral and planting density. *Horticulture, Environment and Biotechnology*, 56(3), 310-315.

[9] Cometti, N. N., Bremenkamp, D. M., Galon, K., Hell, L, R. & Zanotelli, M. F. 2013. Cooling and concentration of nutrient solution in hydroponic lettuce crop. *Horticultura Brasileira*, 31, 287-292.

[10] Ding, X., Jiang Y., Zhao, H., Guo, D., He, L., Liu, F., Zhou, Q., Nandwani, D., Hui, D. & Yu, J. 2018. Electrical conductivity of nutrient solution influenced photosynthesis, quality, and antioxidant enzyme activity of pakchoi (Brassica campestris L. ssp. Chinensis) in a hydroponic system. *PLoS ONE*, 13(8), e0202090. https://doi.org/10.1371/journal.pone.0202090

[11] Dodd, I. C., He, J., Turnbull, C. G. N., Lee, S. K. & Critchley, C. 2000. The influence of supra optimal root-zone temperatures on growth and stomatal conductance in Capcicum annum L. *Journal of Experimental Botany*, 51, 239-248.

[12] Fahey, J. W. 2003. *Encyclopedia of food and sciences and nutrition* (2nd edition.). Baltimore, MD, USA: John Hopkins University.

[13] Greenwood, D. J. 1983. Quantitative theory and the control of soil fertility. *New Phytologist*, 94, 1-18.

[14] He, J. & Lee, S. K. 1998. Growth and photosynthetic responses of three aeroponically grown lettuce cultivars (Lactuca sativa L.) to different rootzone temperatures and growth irradiances under tropical aerial conditions. *The Journal of Horticultural Science and Biotechnology*, 73(2), 173-180.

[15] Hill, T. R. 1990. The effect of nitrogenous fertilizer and plant spacing on the yield of three Chinese vegetables – Kai lan, Tsoi sum and Pak choi. *Scientia Horticulturae*, 45, 11-20.

[16] Isaac, R. A. & Johnson, W. C. 1975. Collaborative study of wet and dry ashing techniques for the elemental analysis of plant tissue by Atomic Absorption Spectrophotometry. *Journal of the AOAC*, 58(3), 436-440.

[17] Kratky, B. A. 2010. A Suspended Net-pot, non-circulating hydroponic method for commercial production of leafy, romaine, and semi-head lettuce. *Vegetable crops*, Sept. 2010, VC-1.College of Tropical Agriculture and Human Resources, University of Hawai'i at Manoa.

[18] Le Bot, J., Adamowicz, S., & Robin, P. 1998. Modelling plant nutrition of horticultural crops: A review. *Scientia Horticulturae*, 74, 47-82.

[19] Lee, J. H., Goudriaan, J., & Challa, H. 2003. Using the expolinear growth equation for modelling crop growth in year-round cut chrystanthemum. *Annals of Botany*, 92, 697-708.

[20] Lee, S. G., Choi, C.S., Lee, J. G., Jang, Y. A., Nam, C. W., Yeo, K. H., Lee, H. J., & Um, Y. C. 2012. Effects of different EC in nutrient solution on growth and quality of red mustard and pak-choi in plant factory. *Journal of Bio-Environment Control*, 21(4), 322-326.

[21] Marschner, H., Kirkby, E. A., & Cakmak, I. 1996. Effect of mineral nutritional status on shoot-root partitioning of photoassimilates and cycling of mineral nutrients. *Journal of Experimental Botany*, 47, 1255-1263.

[22] Moniruzzaman, M. 2006. Effects of plant spacing and mulching on yield and profitability of lettuce (Lactuca sativa L.). *Journal of Agriculture and Rural Development*, 4, 107-111.

[23] Moorby, J. & Graves, C. J. 1980. Root and air temperature effects on growth and yield of tomatoes and lettuce. *Acta Horticulturae*, 98, 29-44.

[24] Mozafar, A., Schreiber, P., & Oertli, J. J. 1993. Photoperiod and root-zone temperature: Interacting effects on growth and mineral nutrients of maize. *Plant Soil*, 153, 71-78.

[25] Norimah, A. K., Safiah, M., Jamal, K., Siti, H., Zuhaida, H., Rohida, S., Fatimah, S., Siti, N., Poh, B. K., Kandiah, M., Zalilah, M. S., Wan Manan, W. M., Fatimah, S. & Azmi, M. Y. 2008. Food consumption patterns: Findings from the Malaysian Adult Nutrition Survey (MANS). *Malaysian Journal of Nutrition*, 14(1), 25-39.

[26] Parks, S. & Murray, C. 2011. *Leafy Asian vegetables and their nutrition in hydroponics*. NSW: Industry and Investment NSW.

[27] Santamaria, P. 2006. Nitrate in vegetables: Toxicity, content, intake and EC regulation. *Journal of the Science of Food and Agriculture*, 86, 10-17.

[28] Silva, L., Gasca-Leyva, E., Escalante, E., Fitzsimmons, K. M. & Lozano, D. V. 2015. Evaluation of biomass yield and water treatment in two aquaponics system using the dynamic root floating technique (DRF). *Sustainability*, 7, 15384-15399.

[29] Sonneveld, C. & van Dijk, P. A. 1982. The effectiveness of some washing procedures in the removal of contaminants from plant tissue samples of glasshouse crops. *Communications in Soil Science and Plant Analysis*, 13, 487-496.

[30] Sonneveld, C. & Voogt, W. (2009). *Plant nutrition of greenhouse crops*. New York, USA: Springer.

[31] Striegel-Moore, R. H., Thompson, D. R., Affenito, S. G., Franko, D. L., Barton, B. A., Schreiber, G. B., Daniels, S. R., Schmidt, M. & Crawford, P. B. 2006. Fruit and vegetable intake: Few adolescent girls meet national guidelines. *Preventive Medicine*, 42, 223-228.

[32] WHO & FAO. 2005. *Fruit and Vegetables for Health.* Report of a Joint FAO/WHO Workshop, 1-3 September 2004, Kobe, Japan. World Health Organization and Food and Agriculture Organization of the United Nations 2005 45p http://www.who.int/entity/dietphysicalactivity/publications/fruit_vegetables_report.pdf?ua=1

[33] Wiangsamut, B. & Koolpluksee, M. 2020. Yield and growth of Pak Choi and Green Oak vegetables grown in substrate plots and hydroponic systems with different plant spacing. *International Journal of Agricultural Technology*, 16(4), 1063–1076.