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Nitrogen and Potassium concentration in the nutrient solution affects growth, yield and physiology in bush snap beans

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Abstract

The study aimed to evaluate the effects of N-K concentration in the nutrient solution on the growth, yield, and physiological characters of two bush snap bean cultivars. 'Torukatto' exhibited a longer vine than 'Super Light Green.' 'Super Light Green' had a larger canopy, more leaves produced, greater leaf area, more shoots developed, and heavier shoot fresh and dry weights. 'Super Light Green' produced a few flowers and low pod number and yield. 'Torukatto' had a higher percent pod setting, but 'Super Light Green' had a heavier weight per pod. There was a significant influence of N-K levels on leaf area and number of shoots produced. Increasing the N-K level slightly increased the leaf area. 'Torukatto' had significantly higher SPAD values and rate of net photosynthesis than that of 'Super Light Green'. The stomatal conductance and transpiration rate differed significantly between the cultivars. Increasing the N-K level markedly improved the physiological measurements at a slightly increasing trend. There was a strong correlation between yield and number of pods and between photosynthesis and leaf color.

Key words: N-K concentration, nutrient solution, bush snap bean, hydroponics.

INTRODUCTION

Beans are an inexpensive and good source of protein, minerals, essential vitamins, and dietary fiber (Valdez-Perez et al., 2011; Ndegwa et al., 2006; Drummond, 1996; Kelly and Scott, 1992). Apart from its nutritive and economic importance, it has been used extensively as suitable plant material in a wide variety of physiological and biochemical researches (Davis, 1997). Snap bean is commonly grown in soil, but it could be grown in nutrient solution or soil-less media, especially in cases where there is an unhealthy soil environment.

Plant nutrition is one of the crucial factors that influence crop growth and development. Nitrogen (N) and potassium (K) are the two macroelements that have been studied, involving different crop species [sweetpotato (Nin and Gilsanz, 1998); carrot (Abrahamson et al., 1998); snap beans (Valdez et al., 2002); pepper and tomato (Ortas, 2013; Ddamulira et al., 2019; Nunes Júnior, 2017); chrysanthemum (Azeezahmed et al., 2016); wheat (Guo et al., 2019); melon (Gratieri et al., 2013); and fennel (Barzegar et al., 2020)].

Previous investigations have shown that fertilization affects crop yields and nutrient element uptake (Abrahamson et al., 1998; Paterson et al., 1966; Brown et al., 1969). An optimum amount of N application is essential for growth and high yield of vegetables and herbs (Wang et al., 2018; Geng et al., 2016). Furthermore, nitrogen fertilization resulted in a significant increase in the vegetative growth as well as the pod yield, and in the NO_3-N, total N, P, Ca, Mg, S, Mn, Fe, and Zn contents of bean leaves (Paterson et al., 1966; Peck et al., 1989).

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Arya et al. (1999) reported that high dosages of N (50kg/ha) and K (100kg/ha) delayed the days to 50% flowering, but high P (100kg/ha) and lower K (50kg/ha) promoted early flowering. Srinivas and Naik (1988) noted that high N and P rates significantly increased pod number and pod weight. Asif and Greig (1972) reported that increased N applications resulted in increased pod yield, higher contents of K, Ca, Mg, and Zn in the plants, and accumulation of NO_3-N in the pods. Rana et al. (1998) found that seed and straw dry matter production increased significantly up to the dosage of 120 kg N/ha. Abou El-Magd et al. (2010) reported that the application of K improved plant length, leaf number, bulb dimensions, fresh and dry weight of leaves and bulbs, and macronutrient content in leaf and bulb tissues of sweet fennel.

In hydroponics, bush and pole-type snap beans increased dry weights and mineral contents (N, P, K, Ca, Mg) with growth in plant organs (Ikeda et al., 1989). Iimura et al. (1999) showed that hydroponically-grown beans increased shoot and dry weights, number of flowers, pod set, and pod yield compared to soil-grown plants. Valdez et al. (2002), found that additional N and K in the solution increased vine length, leaf color, and gas exchange in leaves of bush snap beans. Garcia and Pinchinat (1973) reported that the seed yield of two snap bean cultivars exceeded 6t/ha when grown in gravel culture.

This study's objective was to determine the influence of N and K concentration in the nutrient solution on the growth, yield, and physiology in two bush snap bean cultivars.

Snap bean (*Phaseolus vulgaris* L.) is a legume crop that commands high demand globally. It is cultivated for its green pods or dry seeds. It is a warm-season vegetable crop (Yirga, 2013) grown in all continents except Antarctica (Gepts, 1998).

MATERIALS AND METHODS

Plant material and growth conditions

Two bush snap bean (*Phaseolus vulgaris* L.) cultivars ('Torukatto,' Kyowa Seed Co. and 'Super Light Green', Tohoku Seed Co.) were pre-germinated at 29ºC inside a germination chamber. At radicle emergence, the pre-germinants were re-sown in #72 plug-tray filled with granulated rockwool. The seedlings were raised at days/nights of 25±3/18±1ºC under natural photoperiods and irradiance. Ten-day old seedlings were pulled and transferred to a plastic hydroponic container using a one-fourth strength Enshi-shoho solution (Hori, 1966). After seven days, seedlings were transferred to 1/2000a-size Wagner pot containing 10 L solution. Each pot contained two sample plants and was replicated three times. The treatments used were 4-2, 8-4, 12-8, 16-12, 20-16 N-K me/L. The ½ strength of an Enshi-shoho solution was used as the control treatment (8-4 NK me/L). The culture solution was aerated by continuous bubbling. The experimental treatments were imposed from June 11 until July 13, 2001. The plants were grown at days/nights of 27±5/18±2ºC under 12-hour photoperiod and natural irradiance in the glasshouse of the Faculty of Horticulture, Chiba University, Japan.

Plant sampling, measurements and analyses

The relative leaf chlorophyll content was determined using a hand-held SPAD 502 chlorophyll meter (Minolta Co. Ltd, Japan), and the rate of photosynthesis was determined using a portable photosynthesis system (Kip-8510 Ver. 2.03, Koito Industries) during the early pod development stage. Fully expanded middle lamina of a trifoliate leaf positioned at the third node from the base of the main stem was sampled for leaf color; and net photosynthetic rates were measured between 11:00 to 12:00 noon on a fine day. The number of flowers, flower abscission, and aborted pods was recorded until the termination of the experiment.

Three replicate samples were separated into leaves, stems, and roots, and subsequent vegetative growth parameters such as vine length, leaf number, leaf area, and fresh weight were recorded. Plant samples were dried in a convection oven at 68ºC for 72 hours, and corresponding dry weights were recorded.

The experiment was arranged in a completely randomized design. Data were subjected to a two-way analysis of variance to determine the significance of the treatments.

RESULTS AND DISCUSSIONS

Horticultural characters

Table 1 shows that snap bean cultivar significantly influenced vine length. The 'Torukatto' variety had markedly longer vines compared to the 'Super Light Green.' However, 'Super Light Green' had a significantly higher number of leaves, leaf area, number of shoots, and shoot fresh and dry weights compared to 'Torukatto.' Root dry weight was not significantly different between the two cultivars. The growth and development of crops highly depend on their genetic make-up and the environment where they are grown. The 'Super Light Green' has a very large canopy that makes it comparatively different from 'Torukatto' in terms of vegetative growth. Resh (2012) revealed that different cultivars in the same plant species generally have different requirements, especially for nitrogen (N), phosphorus (P), and potassium (K).

The various nitrogen and potassium rates had no significant influence on vine length, the number of leaves, shoot fresh and dry weights, and root dry weight at harvest in both bush snap bean cultivars. This corroborates with the findings of Wamser et al. (2017) that N and K concentrations in the nutrient solution did not influence dry mass of bell pepper plant shoots. But they added that nitrogen concentrations higher than 9 mmol L^{-1} increased the dry matter in plant shoots. In the present study however, the number of shoots was significantly affected by increasing nutrient levels. Moreover, the leaf area increased with an increase in the N-K level in the nutrient solution (Table 1). Gratieri et al. (2013) found that increasing levels of nitrogen and potassium in the nutrient solution significantly influenced increments in leaf area of melon plants.

There was a significant interaction between cultivar and rates of nitrogen and potassium nutrients on shoots production (Table 1). On the other hand, there was no significant interaction between the two variables on most of the vegetative parameters. The data shows that the level of nutrients used for both the cultivars was insufficient to cause a significant difference in vegetative growth performance.

Reproductive characters

There was a significant influence of cultivar on the number of trusses, number of flowers, number of pods, percent pod set, weight per pod, and pod yield (Table 2). There was a higher number of flowers produced in 'Torukatto' than in 'Super Light Green' that resulted in a higher number of pods harvested and, consequently, high pod yield. The production of higher pod number and pod yield in 'Torukatto' was related to its growth morphology. This variety has fewer shoots and leaves than the 'Super Light Green', thus the photo-assimilates produced in the leaves may have been transported to the flowers and pods to maintain their growth and development. In 'Super Light Green,' a high competition of food may be the reason why there were few flowers that developed, thereby producing low pod yield.

Table 1. Effects of N-K concentration in the nutrient solution on growth attributes of two bush snap bean cultivars.

Cultivar	N-K Level (me/l)	Vine Length (cm)	No. of Leaves	Leaf Area (dm^2)	Shoot FW (g/plant)	Shoot DW (g/plant)	Root DW (g/plant)	No. Of shoots
'Torukatto'								
	4-2	59.8	16.0	28.8	90.1	13.9	2.1	5.0
	8-4	64.9	17.5	29.3	83.1	12.6	2.0	4.3
	12-8	61.0	17.8	30.1	80.5	12.5	1.9	4.0
	16-12	58.9	19.0	30.7	87.8	12.8	2.4	4.8
	20-16	57.5	18.8	31.6	94.3	13.3	1.8	5.7
'Super Light Green'								
	4-2	45.5	32.3	41.4	134.8	17.9	2.0	8.0
	8-4	45.8	31.8	41.5	148.7	19.2	2.6	10.5
	12-8	47.8	30.0	42.8	136.5	17.5	2.1	9.7
	16-12	43.5	28.8	42.6	141.7	18.1	2.3	11.5
	20-16	44.9	30.8	43.8	138.4	17.7	2.4	10.3
ANOVA^z								
Cultivar (A)		**	**	**	**	**	NS	**
N-K level (B)		NS	NS	**	NS	NS	NS	**
A x B		NS	NS	NS	NS	NS	NS	**

^{z}NS, *, ** indicate non-significance and significance at *P<0.01*, respectively.

Table 2. Effects of N-K concentration in the nutrient solution on reproductive attributes of two bush snap bean cultivars.

Cultivar	N-K Level (me/l)	No. of trusses	No. of flowers	No. of pods	% pod set	Pod Weight (g/pod)	Pod Yield (g/plant)
'Torukatto'							
	4-2	16.3	61.5	38.2	81.9	6.0	227.7
	8-4	15.5	63.0	35.5	74.2	6.0	221.4
	12-8	16.0	61.8	36.8	80.4	6.1	224.6
	16-12	16.5	70.3	39.0	77.0	6.3	245.4
	20-16	16.7	71.8	40.3	74.8	6.0	244.4
'Super Light Green'							
	4-2	17.8	43.0	16.0	58.6	6.5	104.4
	8-4	16.5	51.8	20.8	62.0	6.7	139.6
	12-8	17.0	52.8	19.5	55.9	6.6	129.9
	16-12	18.5	53.0	20.8	58.4	6.6	136.9
	20-16	17.5	59.8	20.5	55.9	6.6	136.1
ANOVA^z							
Cultivar (A)		*	**	**	**	**	**
N-K level (B)		NS	**	NS	NS	NS	NS
A x B		NS	NS	NS	NS	NS	NS

^{z}NS, *, ** indicate non-significance, significance at *P<0.05* or at *P<0.01*, respectively.

The rates of nitrogen and potassium significantly influenced the production of flowers in both bush snap bean cultivars. However, the nutrient levels did not affect the production of flower trusses and pods, percent pod set, weight per pod and pod yield. The number of flowers in both cultivars increased with the increasing ratio of nutrient N and K in the solution. The significant reduction in the number of pods was a consequence of high rates of abscission of flowers and small pods (no data shown) as this phenomenon was monitored during the reproductive growth. In leaf vegetable, increasing nitrogen concentration in the nutrient solution increased yield of lettuce both in winter and spring growing seasons (Djidonou and Leskovar, 2019). In fruit vegetable, higher N concentrations in the nutrient solution also increased marketable yield in bell pepper plants (Wamser et al., 2017); and in melons (Gratieri et al., 2013). However, yield and number and weight of marketable fruits were not affected by the K concentration in the nutrient solution (Wamser et al., 2017).

There was no significant interaction between cultivar and N-K level on all the reproductive parameters measured in this experiment. This finding was in agreement with those observed in large fruited vegetable like bell pepper that N and K concentrations did not significantly influence yield and number and weight of marketable fruits (Wamser et al., 2017).

Physiological characters

The relative leaf chlorophyll content in the leaves and photosynthetic rates of 'Torukatto' were higher than 'Super Light Green' (Table 3). The stomatal conductance and transpiration rates differed with the response of each cultivar. Peet et al. (1977) showed that there was a high variation in photosynthesis and stomatal resistances in nine dry bean varieties. They further reported an increase in photosynthesis rate at the early pod development stage than in the first flowering stage in all cultivars. However, the cultivars tested showed variable responses in that some of the varieties tended to increase stomatal resistance during the pod development stage while other varieties decreased or remained similar to the first flowering stage.

In this study, the nitrogen and potassium level in the nutrient solution significantly influenced the relative chlorophyll content in snap bean leaves. The increasing trend in leaf greenness as the amount of N in the solution increase occurred in both cultivars. This indicates that the nitrogen in combination with potassium promoted chlorophyll formation. The increasing tendency in leaf color subsequently resulted in an increased rate of photosynthesis in both cultivars (Table 3). There was a significant effect of N-K level on the transpiration rate and leaf stomatal conductance during the early pod development stage.

The combined effects of variety and N-K nutrition did not significantly affect the stomatal conductance. However, significant interaction effects were found on leaf color, photosynthesis, and transpiration rate.

Table 3. Effects of N-K concentration in the nutrient solution on some physiological characters of two bush snap bean cultivars.

Cultivar	N-K level (me/l)	Leaf Color	Pn^z	Gs^y	E^x
'Torukatto'	4-2	42.87	20.42	0.43	5.89
	8-4	43.68	21.55	0.57	6.31
	12-8	44.82	22.12	0.69	6.52
	16-12	44.95	22.25	0.71	6.63
	20-16	46.66	22.75	0.84	6.76
'Super Light Green'					
	4-2	38.33	15.04	0.40	4.83
	8-4	38.63	15.62	0.56	5.65
	12-8	38.89	17.69	0.62	6.75
	16-12	39.76	18.09	0.65	6.76
	20-16	41.38	18.65	0.76	6.77
$ANOVA^w$					
Cultivar (A)		**	**	**	**
N-K level (B)		**	**	**	**
A x B		**	**	NS	**

^{z}Pn – Net photosynthesis
^{y}E - Transpiration rate
^{x}Gs - Stomatal conductance
^{w}NS, ** indicate non-significance and significance at *P<0.01*, respectively.

Correlations

High correlations were found between yield and number of pods, and between leaf color and photosynthesis (Table 4). However, low correlations were observed between yield and other reproductive parameters and physiological characters. The high positive correlation between leaf color and net photosynthetic rate shows that leaf color directly influenced the rate of photosynthesis. Moreover, a positive correlation between leaf color and photosynthesis agrees with Hesketh et al. (1981) who demonstrated that there was a positive correlation between leaf photosynthetic rate and chlorophyll and soluble protein contents. Ma et al. (1995) reported that leaf greenness, using SPAD-502 hand-held chlorophyll meter to measure relative chlorophyll, was positively correlated with leaf photosynthesis at growth stages R4 to 3 to 10 days after R5 in 16 soybean genotypes. Peet et al. (1977) further revealed that there were significant correlations between rates of photosynthesis of nine dry bean varieties and their biological and seed yield when the rate of photosynthesis was measured during the pod setting stage. The highest photosynthetic rates at pod filling have also been noted in soybean (Dornhoff and Shibles, 1970; Shibles et al., 1975).

Table 4. Correlation analysis between yield and some physiological characters; yield and other reproductive components; and net photosynthesis (Pn) and leaf color of two bush snap bean cultivars.

Cultivar	Parameter	Correlate	R2
'Torukatto'	Pod Yield	No. of Flower	0.208
		No. of Pods	0.601
		No. trusses	0.148
	Pn	Leaf Color	0.856
'Super Light Green'	Pod Yield	Leaf Color	0.640
		Pn	0.130
		No. of Flower	0.190
		No. of Pods	0.990
		% Pod set	0.250
	Pn	Leaf Color	0.856

CONCLUSION

The growth and development of the two bush snap bean cultivars were significantly different which was mainly due to their inherent genetic characteristics. 'Super Light Green' seemed to have a very luxuriant growth as the N-K level in the solution increased. This may have directly affected the production of flowers and consequently reduced pod yield. In 'Torukatto' on the other hand, vegetative growth is much less but the production of flowers and pods and pod yield were higher. The level of N-K did not show much influence on the vegetative and reproductive growth, except in the improvement of leaf color and photosynthesis in both cultivars.

CONFLICT OF INTEREST

The author sees no conflict of interest.

AUTHOR CONTRIBUTION

The author was the one who conducted the research as well as the analysis of data and interpretation and discussion of results.

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