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Enhancement of sweet pepper (*Capsicum annuum* L.) growth and yield by addition of Nigari, an effluent of salt industries, in soilless culture

Md. Jahedur Rahman and Haruhisa Inden*

Laboratory of Advanced Horticulture, Faculty of Agriculture, University of Miyazaki, Miyazaki 889-2192, Japan

***Corresponding author: inden@cc.miyazaki-u.ac.jp**

Abstract

Nigari, an effluent of salt industries, is a less expensive alternative fertilizer source. Without testing its effect on growth and yield, it may not be suitable for use as an alternative fertilizer in a sustainable production system. Greenhouse trials were conducted over two years in response to application of Nigari. Sweet pepper cultivars 'Papri new-E-red' and 'AVRDC PP046-6006' were grown under soilless culture with three Nigari concentrations at 0, 2, 4 mL L^{-1} and additional NPK to equal standard level. Yield, plant dry weights, relative growth rate (RGR), and net assimilation rate (NAR) with their related traits were evaluated. All of them significantly increased with application of Nigari at 2 mL L^{-1} treatment compared to the no addition control, but were reduced by Nigari applied at 4 mL L^{-1} treatment. On the contrary, pH, total soluble solid (°Brix), titratable acidity (TA) and maturity index (MI) of fruit improved with increasing rate of Nigari. Mineral composition in leaves and fruits improved with application of Nigari at 2 mL L^{-1} treatment compared to the control. In both years, 'Papri new-E-red' performed better than 'AVRDC PP046-6006' when Nigari was applied at 2 mL L^{-1} in respect of improved physiological growth, plant dry weights and yield. Therefore, higher yield and improved growth with high quality fruit would be achieved by application of Nigari at 2 mL L^{-1} treatment in sweet pepper cv. 'Papri new-E-red' in soilless culture.

Keywords: Relative growth rate, net assimilation rate, leaf area, plant dry weight, fruit quality, tissue mineral composition.
Abbreviations: LA - Leaf area; LMR - Leaf mass ratio; LAR - Leaf area ratio; RWR - Root weight ratio; RGR - Relative growth rate; NAR - Net assimilation rate; PDW - Plant dry weight; LDW - Leaf dry weight; SDW - Shoot dry weight; RDW - Root dry weight; FSI - Fruit shape index; TA - Titratable acidity; MI - maturity index.

Introduction

There is a gaining interest in reducing the production cost of agricultural crops. Nigari can reduce production cost as it contains many macro, especially calcium (Ca^{2+}), magnesium (Mg^{2+}), and micro nutrients. Nigari is the effluent of salt industries and cheaper than commercial fertilizers. Nigari contains sodium (Na^{+}) that may impose mild salinity, but it also contains some silicon (Si) that may minimize the negative effects of salinity. Bradbury and Ahmad (1990) and Liang et al. (1996) reported that Si minimized the adverse effects of salinity. Ca^{2+} plays a key role in plant growth and fruit development and is involved in many biochemical and physiological processes (Saure, 2005). Significant economic losses of horticultural crops have been linked to inadequate Ca^{2+} nutrition (Grattan and Grieve, 1999). Nigari can supply adequate Ca^{2+} and other micro nutrients to sweet peppers. Thus, it can reduce fertilizer input and make agricultural practices more sustainable. However, there has been no research on Nigari application effects on crop production, even though it is used as an additional fertilizer in Japan. Therefore, it is desirable to investigate the effects of Nigari on growth, yield and quality on crops such as sweet pepper.

Sweet pepper (*Capsicum annuum* L.) is grown in greenhouses to produce high-quality, colored fruit during an extended season.The production costs can be reduced by reducing nutrition or using cheaper fertilizer sources. The problem with traditional soilless culture is that it relies on costly chemical fertilizers, but the use of Nigari may reduce this cost. Plant growth analysis can be performed to monitor changes in overall plant growth affected by the application of Nigari. The efficiency of Nigari can be defined in terms of variation in relative growth rate (RGR) and we studied morphological plant traits, which could be used to simplify RGR. More information is available on the effect of light intensity (Bruggink, 1987; Bruggink and Heuvelink, 1987) and salinity (Villa-Castorena et al., 2003) on RGR and its components. But, there is no information on the relationship between RGR and growth-related traits due to the application of Nigari. Therefore, our experiments were aimed (1) to evaluate the effect of Nigari application on yield, dry weight, physiological growth, fruit quality, and mineral composition in leaves and fruits for suitability of its use, and (2) to study the performance of sweet pepper cultivars under different Nigari rates.

Results and discussion

Vegetative growth

Two trials combined data for vegetative growth of sweet pepper was significantly affected by different Nigari treatments, cultivars, and their interactions, but insignificant for treatment interactions with trials (Table 3). Results showed that vegetative growth decreased by increasing rate of Nigari. The highest main stem diameter and total stem length were found in the control, but number of leaves was higher at 2 mL L^{-1} Nigari treatment. Meanwhile, the lowest values of these parameters were found at 4 mL L^{-1} Nigari treatment. These results revealed that the vegetative growth

Table 1. Composition of Nigari analyzed by inductively coupled plasma emission spectroscopy.

Components	P	K	Ca	Mg	S	Fe	Mn	Zn	B	Mo	Na	Si
(mg L^{-1})	1860	63081	94658	139669	96854	4133	1471	53	941	454	32525	642

Table 2. Macro and micro nutrients, electrical conductivity (EC), and pH of Nigari treatments.

Nigari treatment	Macro nutrients (me L^{-1})						pH	EC (dS m^{-1})
	NO_3^-	P	K	Ca	Mg	S		
0 (control)	17.05	7.86	8.94	9.95	6.00	6.00	≈6.0	2.8
2 mL L^{-1}	17.05	7.86	8.94	9.47	23.28	12.11	≈6.0	3.5
4 mL L^{-1}	17.05	7.86	8.94	18.93	46.56	24.21	≈6.0	3.9
	Micro nutrients (µg L^{-1})							
	Fe	Mn	Zn	B	Mo	Cu	Na	Si
0 (control)	3000	1000	100	500	25	30	-	-
2 mL L^{-1}	8266	2942	106	1882	908	-	65050	1284
4 mL L^{-1}	16532	5884	212	3764	1816	-	130100	2568

was stronger in the control compared to others. This might be due to the fact that Nigari contains some extent of Na^+ that might have imposed salinity. Furthermore, number of leaves was not adversely affected by Nigari at 2 mL L^{-1} and it was the highest in this treatment. The mechanism for improvement of vegetative growth due to application of Nigari at 2 mL L^{-1} is not clear, but the positive impact of Nigari is due to the presence of rather high amounts of Ca^{2+} and Si, which might have contributed to reduce sodium absorption sites. Bradbury and Ahmad (1990) and Liang et al. (1996) reported that Si minimized the effects of salinity in *Prosopis juliflora* and barley, respectively. Calcium sulfate counteracted the toxic effect of NaCl, resulting in greater plant height and leaf number of salt treated *Leucaena leucocephala* plant (Hansen and Munns, 1988). Nigari contains a higher amount of Ca^{2+} which may able to counteract the toxic effects of Na^+ when applied at the rate of 2 mL L^{-1}.

Regarding the cultivars, higher main stem diameter and number of leaves were found in 'Papri new-E-red' but total stem length was higher in 'AVRDC PP046-6006'. The results showed that 'Papri new-E-red' performed better under Nigari treatments in respect to stem diameter and number of leaves.

Significant interaction of Nigari and cultivar was found for vegetative growth of sweet pepper (Table 3). The highest main stem diameter was found in 'Papri new-E-red' under the control treatment, whereas the highest total stem length was found in 'AVRDC PP046-6006' under the control treatment. Meanwhile the highest number of leaves was found in 'Papri new-E-red' under the Nigari at 2 mL L^{-1}, which was statistically similar to that of the control in the same cultivar.

Plant dry weight

Plant dry weights in two trials combined data of sweet pepper significantly varied by Nigari rate, cultivars and their interactions, but insignificant for treatment interactions with trials (Table 4). The highest dry weights of leaf, stem and root were found in 2 mL L^{-1} Nigari compared to the control. Meanwhile, dry weights of plants drastically decreased in 4 mL L^{-1} Nigari treatment. This might be due to 2 mL L^{-1} Nigari containing higher Ca^{2+} compared to the control, which contributed to higher dry weights. On the contrary, 4 mL L^{-1} Nigari contains the highest amount of Ca^{2+} compared to the other treatments, but it might have salinity stress that caused poor dry weight. Epstein and Bloom (2005) reported that Ca^{2+} increased the root dry weight and calcium content in plant tissues. Bar-Tal et al., (2001) found that the shoot and root dry weights decreased with increasing Ca^{2+} in sweet pepper. In our experiments, increasing Ca^+ with other nutrients increased plant dry weights until a certain limit, but further increments showed decreasing trend of dry weights in 4 mL L^{-1} Nigari treatment. In respect of cultivars, it was found that 'Papri new-E-red' produced higher plant dry weights in comparison with 'AVRDC PP046-6006'. It might be due to higher vegetative growth in 'Papri new-E-red'.

In case of interactions between Nigari and cultivars, the highest plant dry weights were found in 'Papri new-E-red' under Nigari at 2 mL L^{-1}, meanwhile the lowest in 'AVRDC PP046-6006' at 4 mL L^{-1} Nigari treatment (Table 4).

Growth analysis

Growth parameters varied significantly by Nigari rates and cultivars (Table 5). Results revealed that leaf area (LA), leaf mass ratio (LMR), NAR, and RGR increased at 2 mL L^{-1} Nigari compared to the control, but these traits drastically reduced at 4 mL L^{-1} Nigari treatment. On the contrary, leaf area ratio (LAR) was the lowest in Nigari at 2 mL L^{-1}, and decreasing trend of root weight ratio (RWR) was found with increasing rate of Nigari. Higher LA is one of the important criteria for producing higher metabolites. Prieto et al. (2007) reported that increased LA gave the plants an increased ability to intercept light. We found higher LA, and LMR due to application of Nigari at 2 mL L^{-1} that may have the ability to produce higher metabolites in sweet pepper. A decreased LAR was found by Starck (1983) in tomato, which agreed with our findings due to application of Nigari at 2 mL L^{-1}. The plant growth analyses data suggested that Nigari at 2 mL L^{-1} provided better nutrition to the plants, followed by the control. This was most relevant in higher RGR and NAR due to application of Nigari at 2 mL L^{-1}. But Nigari at 4 mL L^{-1} may have mild water stress due to salinity that gave the lower growth in sweet pepper. RWR suggested that mild stress might have been occurred when Nigari applied at 4 mL L^{-1} and it may have been responsible for the changes in plant growth affecting the allocation of resources between the root system and the rest of the plant. However, plant growth parameters indicated that application of Nigari at 2 mL L^{-1} supported a higher level of plant growth.

Cultivars had effect on physiological growth parameters. All the studied parameters were higher in 'Papri new-E-red' except for LAR compared to 'AVRDC PP046-6006'.

Regarding the interactions between Nigari and cultivar, the highest physiological growth parameters studied in these experiments were found in 'Papri new-E-red' under Nigari at 2 mL L^{-1} treatment except for LAR (Table 5).

Table 3. Main and interaction effects of Nigari and cultivar on growth and yield attributes of sweet pepper.

Treatment		Main stem diameter (mm)	Total stem length (cm)	Leaf no./ plant	Fruit fresh weight (g)	Fruit no./ plant	%BER (by no.)	Yield/ plant (g)
Nigari concentrations								
0 (Control)		20.1 a[z]	778.7 a	134.7 b	183.3 a	20.2 a	13.0 b	2365.8 b
2 mL L^{-1}		17.9 b	697.0 b	137.4 a	173.9 b	20.4 a	9.1 c	2709.6 a
4 mL L^{-1}		15.6 c	638.9 c	120.0 c	155.7 c	19.3 b	21.5 a	2010.6 c
Cultivar								
Papri new-E-red		18.8 a	690.2 b	134.7 a	127.4 b	25.2 a	13.0 b	2695.0 a
AVRDC PP046-6006		16.9 b	719.5 a	126.7 b	214.6 a	14.8 b	16.0 a	2028.9 b
Interaction (Nigari × cultivar)								
0	'Papri new-E-red'	21.5 a	775.8 a	140.2 a	137.7 c	25.9 a	12.8 c	2664.1 b
2 mL L^{-1}	'Papri new-E-red'	18.4 b	669.0 c	143.2 a	130.1 cd	28.1 a	7.3 d	3096.1 a
4 mL L^{-1}	'Papri new-E-red'	16.5 d	625.8 d	120.8 c	114.2 d	21.5 ab	19.0 b	2324.9 c
0	'AVRDC PP046-6006'	18.6 b	781.5 a	129.2 b	228.8 a	14.9 bc	13.3 c	2067.5 d
2 mL L^{-1}	'AVRDC PP046-6006'	17.0 c	725.0 b	131.7 b	217.7 a	19.0 ab	10.8 cd	2323.0 c
4 mL L^{-1}	'AVRDC PP046-6006'	14.7 d	652.0 c	119.2 c	197.2 b	10.5 c	23.9 a	1696.3 e
Significance								
Nigari		<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Cultivar		<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Nigari × cultivar		<0.001	<0.001	0.001	0.005	0.001	<0.001	<0.001

0, 2 and 4 mL L^{-1}: standard nutrient solution as control, 2 mL L^{-1} Nigari + additional NPK to equal standard and 4 mL L^{-1} Nigari + additional NPK to equal standard, respectively. [z]Means with different letters within columns are significantly different by Tukey's test at P ≤ 0.05.

Table 4. Main and interaction effects of Nigari and cultivar on plant dry weights of sweet pepper.

Treatment		Plant dry weight (g plant^{-1}) Stem	Leaf	Root	Total
Nigari concentrations					
0 (Control)		117.19 b[z]	67.82 b	50.49 b	235.49 b
2 mL L^{-1}		142.39 a	89.89 a	58.31 a	290.59 a
4 mL L^{-1}		87.05 c	55.54 c	33.38 c	175.47 c
Cultivar					
Papri new-E-red		126.74 a	81.87 a	53.78 a	262.05 a
AVRDC PP046-6006		104.36 b	60.29 b	41.00 b	205.65 b
Interaction (Nigari × cultivar)					
0	'Papri new-E-red'	130.10 b	77.86 b	57.22 b	265.18 b
2 mL L^{-1}	'Papri new-E-red'	150.94 a	103.25 a	66.56 a	320.18 a
4 mL L^{-1}	'Papri new-E-red'	99.16 c	64.49 c	37.56 d	200.21 c
0	'AVRDC PP046-6006'	104.27 c	57.77 d	43.76 cd	205.80 c
2 mL L^{-1}	'AVRDC PP046-6006'	133.85 b	76.52 b	50.05 bc	260.42 b
4 mL L^{-1}	'AVRDC PP046-6006'	74.95 d	46.59 d	29.19 e	150.73 d
Significance					
Nigari		<0.001	<0.001	<0.001	<0.001
Cultivar		<0.001	<0.001	<0.001	<0.001
Nigari × cultivar		<0.001	<0.001	0.003	0.012

0, 2 and 4 mL L^{-1}: standard nutrient solution as control, 2 mL L^{-1} Nigari + additional NPK to equal standard and 4 mL L^{-1} Nigari + additional NPK to equal standard, respectively. [z]Means with different letters within columns are significantly different by Tukey's test at P ≤ 0.05.

Fruit quality characteristics

Two trials combined data for fruit quality attributes of sweet pepper including FSI, pH, TA, °Brix and MI under different Nigari treatments are shown in Table 6. As expected, pH, TA, °Brix, and MI significantly increased with increasing rate of Nigari. The highest pH, TA, °Brix, and MI were found at 4 mL L^{-1} Nigari treatment, meanwhile the highest FSI was found at the control. Nigari might be an alternative fertilizer that might have an effect on fruit quality of sweet pepper. Ehert and Ho (1986) found an improvement in fruit quality attributes under deficit irrigation and saline condition. Plant water loss occurred by decreasing uptake of water under salinity and water stress condition. Increasing rate of Nigari might have imposed short-day water stress and mild salinity to the sweet pepper plants. As a result, pH, °Brix and TA increased at 4 mL L^{-1} Nigari due to low water uptake by the plant. Our results agreed with the previous reports that showed a positive effect of produce quality improvement in tomato under salinity and water stress conditions (Del Amor et al., 2001).

Cultivars had an effect in fruit quality attributes, and higher quality attributes studied in this experiment were found in 'Papri new-E-red' compared to 'AVRDC PP046-6006'.

Significant interactions between Nigari and cultivar were found for FSI, TA, pH and °Brix, but not significant for MI (Table 6). However, the highest pH, TA, °Brix and MI were found in 'Papri new-E-red' at 4 mL L^{-1} Nigari, meanwhile the highest FSI was found in 'AVRDC PP046-6006' in the control treatment.

Table 5. Main and interaction effects of Nigari and cultivar on physiological growth traits of sweet pepper.

Treatment		LA (cm^2)	LMR ($g\ g^{-1}$)	LAR ($cm^2\ g^{-1}$)	RWR ($g\ g^{-1}$)	NAR ($g\ cm^{-2}\ d^{-1}$)	RGR ($g\ g^{-1}\ d^{-1}$)
Nigari concentrations							
0 (Control)		2127.8 b[z]	0.29 c	9.1 b	0.22 a	0.06 b	0.54 b
2 mL L^{-1}		2385.7 a	0.31 a	8.3 c	0.20 b	0.08 a	0.67 a
4 mL L^{-1}		1879.7 c	0.32 b	10.8 a	0.19 c	0.04 c	0.40 c
Cultivar							
Papri new-E-red		2264.4 a	0.31 a	8.8 b	0.21 a	0.07 a	0.60 a
AVRDC PP046-6006		1997.7 b	0.30 b	10.0 a	0.20 b	0.05 b	0.48 b
Interaction (Nigari × cultivar)							
0	'Papri new-E-red'	2289.2 b	0.29 bc	8.7 c	0.22 a	0.07 b	0.60 b
2 mL L^{-1}		2506.5 a	0.32 a	7.8 d	0.21 a	0.09 a	0.73 a
4 mL L^{-1}		1997.3 c	0.32 a	10.0 b	0.19 b	0.05 c	0.46 c
0	'AVRDC PP046-6006'	1966.3 c	0.28 d	9.6 b	0.21 a	0.05 c	0.48 c
2 mL L^{-1}		2264.8 b	0.29 bc	8.7 c	0.19 b	0.07 b	0.61 b
4 mL L^{-1}		1762.0 d	0.31 ab	11.7 a	0.19 b	0.03 d	0.35 d
Significance							
Nigari		<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Cultivar		<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Nigari × cultivar		0.001	<0.001	0.001	0.006	<0.001	0.001

0, 2 and 4 mL L^{-1}: standard nutrient solution as control, 2 mL L^{-1} Nigari + additional NPK to equal standard and 4 mL L^{-1} Nigari + additional NPK to equal standard, respectively. LA: Leaf area; LMR: Leaf mass ratio; LAR: Leaf area ratio; RWR; Root weight ratio; NAR: Net assimilation rate; RGR: Relative growth rate. [z]Means with different letters within columns are significantly different by Tukey's test at $P \leq 0.05$.

Table 6. Main and interaction effects of Nigari and cultivar on fruit quality attributes of sweet pepper.

Treatment		FSI	pH	TA (% citric acid)	TSS (°Brix)	MI
Nigari concentrations						
0 (Control)		0.81 a[z]	5.04 c	0.21 c	7.30 c	35.32 c
2 mL L^{-1}		0.77 b	5.19 b	0.23 b	8.28 b	36.79 b
4 mL L^{-1}		0.72 c	5.27 a	0.25 a	9.18 a	37.80 a
Cultivar						
Papri new-E-red		0.62 b	5.27 a	0.24 a	8.66 a	37.43 a
AVRDC PP046-6006		0.91 a	5.06 b	0.22 b	7.85 b	35.84 a
Interaction (Nigari × cultivar)						
0	'Papri new-E-red'	0.66 c	5.16 b	0.22 b	7.83 c	35.50 a
2 mL L^{-1}		0.63 de	5.28 a	0.24 ab	8.67 b	36.33 a
4 mL L^{-1}		0.59 c	5.38 a	0.26 a	9.48 a	37.11 a
0	'AVRDC PP046-6006'	0.96 a	4.93 c	0.19 c	6.76 d	35.44 a
2 mL L^{-1}		0.91 ab	5.10 b	0.22 b	7.90 c	35.77 a
4 mL L^{-1}		0.86 b	5.15 b	0.24 a	8.89 b	36.69 a
Significance						
Nigari		<0.001	<0.001	<0.001	<0.001	<0.001
Cultivar		<0.001	<0.001	<0.001	<0.001	NS
Nigari × cultivar		0.001	<0.001	<0.001	<0.001	NS

0, 2 and 4 mL L^{-1}: standard nutrient solution as control, 2 mL L^{-1} Nigari + additional NPK to equal standard and 4 mL L^{-1} Nigari + additional NPK to equal standard, respectively. FSI: Fruit shape index; TA: Titratable acidity; TSS: Total soluble solid; MI: Maturity index. [z]Means with different letters within columns are significantly different by Tukey's test at $P \leq 0.05$. NS Nonsignificant at $P \leq 0.05$.

Mineral composition in leaves

Mineral compositions in leaves were significantly affected by Nigari, cultivars, and their interaction (Table 7). Results revealed that NO_3-N and PO_4^{3-} concentrations decreased with increasing rate of Nigari. Meanwhile, Mg^{2+}, Ca^{2+} and SO_4^{2-}, and all micro nutrients including Na^+ and Cl^- studied increased with increasing the rate of Nigari. The highest NO_3-N and PO_4^{3-} were found in the control, whereas, the highest Mg^{2+}, Ca^{2+} and SO_4^{2-} were found at 2 mL L^{-1} Nigari treatment. Furthermore, all the micro nutrients including Na^+ and Cl^- were the highest due to application of Nigari at 4 mL L^{-1}. O'Sullivan (1979) stated that the critical plant tissue NO_3-N levels of at least 4000 mg kg^{-1} are necessary to maintain fruit yields of sweet pepper. Our results showed that all the treatments had a higher level of tissue NO_3-N than the critical levels, although it decreased with increasing rate of Nigari. Therefore, it could be said that Nigari could not negatively affect tissue NO_3-N content for growth and yield of sweet pepper. Chartzoulakis and Klapaki (2000) reported that K^+ concentration in leaves of sweet pepper was not affected by salinity. Our result partially agreed with these findings, because K^+ concentration was higher at 2 mL L^{-1} Nigari, but it was lower at 4 mL L^{-1} where mild salinity might be imposed to the plants. This suggests that sweet pepper plants are able to maintain high K^+ level in leaf lamina under mild external salinity at 2 mL L^{-1} Nigari treatment. Fe and phosphorus are antagonistic to each other (Gutschick, 1987) and our results agreed with this finding. In the present investigation, leaf Fe increased with increase in iron content of nutrient solution, but leaf PO_4^{3-}concentration decreased with the increase in leaf Fe^{2+}. The classical

Table 7. Main and interaction effects of Nigari and cultivar on mineral concentrations in leaves of sweet pepper.

Treatment		NO_3-N	PO_4^{3-}	K^+	Ca^{2+}	Mg^{2+}	SO_4^{2-}	Na^+	Cl^-	Mn	Fe	Zn
		g Kg^{-1} DW								mg Kg^{-1} DW		
Nigari concentrations												
0 (Control)		6.17 a	2.99 a	39.8 b	19.8 c	8.76 b	1.63 c	1.17 c	2.28 c	53.0 c	32.0 c	20.2 b
2 mL L^{-1}		5.86 b	2.93 b	42.6 a	31.6 a	14.98 a	3.48 a	2.11 b	3.33 b	67.6 b	43.4 b	19.7 b
4 mL L^{-1}		4.70 c	2.55 c	32.6 c	22.0 b	10.05 b	2.37 b	3.85 a	5.34 a	75.1 a	49.9 a	27.0 a
Cultivar												
Papri new-E-red		6.03 a	2.95 a	40.5 a	25.3 a	11.56 a	2.13 b	2.27 b	3.53 b	66.7 a	39.1 b	22.7 a
AVRDC PP046-6006		5.13 b	2.70 b	36.1 b	23.7 b	10.97 a	2.86 a	2.48 a	3.77 a	63.7 b	44.5 a	21.8 a
Interaction (Nigari × cultivar)												
0	'Papri new-E-red'	6.72 a	3.11 a	42.62ab	20.4 a	9.01 a	1.49 d	1.16 d	2.32 c	57.3bc	26.3 b	20.8 a
2 mL L^{-1}		6.48 a	3.09ab	45.03 a	32.8 a	15.96 a	3.07 b	2.04 c	3.22 b	66.5ab	41.0 a	20.0 a
4 mL L^{-1}		4.87 b	2.66cd	33.97bc	22.9 a	9.70 a	1.83 c	3.61 b	5.05 a	76.3 a	49.8 a	27.3 a
0	'AVRDC PP046-6006'	5.62ab	2.87bc	37.03bc	19.2 a	8.51 a	1.78cd	1.18 d	2.25 c	48.7 c	37.7ab	19.5 a
2 mL L^{-1}		5.24 b	2.78 c	40.20ab	30.5 a	14.01 a	3.89 a	2.17 c	3.43 b	68.7 a	45.8 a	19.3 a
4 mL L^{-1}		4.53 b	2.45 d	31.13 c	21.2 a	10.38 a	2.92 b	4.08 a	5.64 a	73.8 a	50.0 a	26.7 a
Significance												
Nigari		***	***	***	***	***	***	***	***	***	***	***
Cultivar		***	***	***	***	NS	***	***	***	***	***	NS
Nigari × cultivar		***	***	0.005	NS	NS	***	***	***	***	***	NS

0, 2 and 4 mL L^{-1}: standard nutrient solution as control, 2 mL L^{-1} Nigari + additional NPK to equal standard and 4 mL L^{-1} Nigari + additional NPK to equal standard, respectively. ^{z}Means with different letters within columns are significantly different by Tukey's test at $P \leq 0.05$. NS Nonsignificant at $P \geq 0.05$. *** significant at $P \leq 0.001$.

antagonism between leaf Fe and Mn was not evident in this study.

On the other hand, all the macro and micro nutrients studied in this experiment were found higher in 'Papri new-E-red' except for Cl^- and Fe.

All macro and micro nutrients, except for Ca^{2+}, Mg^{2+} and Zn, studied in this experiment were significant for the treatments interaction between Nigari and cultivar (Table 7). The highest K^+, Ca^{2+} and Mg^{2+} were found in 'Papri new-E-red' under Nigari at 2 mL L^{-1}, meanwhile the highest NO_3-N and $PO4^{3-}$ were found in the same cultivar under the control treatment. On the other hand, the highest micro nutrients were found in 'Papri new-E-red' under Nigari at 4 mL L^{-1}. Furthermore, the lowest Na and Cl^- were found in 'Papri new-E-red' under the control treatment and the highest in 'AVRDC PP046-6006' under Nigari at 4 mL L^{-1}.

Mineral composition in fruits

Mineral compositions in fruit were significantly affected by Nigari, cultivars and their interactions (Table 8). The elements do not all enter the fruits continuously, although NO_3-N, K^+, Mg^{2+}, Ca^{2+} and SO_4^{2-} concentrations increased with increasing rate of Nigari. All these minerals sharply increased due to application of Nigari at 2 mL L^{-1}, but comparatively slower increasing were found at 4 mL L^{-1}, except for NO_3-N. The content of NO_3-N in fruits increased until 4 mL L^{-1} Nigari treatment. On the contrary, PO_4^{3-} accumulation in fruit decreased with increasing rate of Nigari. Furthermore, micro nutrients, including Na^+ and Cl^- showed a continuous increment until 4 mL L^{-1} Nigari treatment. Bar-Tal et al. (2001) stated that Ca^{2+} deficiency in fruits may be caused by low Ca^{2+} supply in the solution. We found the highest Ca^{2+} concentration in fruits at 2 mL L^{-1} Nigari, which indicated a sufficient supply of Ca^{2+} in the solution. Because, it reduced (%) BER, which discussed in the next section. High K^+ levels increased fruit acidity and decreased maturity index (Usherwood, 1985). We found high level of K^+ in fruits at 2 mL L^{-1} Nigari that could improve fruit quality. Therefore, our results suggested that Nigari at 2 mL L^{-1} could supply a sufficient amount of minerals in the fruits that might have a positive effect on fruit quality.

Regarding cultivars, all the macro nutrients concentrations were found higher in 'Papri new-E-red' except for NO_3-N and SO_4^{2-} compared to 'AVRDC PP046-6006'. Meanwhile, higher micro nutrients were found in 'AVRDC PP046-6006'.

All macro nutrients except for NO_3-N, were significantly varied among the treatment interactions between Nigari and cultivar, but not significant for micro nutrients (Table 8). The highest K^+, Ca^{2+} and Mg^{2+} were found in 'Papri new-E-red' under Nigari at 2 mL L^{-1} concentration, meanwhile the highest PO_4^{3-} was found in the same cultivar under the control. On the other hand, the highest micro nutrients were found in 'AVRDC PP046-60064' at 4 mL L^{-1} Nigari treatment. Furthermore, the lowest Na^+ and Cl^- were found in 'Papri new-E-red' under the control treatment and the highest in 'AVRDC PP046-60064' under Nigari at 4 mL L^{-1}.

Yield and yield components

Fruit fresh weight, number of fruit per plant, percent of blossom-end rot [(%) BER] and yield per plant were significantly varied by Nigari treatments, cultivars, and their interactions (Table 3). Fruit fresh weight and number of fruit were decreasing with increasing rate of Nigari. The highest fruit fresh weight and number of fruit were found in the control, but the number of fruit was statistically similar to that of Nigari at 2 mL L^{-1} treatment. Meanwhile, the lowest fresh fruit weight and number of fruit were found in Nigari at 4 mL L^{-1}. As expected, (%) BER was lower in Nigari at 2 mL L^{-1} compared to the control. BER in sweet pepper is one of the crucial problems that reduce total marketable yield. In the present study, it was revealed that some degree of (%) BER was reduced by application of Nigari at 2 mL L^{-1}. It contains a higher amount of Ca^{2+} that might have contributed to decrease in (%) BER. On the contrary, 4 mL L^{-1} Nigari treatment might have imposed more osmotic stress, causing higher (%) BER. Water stress and osmotic stress reduce Ca^{2+} transport particularly to the distal end region of sweet pepper fruit, where BER develops (Marcelis and Ho, 1999; Silber et al., 2005). Because of this phenomenon, higher (%) BER was found in Nigari at 4 mL L^{-1}. The highest yield was found in Nigari at 2 mL L^{-1}. This might be due to lower (%) BER, and higher number of fruit by application of Nigari at 2 mL L^{-1}.

Table 8. Main and interaction effects of Nigari and cultivar on mineral concentrations in fruits of sweet pepper.

Treatment		NO_3-N	PO_4^{3-}	K^+	Ca^{2+}	Mg^{2+}	SO_4^{2-}	Na^+	Cl^-	Mn	Fe	Zn
		g Kg^{-1} DW								mg Kg^{-1} DW		
Nigari concentrations												
0 (Control)		0.32 c	2.04 a	0.62 c	1.35 b	0.06 c	0.11 c	0.04 c	0.15 c	10.50 c	7.08 c	9.00 b
2 mL L^{-1}		0.36 b	1.87 b	0.94 a	2.20 a	1.13 a	0.17 a	0.05 b	0.22 b	14.67 b	9.67 b	9.17 b
4 mL L^{-1}		0.37 a	0.84 c	0.65 b	1.45 b	0.99 b	0.14 b	0.11 a	0.28 a	18.75 a	13.75 a	14.08 a
Cultivar												
Papri new-E-red		0.34 b	1.68 a	0.83 a	1.95 a	0.73 a	0.13 b	0.06 b	0.20 b	13.89 b	9.56 b	10.67 a
AVRDC PP046-6006		0.36 a	1.49 b	0.64 b	1.39 b	0.72 b	0.15 a	0.07 a	0.23 a	15.39 a	10.78 a	10.83 a
Interaction (N × V)												
0	‘Papri new-E-red’	0.31 a	2.21 a	0.67 c	1.69 c	0.04 d	0.10 c	0.03 d	0.13 d	9.50 a	6.67 a	8.17 a
2 mL L^{-1}		0.35 a	1.95 b	1.06 a	2.30 a	1.18 a	0.16ab	0.06 c	0.22 c	14.17 a	9.17 a	9.67 a
4 mL L^{-1}		0.36 a	0.89 d	0.75 b	1.86bc	0.97 c	0.12 c	0.10 b	0.27ab	18.00 a	12.83 a	14.17 a
0	‘AVRDC PP046-6006’	0.33 a	1.88bc	0.58 d	1.01 d	0.08 d	0.13bc	0.04cd	0.17 d	11.50 a	7.50 a	8.67 a
2 mL L^{-1}		0.37 a	1.80 d	0.81 b	2.10ab	1.07 b	0.18 a	0.05cd	0.22bc	15.17 a	10.17 a	9.83 a
4 mL L^{-1}		0.38 a	0.80 d	0.54 d	1.05 d	1.02bc	0.16ab	0.13 a	0.30 a	19.50 a	14.67 a	14.00 a
Significance												
Nigari		***	***	***	***	***	***	***	***	***	***	***
Cultivar		***	***	***	***	0.032	***	***	***	***	***	NS
Nigari × cultivar		NS	***	***	***	***	0.003	***	0.004	NS	NS	NS

0, 2 and 4 mL L^{-1}: standard nutrient solution as control, 2 mL L^{-1} Nigari + additional NPK to equal standard and 4 mL L^{-1} Nigari + additional NPK to equal standard, respectively. ᶻMeans with different letters within columns are significantly different by Tukey’s test at $P \leq 0.05$. NS Nonsignificant at $P \geq 0.05$. *** significant at $P \leq 0.001$.

Furthermore, Nigari contains Si that might have a positive effect on fruit yield in sweet pepper. Stamatakis et al. (2003) found a positive effect of Si addition to the nutrient solution under saline condition in tomato fruit yield. Alexander and Clough (1998) also observed that marketable yield of pepper increased due to increased Ca^{2+}, mainly because of decrease in BER-affected fruits. We observed similar results in Nigari at 2 mL L^{-1} treatment.

Regarding cultivars, higher number of fruit and yield, and lower incidence of (%) BER were found in ‘Papri new-E-red’. Although ‘AVRDC PP046-6006’ produced extra large fruit, but marketable and total number of fruits were almost half of ‘Papri new-E-red’. However, ‘Papri new-E-red’ performed better under Nigari treatment in respect of yield parameters. Rahman and Inden (2012) reported the highest yield and number of fruit in ‘Papri new-E-red’ compared to ‘AVRDC PP046-6006’, and some other cultivars under high temperature, which agreed with our present findings under Nigari application.

In case of interaction between Nigari and cultivar, the highest number of fruit and yield, and the lower incidence of (%) BER were found in ‘Papri new-E-red’ under Nigari at 2 mL L^{-1}.

Materials and methods

Experimental site, plant materials and growing conditions

Two repeated experiments were conducted in greenhouses at the University of Miyazaki, Japan. The transplanting and final harvesting dates of the first trial (Expt. 1) were 25th November 2010 and 10th June 2011, and of the second trial (Expt. 2) were 18th February 2011 and 24th August 2011, respectively. Two sweet pepper cultivars ‘Papri new-E-red’ (Marutane Seed Co., Kyoto, Japan) and ‘AVRDC PP046-6006’ (AVRDC-The World Vegetable Centre, Taiwan) were selected on the basis of yield performance under high temperature conditions (Rahman and Inden, 2012). Two 8-week-old seedlings were transplanted 20 cm apart into 40 L containers containing a 50:45:5 (v/v) mixture of bora (volcanic soil), perlite and shodo (burned loam soil) respectively, and cultivated for 198 days. Each row consisted of 18 containers and was treated as a replication. The crop was continuously irrigated by ultra-drip irrigation tube with pH and electrical conductivity (EC) controlled nutrient solution (Table 2). The average minimum and maximum temperatures were 18±2°C and 24±2°C, and 22±2°C and 27±2°C, respectively for Expt. 1 and Expt. 2.

Experimental design and treatments

The experimental design was a 3×2 factorial design with four replications. Two factors of this experiment were three Nigari treatments (standard nutrient solution as control, 2 mL L^{-1} Nigari + additional NPK to equal standard, and 4 mL L^{-1} Nigari + additional NPK to equal standard) and two sweet pepper cultivars (‘Papri new-E-red’ and ‘AVRDC PP046-6006’). The standard nutrient composition was selected according to Rahman and Inden (2012). Standard nutrient solution was applied to the plants for all treatments until one month after transplanting. After that time, Nigari treatment was started and applied every day until harvest. Nigari was collected from Miyazaki Sun Salt Co., Miyazaki, Japan and was analyzed by inductively coupled plasma emission spectroscopy (ICPS-8100, Shimadzu Corp., Kyoto, Japan) for its nutritional composition (Table 1).

Growth parameters analysis

Growth parameters (dry weights of stem, leaf and root), and different physiological parameters [Leaf area (LA), leaf area ratio (LAR), leaf mass ratio (LMR), root weight ratio (RWR), relative growth rate (RGR), and net assimilation rate (NAR)] were determined in both of the experiments. Leaf area and plant dry weights were derived from 56-d old seedling for each cultivar. Other growth parameters were measured as described below.

$$LAR = \frac{LA}{PDW} \quad (1)$$

$$LMR = \frac{LDW}{PDW} \quad (2)$$

$$RWR = \frac{RDW}{PDW} \quad (3)$$

$$RGR = \frac{PDW_1 - PDW_0}{(t_1 - t_0) \times PDW_0} \quad (4)$$

Where, t = time. Subscripts 0 and 1 refer to the transplanting and final harvest (days), respectively.

$$NAR = \frac{RGR}{LAR} \quad (5)$$

Fruit quality measurement

Fruit quality parameters including fruit shape index (FSI), pH, total soluble solids (^{o}Brix), titratable acidity (TA) and maturity index (MI) were measured from four uniform red fruits. FSI was defined by the equatorial (diameter) to longitudinal length ratio. MI was calculated by the ratio of ^{o}Brix to TA.

Vegetative growth and yield parameters

Main stem diameter at the 6th leaf point, total stem length of four shoots for each plant, and leaf number per plant were measured at the end of the experiments. Fruit fresh weight, number of fruit per plant, percentage of blossom-end rot [(%) BER, by number of fruits], and yield per plant were recorded during both the experiments.

Leaf and fruit tissue analysis

At the end of the experiments, leaves and fruits were sampled for determination of mineral compositions. NO_3-N, PO_4^{3-}, Ca^{2+}, K^+, Mg^{2+}, SO_4^{2-}, Na^+ and Cl^- were analyzed using HPLC ion analyzer (IA 300, TOA DKK Corporation, Japan). Manganese (Mn) and Iron (Fe) were analyzed using RQflex® 10 (Merck Chemicals, Germany). Zinc (Zn) was analyzed using spectrophotometer (DR 2800, HACH Company, USA) at 620 nm.

Statistical analysis

Data of the two trials were combined and analyzed by two-way analysis of variance (ANOVA) using SPSS ver. 16.0 and the differences among means were determined using Tukey's test at $P \leq 0.05$.

Conclusion

Application of 2 mL L^{-1} Nigari can significantly improve growth, yield, plant dry weights, fruit quality, and mineral compositions in leaves and fruits of sweet pepper in soilless culture. RGR, NAR, and their related components also improved when 2 mL L^{-1} Nigari was applied compared to the control. But all of these traits were lower at 4 mL L^{-1} Nigari treatment. Meanwhile, fruit quality parameters increased with increasing rate of Nigari. Furthermore, 'Papri new-E-red' performs better under Nigari treatment in respect of vegetative and physiological growth traits, dry matter production, mineral compositions in leaves and fruits, fruit quality traits, and yield.

Finally, we can conclude that 2 mL L^{-1} Nigari can be applied in sweet pepper cv. 'Papri new-E-red' for producing a higher yield of high quality fruit under soilless culture as an alternative addition to fertilizer.

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