Effect of heat treatment around the fruit set region on growth and yield of watermelon [*Citrullus lanatus* (Thunb.) Matsum. and Nakai]

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Abstract The present experiment was aimed to study the effect of imposing modulated temperature treatments 14 °C and 18 °C, around the fruiting region of watermelon plants, and to estimate the economic feasibility of the temperature treatments based on energy consumption for heating. Watermelon cultivar ‘Sambok-gul’ was selected and sown on perlite beds in a plastic house under controlled conditions at Watermelon Farm, Jeongeup-Jeonbuk, longitude 35° 31' 47.51N, 126° 48'48.84E, altitude 37 m during the early spring season (2010–2011). The findings revealed that the temperature treatment at 18 °C caused significant increase in weight (2.0 kg plant⁻¹), fruit weight (8.3 kg plant⁻¹), soluble solid content (11.5 %), and fruit set rate (96.5 %) at harvest stage. Higher contents of Ca²⁺ and Mg²⁺ ions were observed in the 1st upper leaf of the fruit set node (79.3 mgL⁻¹) and the 1st lower leaf of the fruit set node (12.0 mgL⁻¹), respectively at 14 °C. The power consumption and extra costs of the temperature treatment 18 °C were suggested as affordable and in range of a farmer's budget (41.14 USD/22 days). Hence, it was concluded that modulating temperature treatments could be utilized successfully to optimize the temperature range for enhancing the fruit yield and quality in the winter watermelon crops.

Keywords Temperature · Electricity consumption · Yield · Soluble solid content · Ion content

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Abbreviations

Ca²⁺ Calcium

Mg²⁺ Magnesium

Introduction

C. lanatus comprise the cultivated watermelon, which is found in tropical and subtropical climates worldwide. Watermelon requires a long, warm growing season and grows best under temperatures of 21–29 °C, tolerating temperatures up to 32 °C. The seed germinates after 4–8 days at a temperature of 25 °C, and this temperature is optimal for the start of plant growth as well. The species is very sensitive to low temperature and low light intensity. Young plants cannot survive a low temperature of 1 °C, while their growth stops at 10 °C. A minimal temperature of 18 °C is needed for proper growth. Plants do not flower at temperatures below 13 °C; however, mature plants can survive at temperature as high as 45 °C. Watermelon plants need around 1,200 h of sunlight and a 2,000–3,000 °C temperature sum during the vegetation period in order to produce fruits. The average vegetation period in South Korea is 135 days from planting to harvest. That means watermelon fruits can be harvested around 20 June from a crop planted at the beginning of May. The optimum and minimum temperatures required for stable fruiting during the growth period cannot be met during the month of April in watermelon without heating from external sources. It is very difficult for commercial growers of many important horticultural crops to harvest a good yield at desired dates, mainly due to temperature differences during the growing season (Baker and Reddy 2001). Several methods of heating have been attempted in different crops. Low air temperatures at

Table 1 Changes in low temperature prior to and after fruit set during 2010–2011 in control, 14 °C and 18 °C

	Control	14 °C 2010	18 °C	Control	14 °C 2011	18 °C
30-Mar	6.3	12.5	15.9	10.1	13.0	13.2
31-Mar	11.7	13.8	18.4	9.8	11.0	11.4
01-Apr	8.0	13.8	18.3	9.9	10.5	11.6
02-Apr	6.0	11.1 ^z	13.1 ^z	14.0	14.0	14.9
03-Apr	5.2	11.3	13.6	14.1	13.9	15.7
04-Apr	5.3	11.9	14.4	11.4	11.6	13.2
05-Apr	13.3	14.4	18.8	9.2	11.8	11.6
06-Apr	10.4	16.0	18.3	9.3	11.3	11.9
07-Apr	5.9	12.0	14.5	15.8	15.0	16.1
08-Apr	6.4	12.5	14.8	15.1	14.6	16.7
09-Apr	11.8	13.2	19.2	13.7	13.3	15.5
10-Apr	12.2	13.8	18.0	11.8	10.9	13.9
11-Apr	13.7	14.7	18.2	15.2	14.1	16.4
12-Apr	16.3	16.8	18.3	10.1	10.4	12.6
13-Apr	7.4	14.1	18.4	10.5	11.6	12.6
14-Apr	6.4	14.0	15.7	10.3	11.4	12.3
15-Apr	4.9 ^z	13.7	14.4	18.0	17.9	18.3
16-Apr	7.5	13.5	15.2	14.5	14.2	15.3
17-Apr	6.3	14.4	14.6	10.6	10.9	14.4
18-Apr	10.1	14.9	17.4	15.9	15.9	17.3
19-Apr	14.0	16.0	18.0	9.4	10.9	11.9
20-Apr	11.4	12.6	17.0	8.9 ^z	9.6 ^z	9.0 ^z
21-Apr	13.8	14.9	18.0			

^z values represents the minimum temperature in control, 14 °C and 18 °C during the year 2010–2011

morning and night time was found to prolong the growing season (Osvald and Vrscaj 1998) but controlling air temperature during the early growing stages can induce new shoot and fruit growth (Ikeda et al. 2009). The yield was reported to be consistently higher with greater positive net revenue (3892 USD/acre) under best management practices (Taylor

et al. 2003). An alternate temperature cycle and chamber heating was found to reduce heating cost by about 40 % and 50 %, respectively (Arai et al. 2009). Higher fruit weight and fruit per unit area were observed in high intensity management (Lu et al. 2003). Water tube mulching found to keep the mean air temperature warmer than using only plastic tunnels (Miyamoto and Abe 2006). The number of seeds, fruit yield and quality were significantly higher with daytime heating in the greenhouse (Hikawa 2008). Temperatures below or above optimum levels may influence plant metabolic activity positively or negatively (Naxawe et al. 2010). The uptake of nutrients was observed 5 times greater on sunny days than on rainy days that suggested solar radiation is a major factor affecting nutrient solution uptake and growth processes in plant as a whole (Kim et al. 2008 and Went 1953). Magnesium absorption was observed to be lower at 15 °C than at 24 °C and 18 °C (Choi et al. 2009). These studies suggested that there is possibility of a high fruit yield at harvest by increasing the day/night temperature differences using cost-effective methods. Hence, the present experiment was conducted to study the effect of modulating temperature on growth and fruit characteristics of watermelon and to estimate cost efficiency based on the electric power consumption for heating.

Material and methods

Watermelon cultivar ‘Sambok-gul’ was selected and sown on perlite beds in a plastic house under controlled conditions at Watermelon Farm, Jeongeup-Jeonbuk, longitude 35° 31' 47.51N, 126° 48'48.84E, altitude 37 m for 2 years consecutively during the early spring season (2010–2011). A total of 15 plants each were randomized into 3 replications in 3 different treatments (control, 14 °C and 18 °C). The plants were spaced 45 cm and the row length was 3 m wide. Temperature treatments, 14 °C and 18 °C were given around

Table 2 Growth characteristics during 15 days after fruit set and harvest stage in control, 14 °C and 18 °C

Temperature	Plant height (cm)	Number of fruit set node	Length of 1st cotyledon to 20th node (cm)	Stem thickness of fruit set node (cm)	Fresh weight (kg)	Leaf length (cm)	Leaf width (cm)	Petiole length (cm)	Leaf area (cm ²)
Fifteen days after fruit set									
Control	406.6a ^z	21.0a	194.1b	7.1b	1.4b	30.0a	29.4a	18.2a	309.3b
14 °C	424.5a	21.2a	209.3b	8.5a	1.9a	32.3a	31.7a	20.3a	355.3a
18 °C	430.6a	20.5a	226.4a	7.9a	1.7a	32.5a	30.3a	19.7a	346.8a
Harvest stage									
Control	543.4a ^z	20.1a	201.9ab	7.7a	1.5b	31.0b	29.4b	20.0a	295.8b
14 °C	546.1a	19.9a	194.4b	8.6a	1.9a	30.6b	30.2b	19.6a	300.8b
18 °C	557.0a	20.7a	210.5a	8.1a	2.0a	32.6a	33.7a	20.8a	351.7a

^z Means followed by identical letter(s) in a column were not significantly different at the 5 % level by DMRT

Table 3 Fruit characteristics during 15 days after fruit set and harvest stage in control, 14 °C and 18 °C

Temperature	Fruit length (cm)	Fruit width (cm)	Fruit weight (kg)	Soluble solids (Centre) (%)
Fifteen days after fruit set				
Control	16.1b ^z	15.1b	2.3b	4.1a
14 °C	16.5b	15.6b	2.5b	3.8a
18 °C	17.8a	16.6a	3.0a	4.0a
Harvest stage				
Control	24.7b ^z	22.6b	7.1b	10.8ab
14 °C	25.5ab	23.7ab	8.1a	10.6b
18 °C	26.6a	24.0a	8.3a	11.1a

^zMeans followed by identical letter(s) in a column were not significantly different at the 5 % level by DMRT

the fruiting region of the watermelon plants for a period 1 week prior (58 days after transplanting) to 15 days after fruit setting (63 days after transplanting), on 31st March to 21st April, 2010 and on 30th March to 20th April, 2011. The daily low temperatures prior to and after fruit set were recorded from 30 March to 21 April (Table 1). The phenotypic data was collected on different growth and fruit characteristics mainly, length of the 1st cotyledon to the 20th node, stem thickness at the fruit set node, leaf length, leaf width, petiole length, fruit length, and fruit width (all in cm plant⁻¹), leaf area (in cm² plant⁻¹), number of fruit set nodes, and fresh fruit weight (in kg plant⁻¹) at 15 days after fruit setting and at harvest (2010–2011). The soluble solid content (%) was measured from the centre part of the fruit during 2010. The Ca²⁺ and Mg²⁺ contents (mgL⁻¹) in the digested leaf's samples (1st lower leaf of the fruit set node, leaf of fruit set and 1st upper leaf of the fruit set node of fruit set regions) were estimated by using RQflex Plus 10 (Merck, KGaA, Germany). All data was subjected to mean analysis to compare the effects of treatments using SAS software (SAS Institute, 1995).

Results and discussion

Growth characteristics at 15 days after fruit set and at harvest

The stem thickness of fruit set node, fresh weight and leaf area were observed significantly different and higher in temperature treatment 14 °C (8.5 mm plant⁻¹, 1.9 kg plant⁻¹, 355.3 cm² plant⁻¹) than at 18 °C and in control (Table 2). The length of the 1st cotyledon to the 20th node (210.5 cm plant⁻¹) was found significantly higher at 18 °C. This increase in shoot growth is considered as a parameter for the shoot demand for nutrients uptake and was concluded as a positive impact of temperature treatments on growth of plant. In particular, the plants had significantly larger leaf area (351.7 cm² plant⁻¹) at temperature treatment 18 °C that might be due to increase in leaf length and leaf width. The

fresh weight was also found significantly higher in temperature treatments (2 kg plant⁻¹, 18 °C; 1.9 kg plant⁻¹, 14 °C) than controls (1.5 kg plant⁻¹). Temperature treatments 14 °C and 18 °C had non-significant effect on plant height, number of fruit set nodes and petiole length. The temperature treatments 14 °C and 18 °C had significant positive effects on most of the growth characteristics particularly, fresh weight, leaf area, stem thickness of fruit set node and length of the 1st cotyledon to the 20th node starting 15th day after fruit set and at the time of harvest. The results are supported as previously reported by others. The modulated temperature treatments significantly affected photosynthetic activity, increase in lateral main shoot length, growth and development of root and shoot, plant height, internode length, number of branches, flower number, leaf number, leaf area and yield in various crops. (Buttrose and Sedgley 1978; Engles et al. 1992; Son and Han 2000; Moon and Moon 2001; Lim et al. 2002; Son et al. 2002; Chang et al. 2003; Kwon et al. 1999, 2004; Shim et al. 2005; Son et al. 2003; Hwang et al. 2005).

Fruit characteristics at 15th day after fruit set and at harvest

Significant differences were observed for different fruit characteristics in control and temperature treatments (Table 3). The

Fig. 1 Fruit set rate in control, 14 °C and 18 °C

Table 4 Content of Ca^{2+} and Mg^{2+} in fruit set region at harvest stage

Leaf position	Control		14 °C		18 °C	
	Ca^{2+} (mgL^{-1})	Mg^{2+} (mgL^{-1})	Ca^{2+} (mgL^{-1})	Mg^{2+} (mgL^{-1})	Ca^{2+} (mgL^{-1})	Mg^{2+} (mgL^{-1})
1st lower leaf of fruit set node	51.7	8.6	69.4	12	77.9	10.4
Leaf of fruit set node	53.3	6.4	66	10.8	70.9	11.1
1st upper leaf of fruit set node	59.8	5.5	79.3	11.5	69	8.6
Mean	54.9b ^z	6.8b	71.5a	11.5a	72.6a	10.0a

^z Means followed by identical letter(s) in a column were not significantly different at the 5 % level by DMRT

temperature treatments 18 °C had significant and positive effects on fruit length and fruit width, resulting in higher fruit weight on the 15th day after fruit set (3 kg plant⁻¹) and harvest stage (8.3 kg plant⁻¹) than at control and 14 °C. This may corresponds to enhancement in photosynthetic productivity due to the positive effect of temperature treatments on leaf area. The soluble solid content was found significantly higher in temperature treatment 18 °C (11.1) compared to 14 °C (10.6) and control (10.8) at harvest stage. The integrated data was analysed on fruit set percentage for the years 2010–2011 (Fig. 1). The fruit set percentage was found comparatively higher in temperature treatments 18 °C (96.5 %) and 14 °C (78.4 %) than at control (66.8 %). It was evident that imposing of temperature treatment 18 °C had advantage not only in improving cultivar performance in terms of fruit weight on the 15th day after fruit set and at harvest stage, but also the soluble solid content and fruit set percentage at harvest. These findings were supported by earlier reports on different crops. Temperatures below or above optimum levels may influence greater differences in yield, plant metabolic activities, fruit setting percentage, number of seeds per fruit, fruit quality, flower morphology and fruit quality and marketable yield (Hartz and Bogle 1989; Myster and Moe 1995; Moon and Ko 2002; Neji et al. 2003; Lu et al. 2003; Watanabe et al. 2003; Hikawa 2008; Naxawe et al. 2010; Ikeshita et al. 2010).

Content of Ca^{2+} and Mg^{2+} in leaves of fruit set region

The modulated temperature treatments 14 °C and 18 °C were found to have accelerated the accumulation of Ca^{2+} and Mg^{2+} ions with significant variations in different leaves emerging from fruit set nodes (Table 4). However, the contents of Ca^{2+} and Mg^{2+} ions were observed higher in the 1st upper leaf of the fruit set node (79.3 mgL^{-1}) and the 1st lower leaf of the fruit set node (12.0 mgL^{-1}), respectively at 14 °C. It was concluded that increase in leaf area in the heat treated plants promoted high photosynthetic activity and transpiration rate, which in turn accelerated ion uptake rate, in particularly leaves around fruit set region. The leaf at the fruit set node was speculated to be supportive source and lead to the increase in fruit size and solid soluble content during harvest stage. Further study on the process of ions

flow rate under different temperature regimes may provide information on ion uptake mechanism in watermelon. Earlier studies also revealed higher content of calcium and magnesium in the leaves at 25 °C (Park and Oh 2000; Choi et al. 2009). Very low or high temperatures in the growth environment may be detrimental to various metabolic processes in plant tissues, such as nutrient uptake, fluctuation in the anion exclusion volume and exchangeable Ca^{2+} , chlorophyll formation and photosynthesis (Taylor and Rowley 1971; Rhee and Gotham 1981; Markwell et al. 1986; Polubesova et al. 1994).

Electric power consumption

The average integrated power consumption was recorded as 21.9 kW, which incurred the expense of 795.3 WON (0.68 USD in 2011) on a daily basis to maintain the temperature of 14 °C (Fig. 2). However, higher energy (60.1 kW per day) was required to keep the temperature at 18 °C, that cost 2185.8 WON (1.87 USD) per day. Both the power consumption and charges were estimated 64 % higher in 18 °C over 14 °C on daily basis. It was observed that every one unit increase in temperature resulted in an increase in power consumption and proportionate electricity charges.

Fig. 2 Electric power consumption in control, 14 °C and 18 °C

The modulated temperature treatments given around the fruiting region of the watermelon cultivar for a total of 22 days (1 week prior to 15 days after fruit setting) were estimated to cost around 14.96 USD and 41.14 USD for 14 °C and 18 °C, respectively. A farmer in Korea usually has an average income in the spring season of around 4,63,554 WON (3972.20 USD) in 2011. This extra cost incurred is suggested to be quite in the range of a farmer's budget and has yield benefits also. The present findings were supported by earlier reports (Choi et al. 2001; Taylor et al. 2003; Arai et al. 2009).

Conclusion

Our study confirms the potential of modulated temperature treatments in improving growth and fruit characteristics at the 15th day after fruit set and at harvest. The data showed that temperature treatment 18 °C enhanced good fruit set rate and soluble solid content in the centre part of the fruit. With regard to uptake of ions, accumulation of Ca^{2+} and Mg^{2+} were increased in leaves of the fruit set node. The power consumption and extra costs of the temperature treatment 18 °C were suggested as affordable and in range of a farmer's budget (41.14 USD/22 days). Hence, it was concluded that modulated temperature treatments could be utilized successfully to optimize the temperature range for enhancing the fruit yield and quality in the winter watermelon crops.

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