Effect of Supplemental Light on the Quality of Green Asparagus Spears in Winter ‘Fusekomi’ Forcing Culture

Daniel Z. K. WAMBRAUW\textsuperscript{1,2}, Taisuke KASHIWATANI\textsuperscript{1}, Akihiro KOMURA\textsuperscript{1}, Hiroyuki HASEGAWA\textsuperscript{1}, Kaori NARITA\textsuperscript{3}, Satoshi OKU\textsuperscript{1,3}, Takayuki YAMAGUCHI\textsuperscript{1}, Kazushige HONDA\textsuperscript{1} and Tomoo MAEDA\textsuperscript{1}

\textsuperscript{1} The United Graduate School of Agricultural Science, Iwate University, Morioka, Iwate 020-8550, Japan
\textsuperscript{2} Faculty of Agriculture and Life Science, Hiroaki University, Hiroaki, Aomori 036-8560, Japan
\textsuperscript{3} Graduate School of Agriculture, Hokkaido University, Sapporo, Hokkaido 060-0808, Japan
\textsuperscript{4} Iwate Agricultural Research Center, Kitakami, Iwate 024-003, Japan

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Winter ‘fusekomi’ forcing culture of asparagus is becoming popular in Japan because the method can make production of asparagus possible during cold season. However, there are some problems such as color of the spear is pale, and rutin content is lower compared to spring harvest due to the low light intensity, especially in the production area which has much snow and short sunshine. The objective of this study was to clarify the effect of supplemental lighting on the yield, rutin content, sugar component (fructose, glucose, sucrose), and the color of spears. The experiments were conducted by using different irradiation time and different numbers of fluorescent lamps hanging on the tunnel poles over the cultivation bed on the winter ‘fusekomi’ forcing culture. Compared to the control, rutin content was significantly increased under supplemental lighting plots. No significant difference or negative impact was observed in sugar contents and yield on each plot. Moreover, spear color also appeared to be better under supplemental lighting than that of the control. These results suggested that supplemental lighting was effective to improve the quality of asparagus spears (such as rutin contents, spear color), especially for the production area that has low light intensity or in short day conditions.

Keywords : Asparagus officinalis, environmental control, HPLC, rutin, spear color, sugar

INTRODUCTION

Asparagus (Asparagus officinalis L.) is known to be a rich of some functional compounds beneficial for human health. In recent years, consumer’s interests on functional food such as flavonoids are increasing (Maeda et al., 2010). Green asparagus contains certain amount of rutin (Chin et al., 2002, Maeda et al., 2005; Sun et al., 2007; Maeda et al., 2010; 2012; Motoki et al., 2012). Rutin is one of the major flavonoids that have been reported to show biological and pharmacological activities such as anti-inflammatory, anti-tumor, and anti-bacterial/viral properties along with potent radical-scavenging activity, as well as protective effects in protecting against capillary fragility and arteriosclerotic vascular changes (Griffith et al., 1944; Hellerstein et al., 1951; Calabro et al., 2005; Guo et al., 2007). Asparagus is widely grown in Japan. The conventional spring harvest and mother-fern culture is the most popular method of harvesting asparagus. Therefore, during winter season, domestic production of asparagus almost drops to zero; the price tends to be high substantially; but asparagus are imported from other country to respond the market needs. Winter ‘fusekomi’ forcing culture system has been conducted in Japan to make asparagus production possible during this season (Koizumi et al., 2003) by heating one to two years old rootstocks in a ‘fusekomi’ forcing system. The preparation of this method is usually started in January; the seeds are sown and grown in the greenhouse. Then in the early May, seedlings are transplanted into an open field. After the yellowing of the fern (October-November), the rootstocks are dug up from the field and densely planted in the ‘fusekomi’ forcing system. In the ‘fusekomi’ forcing system, heating wires were set under the bed, and the rootstocks were covered by the soil and warmed by the heating wires. Finally asparagus could be produced even in the winter, but spears are mostly growing under small amount of light because of much snow and low sunlight in the production area. These conditions cause some problems; namely, the color of the spear is pale, and rutin content is relatively low as compared to those harvested in spring. According to the previous study, reported by Maeda et al., 2010, in the mother fern culture, improvement of the light condition by net screen method led to both the increase of rutin content of spears and the improvement of spear color. On the other hand, ‘fusekomi’ forcing cultivation is conducted in a relatively small space with dense planting (planting density is more than twenty times, comparing to the open field cultivation). Therefore, this method makes ‘environment control’ easier such as light condition.

The objective of this study was to obtain basic knowledge to improve the quality (color and rutin) of asparagus
spear in order to produce high value of the spear during winter season by using different irradiation time (2012) and different quantity of fluorescent light (2013) on the winter ‘fusekomi’ forcing culture.

MATERIALS AND METHODS

Preparation for experiment by using winter ‘fusekomi’ forcing culture

Trial on 2012 were conducted to evaluate the effects of different irradiation time on asparagus spear and trial on 2013 were conducted separately in purpose to investigated the effect of different quantity of fluorescent light.

Preparation for the experiments were conducted as follows; one-year-old rootstocks of ‘UC157’ were dug up from an open field of Iwate Agricultural Research Center on December 6, 2011, or November 22, 2012. The rootstocks had been planted in the heated cultivating beds (‘fusekomi’ system) set in a greenhouse at the trial field of Hirosaki University on December 16 to 19, 2011 or ‘fusekomi’ system set in a greenhouse at the trial field of Hirosaki University on December 16 to 19, 2011 or November 30 and December 3 to 4, 2012. Thirty to forty rootstocks were planted for one plot (80 cm × 120 cm × 45 cm), and were covered with rice hull compost. All the test plots were covered with the plastic tunnels and the house was covered with a shading net (only on 2013 trial). The minimum air temperature was kept more than 10°C using an oil heater and soil temperature was kept around 18°C using the heating wires.

Experimental treatments by using winter ‘fusekomi’ forcing culture

In 2012, three trial plots with 2 repetitions were prepared as follows: Control; with no supplemental light, FL1-16; 1 supplemental lighting for 16 h a day (FHF 32EX-N-H, Panasonic Co., Japan), and FL1-24; continuous (24 hours a day) lighting with 1 white fluorescence lamps. All the test plots were covered with a light reflecting material Tyvek sheet (DuPont-Asahi Flash Spun Products Co., Japan) during the night (Fig. 1). The trial was conducted from January 16 to March 5, 2012.

In 2013, three trial plots with 2 repetitions were prepared as follows: Control; with no supplemental light, FL1-24; continuous (24 h a day) lighting with 1 white fluorescence lamps (FHF 32EX-N-H, Panasonic Co., Japan), and FL2-24; continuous (24 h a day) lighting with 2 white fluorescence lamps. All the test plots were covered with a light reflecting material Tyvek sheet (DuPont-Asahi Flash Spun Products Co., Japan) during the night (Fig. 1). The trial was conducted from January 15 to February 25, 2013.

Light intensity and air temperature measurement

Light intensity at night and daytime, and air temperature of the plots were measured during the harvest period. Light intensity was measured under different weather, with 24 cm height from the compost level by using photo quantum meter (Kaito memory sensor MES-136 light logger, Yokohama, Japan). Air temperatures were recorded by using thermo recorder (T&D wireless thermo recorder RTR-52A, Nagano, Japan).

Spear weight observation and spear color analysis

Yields observation were difficult to conducted in this study because of the limited plots, so we used the average of spear weight per plot as the parameter to observed the effect of irradiation time on yield in this experiment, consider spear weight also are the important factor for yields.

Spear weights were harvested at 27 cm and cut to a length of 24 cm for weight observation. The weight of spears in each plot was measured every day during the harvest period. Spear color was investigated by measuring L* (lightness), a* (red-green), and b* (yellow-blue) values in the bottom section (3–4 cm from the cut) of M (middle; 13–18 g) to L (large; 18–23 g) sized spears in each plot. The values were obtained using an NF333 (Nippon Densyoku Industry Co., Japan) color difference meter and the reconstruction of color and/or the average of L*a*b* value were obtained by using the software ‘Irodashimeijin for windows’.

Determination of rutin and sugar contents

For component analysis, rutin and sugar content observation were determined. Three to four of M (middle; 13–18 g) to L (large; 18–23 g) sized spears in each plot were cut into 3 sections of equal length (8 cm of each section), immediately frozen, and then lyophilized. The top section of the spears was used for rutin analysis and the bottom section was used for sugar analysis (fructose, glucose, sucrose). Rutin were extracted from 20 mg of freeze-dried powder of M to L size spears (11 to 20 g) from each experimental plot by using 1 ml of 80% methanol. The extraction was conducted for three hours at room temperature. Sample solutions were then centrifuged (10,000 rpm, 10 min) and filtered. Rutin content was determined by high performance liquid chromatography (HPLC) as described by Maeda et al. (2012). HPLC analysis was conducted using a Waters Sunfire C18 (4.6 × 250 mm) column. The mobile phases were consisted of 0.1% trifluoroacetic acid (A) and acetonitrile (B). Analysis was performed by running each sample for 30 min at a column temperature of 40°C, using a linear gradient system at a flow rate of 1.0 ml min⁻¹ and each run was monitored at a wavelength of 354 nm UV detector. The gradient condition was 0 min, 84% solvent A and 16% solvent B; 20 min, 60% solvent A and 40% solvent B; 30 min, 40% solvent A and 60% solvent B, and the post running time was 10 min. Sugars were
extracted from 20 mg of the freeze-dried powder with 1 ml of 70% ethanol for 1 h at room temperature. The extracted solution was centrifuged, and the supernatant was used for sugar analysis. Sugar content was determined by using HPLC system equipped with a Shodex Asahipak NH2P-50 4E (4.6 × 250 mm) column. The mobile phases consisted of 78% acetonitrile. Analysis was performed by running each sample for 20 min at a column temperature of 35°C, with a flow rate of 1.0 ml min⁻¹ each run was monitored by evaporative light scattering detector (Model 300S ELSD, M&S Instruments Inc., Japan).

RESULTS

Light intensity and air temperature inside the tunnel on each test plot

In order to examine the effect of supplemental lighting to the environment inside the tunnel, light intensity at night and daytime, and air temperature of the plots were measured during the harvest period. The average of light intensity at night and daytime on control, FL1-24, and FL2-24 were as follows; 0, 59, 143 μmol m⁻² s⁻¹ and 68, 103, 163 μmol m⁻² s⁻¹ (Table 1). The average of air temperature inside the tunnel on control and FL2-24 were 11.9°C and 17.2°C, respectively. In addition, the average of the air temperatures on the aisle between examination beds were 10.6°C.

Effect of irradiation time on rutin content (2012)

On 2012, during the harvest period rutin content of control shows 2.14 mg g dry weight⁻¹ (dw), followed by FL1-16 and FL1-24 with 2.35 and 2.56 mg g dry weight⁻¹ (dw) of rutin average (Fig. 2). Rutin content on the FL1-16 and FL1-24 plots were higher than in the control plot (Tukey-Kramer test, P<0.05, n=18).

Effect of different quantity of fluorescent light on rutin content (2013)

We confirmed that rutin content was increased in the both supplemental lighting plots, FL1-24 and FL2-24 (Fig. 3). Control plot showed 1.66 mg g dry weight⁻¹ (dw) of rutin average. FL1-24 and FL2-24 was observed to contain 2.45 and 2.61 mg g dry weight⁻¹ (dw) of rutin, respectively. FL1-24 and FL2-24 showed the highest rutin content, and there was a significant difference against control (Tukey-Kramer test, P<0.05, n=18).

Effect of different quantity of fluorescent light on spear color (2013)

The result of color difference, L* value of the spears harvested at control, FL1-24, and FL2-24 plots were 59.35, 53.54, and 49.54, respectively (Fig. 4). Compare to the control plots, both supplemental lighting plots showed low L* value, which meant that the spear color became deeper. Significant differences were observed among the plots by Tukey’s test P<0.05 on L* value. L* value of the spears harvested at supplemental lighting plot were significantly low compare to the control plot. Also, within the supplemental lighting plots, L* value of the spears harvested at the plot of FL2-24 was lower than that of the FL1-24 plot, significantly (Tukey-Kramer test, P<0.05, n=41–63).

Table 1 The average of light intensity and air temperature during harvest period.

<table>
<thead>
<tr>
<th></th>
<th>Light Intensity (μmol m⁻² s⁻¹)</th>
<th>Average</th>
<th>Range</th>
<th>Night</th>
<th>Average</th>
<th>Range</th>
<th>Air Temperature (°C)*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Daytime</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>68</td>
<td>21–136</td>
<td></td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>11.9</td>
</tr>
<tr>
<td>FL1-24</td>
<td>103</td>
<td>44–171</td>
<td>136</td>
<td>77–243</td>
<td>59</td>
<td>40–78</td>
<td>112–176</td>
</tr>
<tr>
<td>FL2-24</td>
<td>176</td>
<td>17.2</td>
<td>11.9</td>
<td>59</td>
<td>40–78</td>
<td>112–176</td>
<td>11.9</td>
</tr>
</tbody>
</table>

* Measured by using photo quantum meter under different weather at around noon during harvest period.

# Measured by using photo quantum meter after the sunset (completely dark period).

\* Recorded by using thermo recorder every 20 min during the harvest period.

\* Not recorded.
FL1-24, and FL2-24 were measured. The values of a* and b* on control, FL1-24, and FL2-24 were as follows: −7.64, −13.36 and −12.70; 20.95, 31.04 and 28.13, respectively. a* values on FL1-24 and FL2-24 shows a significant difference compare to the control, same trend also have been observed in b* values, both supplemental lighting plot has a significant difference compare to the control (Tukey-Kramer test, P < 0.05, n = 41–63).

Effect of different quantity of fluorescent light on sugar content (2013)
Sugar contents were determined during the harvest periods (Fig. 5). The average of sugar contents was stable during the harvest period and there was no significant differences observe among the experimental plot. These results indicated that there was no negative impact of supplemental lighting on sugar contents.

Effect of different quantity of fluorescent light on spear weight (2013)
The yields observation were conducted every day during harvest period, we measured the weight of spear and took average only from the spear over 8 g and under 23 g. The average of spear weight of control plot, FL1-24 and FL2-24 plot were 16.7 g, 15.8 g, and 14.8 g, respectively (Fig. 6). No significant difference was observed between control and FL1-24 plot, however, there was a significant difference between control and FL2-24. Compare to the average of spear weight on control, FL2-24 spear’s become a bit lighter (Tukey-Kramer test, P < 0.05, n = 400–500).

DISCUSSION
The effects of supplemental light on spear color were observed. L* value defines lightness if the values near hundred, and in contrast, if the value are low and/or near zero, it defines dark in color. We found that L* value of the spear harvested at supplemental lighting plots, were significantly lower, compare to the control, even within the supplemental lighting plots, L* value of spears harvested at the plot of FL2-24 showed significantly lower than that of the FL1-24 plot. a* and b* value also on both supplemental lighting shows a significant difference against control. These results suggested that the color of the spear became deeper than the control plots in association with numbers of the fluorescent lamps, and it lead to be better color, distinguishable with naked eyes (Fig. 7).

Sugar composition in the spears showed similar results to other former studies, consisting 50–54% of fructose, 42–44% of glucose and 4–5% sucrose (Matsubara, 1981; Shou et al., 2007; Brueckner et al., 2010), and there was no significant difference among experimental plot observed. So, it is clear that there was no negative impact of supplemental lighting on sugar.
The investigation of rutin content by using different irradiation time (2012) and different quantity of fluorescent light (2013) shows that rutin were increased significantly by the presence of fluorescence lamps. On 2012, rutin content on FL1-24 hours treatment were significantly increased against control and even 16 h treatment tend to be increase. The same trends also were observed on 2013 trial. Rutin content on FL1-24 and FL2-24 h treatment were significantly increase against control plot. The relations between light and rutin (flavonoids) have been studied well and reported that the rutin played a role as protector against ultraviolet (UV) in living plants (Kubasek et al., 1992; 1998; Wade et al., 2001; Rozema et al., 2002; Ebizawa et al., 2008). In the mother-fern culture during summer to autumn harvest, by improved the light environment rutin content become significantly high (Maeda et al., 2010). Autumn harvest, by improved the light environment rutin content getting higher become significantly high (Maeda et al., 2010). Particular studies about autumn harvest, by improved the light environment rutin content getting higher become significantly high (Maeda et al., 2010). Particular studies about autumn harvest, by improved the light environment rutin content getting higher become significantly high (Maeda et al., 2010).

As the conclusion, the results of this study showed that the method was effective to improve the quality of asparagus spears, especially for the area that has low sunlight in winter season. And beside it is easy to conduct and could help to improve spear quality, it also could keep temperature inside the tunnel warm.

ACKNOWLEDGEMENTS

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REFERENCES


