Utilization of Snow and Geothermal Cold Heat for Temperature Control and Head Production in Witloof Chicory Hydroponic Forcing Culture in Summer

Tetsuro UNO1, Takahiro KUMANO1 and Hajime ARAKI2,3

1 Graduate School of Environmental Science, Hokkaido University, Kita 10 Nishi 5, Kitaku, Sapporo, Hokkaido 060-0010, Japan
2 Field Science Center for Northern Biosphere, Hokkaido University, Kita 11 Nishi 10, Kitaku, Sapporo, Hokkaido 060-0011, Japan
3 Faculty of Agro-Food Science, Niigata Agro-Food University, Tainai, Niigata 959-2702, Japan (Current address)

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Forcing culture of witloof chicory (Cichorium intybus L.) is conducted in an enclosed and dark space at a temperature of roughly 15 °C, and the forcing space is cooled in summer. Temperature control in the forcing space for etiolated head (chicory) production was attempted using natural heat for a period of two years. Etiolated heads were obtained in the hydroponic culture of chicory roots. In 2015, air temperature in the culture room changed to roughly 21 °C during the hottest season because of the use of a combination of geothermal and underground water temperatures. In 2016, the average air temperature in the cooling treatment room (cooling) decreased to 16.8 °C, and the control room (non-cooling) temperature was 22.2 °C during the hot season, achieved via geothermal and snow’s cold heat. Quantity of cold heat supplied by snow into the culture room was four to five times higher than that of geothermal cold heat. Tightness of etiolated heads obtained in cooling was better compared to the control during the hot season. These results indicate that chicory forcing culture had been successful in an enclosed space cooled by geothermal and snow’s cold heat in summer.

Keywords : chicory, cooling, hydroponic forcing culture, geothermal cold heat, snow’s cold heat

INTRODUCTION

The exhaustion of finite fossil fuels and the impact of their mass use on the environment are of global concern. Attention is focused on the use of renewable energies such as sun, wind power and geothermal heat. The use of these energies is also desired in greenhouse horticulture, where large amounts of electric power and fossil fuels are employed (Kawamura et al., 2006; Fukui et al., 2009). Examples of using renewable energy in agricultural production are heating the inside of greenhouses through biomass combustion (Kawamura et al., 2006) and crop preservation using snow (Nakamura and Osada, 2001; Ishihara et al., 2005; Nikaido et al., 2014). However, using natural energy in agricultural production can be difficult as its abundance and form depending on geography and season. Previous research suggests that its unstable nature and energy smallness can be compensated by combining multiple energy types and inputting it locally (Angelis-Dimakis et al., 2011).

In recent years, the demand for Western vegetables, including witloof chicory (Cichorium intybus L.), has increased in Japan (Ohtani, 2004), where almost all witloof chicory to date has been imported. However, doing so is expensive, and as such, domestic production of witloof chicory is anticipated for introduction to the Japanese market at a low price and high quality.

Cultivation of witloof chicory comprises two stages: firstly, plant growing and harvesting of chicory roots in an open field and, secondly, implementing forcing culture of harvested roots for production of etiolated heads. Chicory roots are generally stored at a low temperature of roughly 0 °C and high relative humidity until forcing culture is implemented. The storage period is cultivar-dependent (König and Combrink, 2002). Forcing culture is generally carried out by employing high-density planting in a dark space under a controlled and constant temperature of 14 to 18 °C (Morishita, 1988). High temperatures cause rapid growth of loose and elongated heads, whereas low temperatures reduce growth rate and produce shorter and tighter heads (Ryder, 1998). Since loose, irregular shaped or small heads are not marketable (Sterrett and Savage, 1989), temperature control within a suitable range is important in forcing culture. In order to produce etiolated heads throughout the year, special equipment is needed for controlling the temperature within a suitable range in Japan (14 to 18 °C), particularly in summer and winter. In the commercial production of chicory heads, electrical air conditioning systems are applied in the forcing room, but this is a costly process. Since forcing culture can be carried out in an enclosed and narrow space, it is potentially viable to control temperature using natural heat sources, despite the limited energy density, compared to fossil fuels.

Several studies have explored the feasibility of geo-
thermal heat application for controlling the temperature in greenhouses (Goswami and Dhalwai, 1985; Santamouris et al., 1995; Ozgener and Ozgener, 2010). Geothermal heat can be applied as a source of both heating and cooling and can be used almost anywhere. Its average temperature varies depending on environmental conditions. According to Sasada et al. (2011), underground temperature becomes stable over time at a depth of 10 to 15 m and is generally 1 to 2 °C higher than the average ambient temperature in the location aboveground.

In Yubari city, Hokkaido, an experiment involving forcing culture of witloof chicory using compost heat was conducted in winter, and marketable heads were produced as a result (Kumano and Araki, 2016). Yamakawa et al. (2014) conducted forcing culture for chicory roots planted in soil inside a culture box using geothermal heat and snow’s cold heat in an airtight room in summer in Yubari city. However, most of etiolated heads decayed or became loose shape.

In the present study, the authors conducted hydroponic forcing culture using natural heat sources. A hydroponic system contributed to supporting a stable temperature around the emergence portion of etiolated heads. Geothermal heat, underground water’s cold heat, and snow’s cold heat were used as available natural heat sources for cooling in the study location, Yubari City. The objective of the present study was to investigate the feasibility of temperature control in a witloof chicory hydroponic forcing culture room and etiolated head production in summer using local cold heat sources.

MATERIALS AND METHODS

A hydroponic culture room (4.88 m$^2$; 1.65 W×1.60 L×1.85 H (m)) for chicory head production was installed in the gym of a closed elementary school (Fig. 1A) in Yubari city, Hokkaido (E141°9’7”N, 43°0’5”E). The experiments were conducted from July to October in 2015 and 2016. The monthly average temperatures were 18.3, 19.7, 15.1 and 8.7 °C in July, August, September, and October, respectively from 1981 to 2010 (Japan Meteorological Agency). The culture room and hydroponic culture solution were cooled using geothermal and underground water’s cold heat in 2015, and geothermal and snow’s cold heat in 2016.

**Hydroponic culture room for chicory forcing culture**

The culture room was made using 12-mm-thick wooden boards. Polystyrene foam of 25 mm thickness was attached inside the room in 2015 and attached both inside and outside in 2016 for heat insulation. Two plastic culture containers and one water receiver tank were installed in the culture room (Fig. 1B). These were covered by a black film during the experiment to increase cooling efficiency. A nutrient solution including only NO$_3$-N (100 mg/L) was prepared by dissolving chemical fertilizer (OAT House No.2, OAT Agrio Co., Ltd., Tokyo, Japan) in water. The solution was added up to a 20 cm height from the bottom in each container and circulated among two culture containers and the receiver tank by a water pump (FP-10S, Tsurumi Manufacturing Co., Ltd., Tokyo, Japan). In 2016, one more hydroculture room of the same size and construction, including the same containers, was installed as a control (non-cooling).

**Temperature control using natural cold heat**

**Geothermal heat**

Air in the hydroponic culture room was cooled by geothermal heat. In 2015, air in the gym was aspirated by a sirocco fan (Sirocco Fan, 190 W, BFS-100SC, Mitsubishi Electric Co., Tokyo, Japan) into ducts buried underground (3 m depth, 100 m length, 150 mm diameter; 47.1 m$^2$ of surface area), and the air was cooled by heat exchange with geothermal heat and returned aboveground before finally being exhausted into the culture room (Fig. 1A). Ducts were made of iron with zinc plating. The distance between the air-return point and the culture room was 14.5 m, and the surface area of the aerial duct was 6.8 m$^2$.

In 2016, air was circulated between the culture room and the duct buried underground using a sirocco fan (Fig. 2A). Accordingly, the length and surface area of ducts in the aerial part were changed to 20.3 m and 9.6 m$^2$.
respectively. In addition, ducts were surrounded by a heat insulator in 2016.

**Underground water**

In 2015, underground water flowing at 3 m depth was trapped in a 1 m³ water tank buried underground (Fig. 1A). The water’s cold heat was transferred to the culture room via heat exchange by circulating water filled into a pipe installed between the water tank buried underground and undersurface of the hydroponic culture containers (Fig. 1B). The pipe was made of copper, and its length, diameter, and surface area in the culture room were 15 m, 16 mm, and 0.75 m², respectively.

**Snow**

Snow was stored in a snow vault (43.7 m³; 3.6 W/m²) from April 19, 2016, to the end of the experiment. An antifreeze solution, cooled at the bottom of the snow vault, was circulated through the pipe, which was connected between the snow vault and undersurface of the hydroponic culture container (Fig. 2B). The pipe installed at the bottom of the snow vault was made of iron, and its length and surface area were 100 m and 6.28 m², respectively. The systems described above were constantly in operation during the experiment. However, circulation of the antifreeze solution was automatically stopped when the temperature of culture room dropped below 14 °C.

**Temperature measurements**

Temperatures in selected sites were recorded as shown in Fig. 1 and 2B: gym (a), underground at 3 m depth (b), returned air from underground (c), air exhausted into the culture room (d), hydroponic solution in the container (f), and circulated water cooled by underground water (g). The inlet and outlet of the antifreeze solution into and from the culture room were investigated using a thermocouple (T type) and recorded hourly using a data logger (GL820 midi Logger, Graphtec Co., Kanagawa, Japan). In 2016, antifreeze solution flow was measured using a liquid flow meter (LD20-PATAAA-RC, Horiba Ltd., Kyoto, Japan).

Two heat sources were consistently used during chicory forcing culture as described below. However, temperature in case of the single use of either geothermal heat or snow’s cold heat was measured for several days in July, August, and September 2016 to evaluate their cooling capacity. Cold heat supplied into the room was calculated as follows:

\[ Q = 60\Delta Tpq \]

where \( Q \) is the quantity of heat (kJ/h), \( c \) is the specific heat (J/(kg K)), \( p \) is the density (kg/L), \( q \) is the flow rate (L/min), and \( \Delta T \) is the temperature difference between the inlet and outlet of the medium [K].

**Chicory forcing culture and evaluation of etiolated heads in 2016**

Witloof cultivar ‘Vintor’ (Nunhems B.V., Nunhem, the Netherlands) was employed in the present study. The chicory roots were produced at the Experimental Farm, Field Science Center for Northern Biosphere, Hokkaido University, Sapporo (E141°34’N43°07’). Harvested roots were cut to a 20 cm length, from the neck of the root to the bottom end, and washed using tap water. The trimmed roots were placed in plastic bags and stored in a refrigerator, where air temperature was approximately 2 to 3 °C, with a relative humidity of 100%, until the start of forcing culture.

Hydroponic cultures were carried out four times: from July 7 to 22, from July 31 to August 14, from August 26 to September 9, and from September 17 to October 1 in 2016. Twenty-four chicory roots were cultured in hydroponic culture containers for roughly two weeks in each culture period. The average fresh weight of roots was 352.9 g in 2016. After implementing forcing culture, etiolated heads were harvested from roots. Head tightness, fresh weight (FW) before and after removing the outer leaves, and the height of all etiolated heads were measured. Head tightness was classified into five grades, as shown in Fig. 3, prior to removing loose outer leaves. Thereafter, outer leaves were removed until the head shape became tight. Measured data for each characteristic were statistically analyzed using the
Student’s t-test for comparison between the cooling and control in 2016.

RESULTS

Temperatures in 2015

The average temperatures of the selected sites from late July to mid-September are shown in Table 1. The recorded underground temperature ranged from 15.3 to 17.2 °C. The temperature of air exhausted into the hydroponic culture room was 1 to 2 °C lower than the gym air temperature because of heat exchange of circulated air when passing through the duct buried underground. However, it remained above 19 °C until mid-August. Additionally, a 2 to 3 °C rise in air temperature, the difference between returned and exhausted air which recognized as cold heat loss, was observed during the hottest period in July and early August. The temperature of circulating water cooled by underground water was approximately 19 °C in the culture room until end of August. The temperature of the hydroponic solution in the culture container was almost the same as the temperature of circulating water. Room temperature was approximately 2 °C lower than the gym’s air temperature in late July and early August. However, it remained above 18 °C until mid-September.

The average air temperature in the gym was the high-

| Season 2015 | Air circulation | Culture room |
|-------------|-----------------|--------------|
|             | Gym | Underground | Returned air (A) | Exhausted air (B) | Heat loss (B) - (A) | Room | Solution | Circulating water cooled by underground water |
| Jul. 20-31  | 22.2 | 16.5 | 18.0 | 21.3 | 3.3 | 20.1 | 19.5 | 19.4 |
| Aug. 1-10   | 22.3 | 17.2 | 18.6 | 20.7 | 2.1 | 20.7 | 19.6 | 19.5 |
| Aug. 11-20  | 20.4 | 16.9 | 18.0 | 19.1 | 1.1 | 20.2 | 19.5 | 19.4 |
| Aug. 21-31  | 18.5 | 15.9 | 16.8 | 17.5 | 0.7 | 19.2 | 18.8 | 18.7 |
| Sep. 1-10   | 17.7 | 15.8 | 16.6 | 16.8 | 0.2 | 18.8 | 18.5 | 18.5 |
| Sep. 11-20  | 15.9 | 15.3 | 15.9 | 15.8 | — | 16.3 | 16.4 | 16.6 |

Fig. 3  Head tightness scores for etiolated heads that emerged from roots: loose (1) to tight (5).

Fig. 4  Temperature changes of the air in the gym, returned air, and air in the culture room during mid-summer 2015.
Temperatures in late July and early August 2015 (Table 1). Temperature changes in room and gym during the hottest period are shown in Fig. 4. The temperature in the gym ranged from 17.3 to 29.8 °C, and it was 21.8 °C on average. Room temperature was marginally influenced by the gym’s air temperature and stabilized at roughly 21 °C, with an approximately 3 °C variation.

Temperatures in 2016

Table 2 showed the average temperature in selected sites during forcing culture from July 4 to October 1, 2016. The underground temperature ranged from 12.6 to 16.5 °C. Owing to the improvements made in the air duct insulation in 2016, the loss of cold heat for air on the way to the culture room was reduced compared to that in 2015 (Tables 1, 2). For example, the temperature of air exhausted into the room was 18.5 °C, and the rise in temperature was 1.3 °C even during the hottest period (July 31 to August 14). The temperature of the culture room during cooling ranged from 14.1 to 17.2 °C, reducing around 5 to 6 °C compared to the control (non-cooling), which ranged from 17.7 to 23.5 °C.

The inlet temperature of the antifreeze solution inputted into the culture room on snow cooling system was approximately 9 to 10 °C during working (Table 2). Therefore, the temperature of the culture solution was between 11.2 to 13.4 °C during the experiment, significantly lower than that of the control.

Cooling capacity of geothermal and snow’s cold heat in 2016

For single-use air circulation cooled by geothermal cold heat, the room temperature in the cooling was reduced by 1 to 2 °C, compared to the control during daytime, from August 17 to 22 and September 12 to 15, 2016 (Fig. 6a). The average room temperatures in the control were 21.7 °C in August and 18.7 °C in September, and these were 20.9 and 17.2 °C in the cooling, respectively. Hydroponic solution temperature also showed a similar tendency (data not shown). Supplied quantity of cold heat was calculated using Eq. 1 and resulted in 197.3 and 178.1 kJ h⁻¹ for
August and September, respectively, when the average air flow rate was 1,440 L min⁻¹.

In the single-use of snow’s cold heat, the average room temperatures in the cooling were 13.9, 16.1, and 14.9 °C in July, August, and September, respectively, i.e., 4 to 8 °C lower than those of the control (Fig. 6b). The solution was further cooled, resulting to average temperatures of 10.9, 11.5, and 13.8 °C in July, August, and September, respectively, i.e., 7 to 10 °C lower than those of the control (almost same with the control room temperature). The quantity of cold heat supplied into the room were 1,156, 1,023, and 765.7 kJ h⁻¹ in July, August, and September, respectively, when the average antifreeze solution flow rate was 5.2 L min⁻¹.

Characteristics of etiolated heads in 2016

The average room temperature affected characteristics of etiolated heads (Table 3). In the control, FW (before removing of outer leaves) more than 218 g/plant was recorded. However, FW after removing of outer leaves became small (45 and 79 g/plant) in mid-summer, from July 31 to September 9, because of small head tightness (score 1.0 and 1.4), resulting a lot of expanded outer leaves. Therefore, FW ratios were only 0.2 and 0.3.

On the other hand, in the cooling, though FW before removing was smaller (below 200 g) than those in the control, FW after removing was higher (above 80 g) due to significantly higher head tightness (score 2.1 and 2.7) in mid-summer, from July 31 to September 9. Thus, FW ratios were also higher than those in the control (0.45 and 0.49). Throughout the experimental period in 2016, FW ratios in the cooling were significantly higher than those in the control. The scores for head tightness in the cooling were significantly higher compared to those in the control, up to early September. Good etiolated head with tightness score 4.2 and 138 g in FW after removing was obtained in the cooling from July 7 to 22. The height of etiolated heads

Fig. 6  Temperature changes in the case of single-use geothermal (a) or snow’s (b) cold heat in 2016.
Table 1  Yield and quality of etiolated heads obtained by forcing culture in 2016. 

| Period of forcing culture | Average room temperature (°C) | Before removing of outer leaves | After removing of outer leaves | NW Ratio (After/Before) |
|--------------------------|-------------------------------|---------------------------------|-------------------------------|-------------------------|
|                          | Control                        | Cooling                         | Control                        | Cooling                  |
|                          | Fresh weight (g/plant)         | Height (cm)                      | Head tightness score           | Fresh weight (g/plant)   | Height (cm)                      |
|                          |                                |                                 |                                |                         |                                 |
| Jul. 7                    | 19.9                           | 15.1                            | 2.6                            | 19.9                    | 15.1                            | 2.6 |
| Jul. 31                   | 23.7                           | 18.7                            | 1.0                            | 23.7                    | 18.7                            | 1.0 |
| Aug. 26                   | 22.2                           | 16.8                            | 2.7                            | 22.2                    | 16.8                            | 2.7 |
| Sep. 17                   | 17.6                           | 14.0                            | 2.8                            | 17.6                    | 14.0                            | 2.8 |

** The fresh weight of roots used in this experiment was 352.9 g on average.

n.s., *, and ** indicate no significant differences, significant differences at \( P < 0.05 \), and significant differences at \( P < 0.01 \), respectively.

*The fresh weight of chicory produced in 2015 (Fig. 4). This temperature is too high for the production of marketable chicory where etiolated heads are concerned. However, since the hydroponic culture room was surrounded by a heat insulator, variation in room temperature became smaller compared to that of air temperature in the gym. Yamakawa et al. (2014) reported that air temperature decreased by 1 °C when circulating air within a culture room (136 m³; 2.1 W×27 L×2.4 H (m)) with heat insulation and a duct 25 m in length buried at 2 m depth. According to a report by Ozgener et al. (2010), the maximum air temperature decrease was approximately 5 °C when air passed through a pipe 0.56 m in diameter and 47 m in length buried at a depth of 3 m underground. In the present study, the total length of the buried duct was 100 m, and the temperature of returned air from underground decreased by 4 to 7 °C compared to the gym air temperature during daytime (Fig. 4). This may indicate that the cooling capacity in the present system was efficient as a result of the longer duct.

However, since the temperature of returned air from underground was strongly affected by the gym’s air temperature on the way to the culture room, the culture room was not sufficiently cooled in 2015. The duct in the aerial section was therefore enclosed in a heat insulator to decrease loss of cold heat in 2016. In addition, the system was changed to circulate air between the hydroponic room and the underground duct in order to increase cooling efficiency in 2016.

The temperature of the hydroponic solution in 2015 experiment was slightly lower than the gym’s air temperature, which was achieved by circulating water cooled by underground water, but it remained above 18 °C until mid-September (Table 1). As a result, it was impossible to cool temperatures to a desirable range for the production of tight etiolated head, below 18 °C, in 2015.

In the 2016 experiment, the average air temperature in the gym was 21.8 °C from August 26 to September 9, and the average temperatures for the culture room and hydroponic solution were 16.8 and 13.4 °C, respectively, in the cooling (Table 2). These data indicated an improvement in cooling capacity in 2016 compared to the 2015 experiment. The loss of cold heat in the air circulation system was decreased by the insulation attached to the duct in 2016 (Tables 1, 2). The temperature of the antifreeze solution cooled in the snow vault was extremely low and appeared to have a significant influence on cooling, especially the hydroponic solution (Table 2 and Fig. 6b). Consequently, the culture room temperature was influenced by

ranged from approximately 10 to 20 cm in the control and from 11 to 14 cm in the cooling, compact shaped etiolated heads were produced in the cooling.

**DISCUSSION**

Temperatures in the culture room

Culture room temperature, one of the most important factors for the growth and quality of etiolated heads in this system, was changed to roughly 21 °C during mid-summer in 2015 (Fig. 4). This temperature is too high for the production of marketable chicory where etiolated heads are concerned. However, since the hydroponic culture room was surrounded by a heat insulator, variation in room temperature became smaller compared to that of air temperature in the gym. Yamakawa et al. (2014) reported that air temperature decreased by 1 °C when circulating air within a culture room (136 m³; 2.1 W×27 L×2.4 H (m)) with heat insulation and a duct 25 m in length buried at 2 m depth. According to a report by Ozgener et al. (2010), the maximum air temperature decrease was approximately 5 °C when air passed through a pipe 0.56 m in diameter and 47 m in length buried at a depth of 3 m underground. In the present study, the total length of the buried duct was 100 m, and the temperature of returned air from underground decreased by 4 to 7 °C compared to the gym air temperature during daytime (Fig. 4). This may indicate that the cooling capacity in the present system was efficient as a result of the longer duct.

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both the antifreeze and hydroponic solution temperature: thus, the average room temperature was within the desirable temperature range (below 18 °C) during forcing culture in 2016. On the other hand, the maximum room temperature exceeded the desirable range (reached 20 °C) during the daytime when the maximum gym temperature was close to 30 °C (Fig. 5). Therefore, further improvement is necessary to reduce and stabilize the room temperature.

Evaluation of a single natural cold resource effect
In the case of single-use of geothermal cold heat, the temperature of the culture room during cooling was indicated as being above 20 °C, outside the desired temperature range for etiolated head production in August 2016 (Fig. 6a). On the other hand, it ranged from 16 to 19 °C in September, closer to the desirable range. This indicates that room temperature can potentially be controlled using only a geothermal cooling system both prior to and after the hottest period.

Snow’s cold heat showed a strong effect on the reduction of temperature in the culture room and culture solution (Fig. 6b). The quantity of cold heat supplied into the room by snow was 4 to 5 times higher than geothermal cold heat. As a result, the average room temperature during cooling was below 17 °C, indicating temperature within the desired range through the use of snow cooling only even in the hottest period.

Geothermal and snow’s cold heat for temperature control in summer can be employed in various ways. Yamakawa et al. (2014) reported that, by using soil beds chicory production system in a culture room with a high insulation effect in mid-summer, air temperature in the culture room can be controlled at roughly 18 to 20 °C via air circulation between the culture room and underground, and subsequently, soil temperature was stabilized at roughly 15 °C by snow’s cold heat. Such a system suggests the importance of geothermal and snow’s cold heat for temperature control during summer. Kumano and Araki (2016) reported that air temperature inside the forcing bed reached 18 °C via a compost heating system when room air temperature was maintained above 0 °C in a winter experiment. They noted that a geothermal heat recovery system can be considered a practical option for adjusting room temperature.

In the present study, the potential for room temperature control within a desirable range for chicory production using only geothermal cold heat prior to the hottest period, for example, until mid-July, was illustrated. On the other hand, during mid-summer, using snow’s cold heat was essential for sufficient cooling. During the hottest period, the geothermal cooling system may be suitable as a supplementary source of cold heat to further stabilize temperature. It is proposed that using only geothermal cold heat in order to save snow use prior to the hottest period and employing a blend of geothermal and snow’s cold heat during the hottest period may be the best option for controlling temperature and for the effective use of heat resources at present.

Outlet antifreeze solution temperature was almost 10 °C (Table 2), indicating that the antifreeze solution retained sufficient capacity for additionally cooling the hydroponic room. By improving the snow cold system, for example, changing the flow rate or pipe placement, better temperature control for etiolated head production can be achieved.

Evaluation of etiolated head quality
FW after removing of outer leaves was above 63 g in the cooling in all forcing periods (Table 3) and was considered to represent a marketable product (Sterrett et al., 1989). According to the international marketable standard of etiolated heads, heads with a height between 9 and 24 cm are considered marketable (Organization for Economic Co-operation and Development (OECD), 1994). The average height in the current study satisfied these requirements in all forcing cultures, and height range was stable in the cooling for all periods compared to the control. A stable height range is an important factor because, the higher the quality class grade, the smaller the required height range becomes (OECD, 1994).

There was a clear difference in etiolated head characteristics between the control and the cooling. Owing to high temperatures, FW before removal of outer leaves in the control was higher than that in the cooling; but the scores for head tightness were lower. FW ratio was significantly higher for the cooling group than the control group throughout the study period because of the decreasing weight of outer leaves removed in the cooling. The scores for head tightness in the cooling group were significantly higher compared to the control group because of lower room temperature, up to early September 2016. On the basis of these results, cooling treatment contributed to achieving marketable chicory production.

Although the average room temperature in the cooling was within the desirable range, the scores for head tightness were relatively low during the hot season. It was deduced that exceeding a suitable temperature range during daytime (reached 20 °C, see Fig. 5), in addition to unstable temperatures, was to blame in this instance. Morishita (1988) reported that loose heads were produced when roots were cultured under 13 to 25 °C, indicating a rather large variation in temperature. Constant temperature in forcing culture is extremely important for producing tight heads (Sasaki, 1990).

In conclusion, etiolated witloof chicory heads, which are considered to be most marketable, were produced in summer via cooling in a hydroponic forcing culture room using two local cold heat sources, i.e., geothermal and snow’s cold heat. Additional improvement of the cooling system will enable the production of better quality heads.

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