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REVIEW

Post-harvest Techniques for Practical Use Regarding a Steady Year-round Supply of Garlic Bulbs

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Abstract

For a year-round supply of high-quality garlic, a technological system that combines the post-harvest curing of bulbs and long-term storage is essential. For long-term storage after harvesting and curing, storage at a subzero temperature effectively suppresses germination and rooting. However, after being delivered from a storehouse through distribution and sales to consumers, instances of "concavities on the surface of scales" of garlic bulbs have been witnessed when kept at ambient temperature. As a method of suppressing the occurrence of concavities, we focus on curing after harvesting. We confirmed that the incidences of concavities after storage at subzero temperatures are greatly reduced by introducing a tempering method that ventilates hot air during the daytime and ambient temperature air overnight. And based on the demands of growers, we showed how the tempering method can be applied at production sites. These results are summarized in the "Post-Harvest Processing Manual for a Year-Round Supply of Garlic" and utilized at production sites.

Discipline: Horticulture
Additional key words: concavities on scales, subzero temperature, tempering method

Introduction

Known as a food that may increase stamina and maintain health, garlic is a vegetable that can be preserved longer than other vegetables. The large-scale planting of garlic in Aomori Prefecture, located in the Tohoku region of Japan, began in the 1960s. In 1976, Aomori Prefecture became the largest garlic producer among all Japanese prefectures, accounting for 21.8% of the domestic supply, and in 2016 it produced 14,200 t, accounting for 67% of the domestic supply and thus overwhelming all other prefectures. Aomori Prefecture's harvest takes place annually from June to July. Garlic bulbs are cured with heaters for about a month in facilities before being stored. The year-round supply is made possible by systematically shipping batches one after another. Maleic hydrazide solution, a plant growth regulator, was registered in 1986 as an agrochemical for suppressing the germination (and rooting) of garlic, and has since been widely used in Aomori Prefecture for providing a year-round supply of garlic. However, the expiration of its agrochemical registration in 2002 made it necessary to establish new technology for keeping garlic fresh over a long period of time, independent of plant growth regulators, in order to maintain the year-round supply of garlic.

In collaboration with the JA National Federation of Agricultural Cooperative Associations - Aomori (abbreviated as "ZEN-NOH Aomori") in Aomori Prefecture, we thus established a yearly supply by utilizing storage at −2°C as a long-term storage technology that contributes to the preservation of quality. In parallel with the aforementioned technological development, the improvements being made at production sites to existing large refrigerators for vegetables in order

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to accommodate subzero storage are being urgently advanced with the aid of government subsidies, and since 2002, the method of storing garlic from Aomori Prefecture has been changed from storage under ambient temperature to that under subzero temperatures.

The effect of storage temperature on scale quality

After −2°C storage was introduced in Aomori Prefecture, the occurrence of chilling injuries that significantly lower marketability, as well as germination and rooting in the distribution and sales processes were confirmed as being problems for distribution and sales (Figs. 1 and 2).

Yamazaki et al. (2006) conducted detailed studies on maintaining the storage temperature and quality of garlic, in order to sort out and solve these problems. First, the harvested and cured garlic bulbs are stored and then shipped out over a period of up to 10 months, from July to May of the following year. Then garlic delivered from the storehouse was kept at 15°C for four weeks, when we looked for the occurrence of any problems, germination, or sprouting. As for disorders that lower the commodity value, we reproduced the symptoms of discoloration and rarefaction of the scales, and the symptom (concavities on scales) of concavities forming on the surface of the scales. As a result, we found that storage at −1°C or lower is essential for suppressing germination and rooting, and that the lower the storage temperature, the higher the suppression of bud growth after storage. However, −2°C is considered the most suitable temperature for long-term storage because freezing occurs below −5°C, and concavities form more easily below −3°C (Fig. 3). According to Uemachi et al. (2011), concavities are known to develop due to the collapse of one or two cell layers parallel to the epidermis, and the symptoms progress as the cell collapse spreads in the layers.

The effect of curing temperature on the occurrence of concavities

Storage at −2°C was widely used as a storage method that contributes to the year-round supply of garlic in Aomori Prefecture, but since 2003, frequent cases of concavities on scales have been confirmed according to producers. Conversely, almost no concavities on scales were confirmed in the garlic produced, harvested, and cured at the Aomori Prefectural Industrial Technology Research Center’s Vegetable Research Institute (hereinafter referred to as the “Aomori Vegetable Research Institute”). Therefore, in order to investigate this disparity, Yamazaki et al. (2010) selected growers with different incidence rates of concavities on scales, and investigated the curing conditions and the incidence rate of concavities on scales after harvesting. As a result, when the average temperature during curing was 31°C or higher, and the average saturation deficit was 2.2 kPa or higher, concavities had a higher likelihood of occurrence. This showed that the curing conditions before storage are closely related to the development of concavities.

The curing method used by the Aomori Vegetable Research Institute, which had almost no occurrences of concavities, entailed hot air ventilation at 30-35°C during the day and air ventilation at ambient temperature during the night. (This process is hereinafter referred to as the “tempering method.”) In contrast, the production sites used a curing method with hot air ventilation at 30-35°C continuously throughout the day and night. (This process is hereinafter referred to as “continuous heating.”) This

Fig. 1. Normal scales (left half) and frozen scales (right half)

Fig. 2. Concavities on the surface of scales

suggests that the curing temperatures used in the tempering method and continuous heating affect the incidence of concavities during storage. Therefore, Yamazaki et al. (2014) conducted a test on curing methods and the occurrence of concavities on scales. The test section created a 33°C continuous heating zone where 33°C hot air was ventilated all day, as well as a tempering method zone where 34°C hot air was ventilated during the daytime, with ambient temperature air being ventilated at night. After curing, the garlic bulbs were stored at −2°C from September until March of the following year, with some being shipped out every month during the storage period. The index of concavities was immediately investigated after the delivery of each batch, as well as two weeks after delivery. As a result, the tempering method had a lower concavity index than that of continuous heating. Moreover, it was slower in starting to increase. In addition, the concavity index at −3°C was higher relative to storage at −2°C. And as a characteristic of the occurrence of concavities, irrespective of curing conditions, the concavity index increased after storage at 15°C for two weeks from the time of delivery when compared to the situation immediately after delivery (Fig. 4).

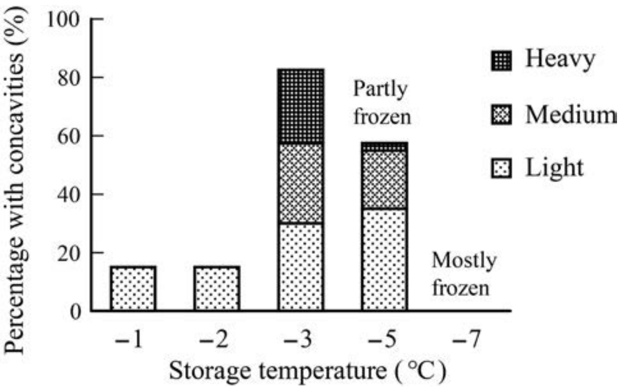

Fig. 3. The effect of storage temperature on the occurrence of concavities (partially modified from Yamazaki et al. (2013a))

Note: Bulbs initially placed in storage in August using the tempering method were delivered in January of the next year, and then examined after being stored for an additional four weeks. Percentage with concavities was determined by visual confirmation.

Curing method on a practical scale

1. Curing characteristics of continuous heating and tempering method

Unlike the circulation-type curing for general cereal

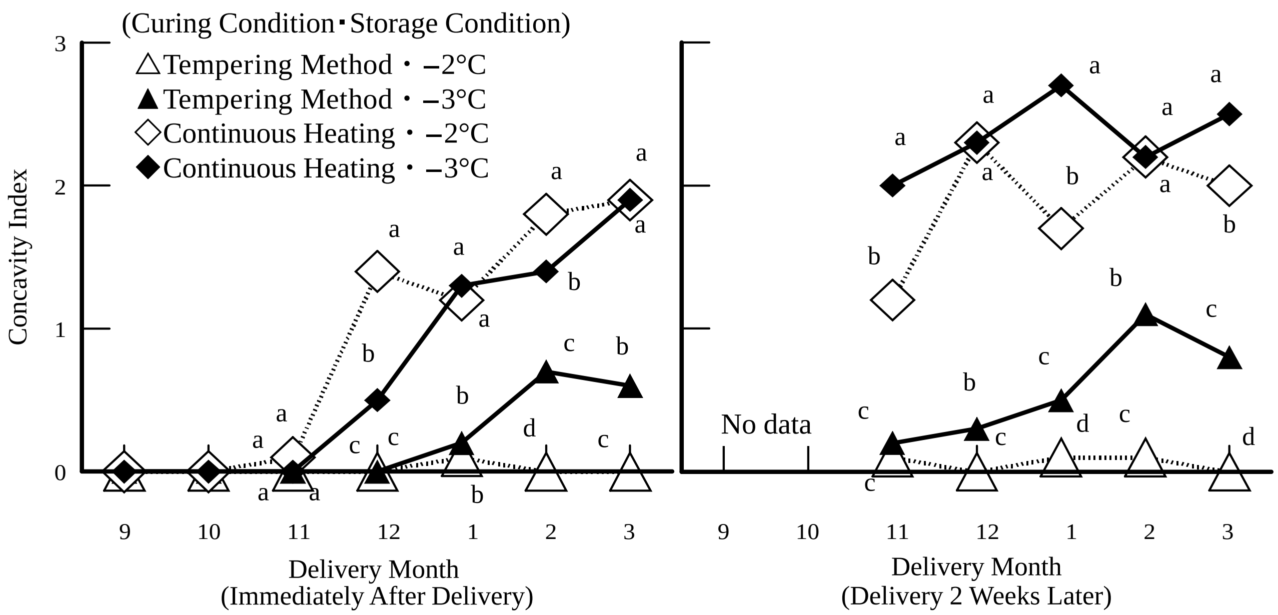

Fig. 4. Concavity index immediately after delivery and two weeks after delivery due to differences in curing and storage conditions

The extent of the occurrence of concavities was evaluated using concavity index 0: non-occurrence, index 1: mild, index 2: moderate, and index 3: severe. The concavity index was determined by visual confirmation. There is a statistically significant difference of 1% in multiple Steel-Dwass inspections between different lowercase letters of the same delivery month. Concavities did not occur with the pre-November tempering method and 0°C storage for all processing zones and periods.

grains, garlic has to cure while being left standing. Furthermore, it is clear that through the process of air passing through the object to be cured, that is, the process of air intake and exhaust, the quality of air changes due to lower temperature and higher humidity. The most popular curing method in Aomori Prefecture is the sheet system, in which stacked harvesting containers are covered on three sides (both sides and the top). At the same time, a hot air generating source is placed on the air inlet side, and a suction fan is installed on the exhaust side. This restricts the flow of air and then ventilates it out. The containers consist of a total of 210 pieces of 7 columns × 2 rows × 15 lines (1.8-m high × 1.8-m wide × 4.7-m long), and are calculated to store about 40 a's worth of harvested crops. The container is 300-mm long × 730-mm wide × 280-mm high, and one container stores around 20 kg of bulbs (pre-cured weight) (Fig. 5). Curing when using the sheet system processes a large volume of garlic per volume in the curing facility, and when curing the insides of the stacked containers while air is flowing, there is a likelihood that the temperature, humidity, and curing rate may differ between the air inlets and the air exhaust vents.

In order to clarify the curing characteristics of the tempering method in the sheet system according to Niwata et al. (2010), the Aomori Vegetable Research Institute set up two greenhouses and is conducting research on the sheet system. In order to clarify the temperature difference between the inlet side and the exhaust side, the temperature of air passing through the thermocouples was measured in each arbitrarily selected container at three places (i.e., intake side, central area, exhaust side) (Fig. 6). And in order to clarify the uneven curing of garlic during the curing period, the reduction rate of garlic bulbs was investigated. The established test section was divided into two groups: a continuous heating zone kept at 33°C, and a tempering method zone (33°C from 8 a.m. to 6 p.m., ambient temperature from 6 p.m. to 8 a.m.). In both test sections, the airflow rate ratio (airflow / garlic bulbs weight) was 0.25m^3/s·t at the start of curing.

The average ventilation temperature in the continuous heating area was 32.5°C on the inlet side, 31.1°C in the center of the container, and 29.4°C on the exhaust side. In the tempering method zone during the ventilation of hot air in the daytime, the inlet side was

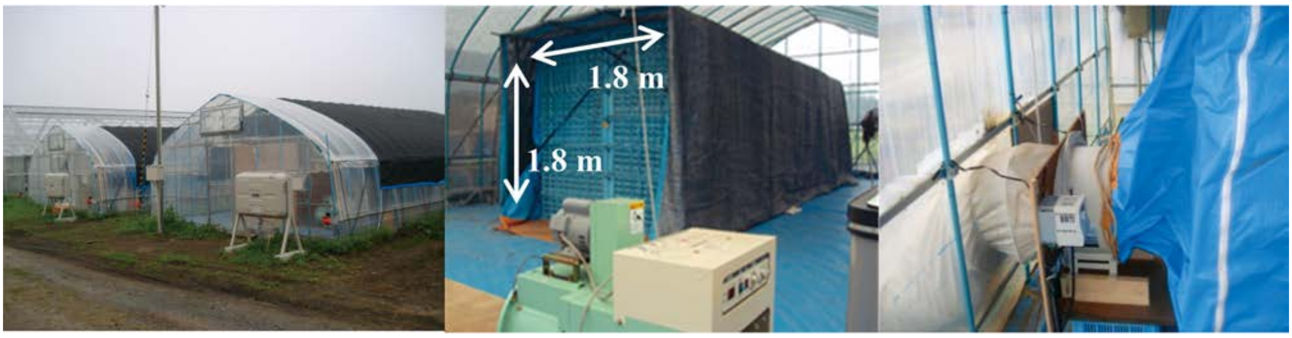

Fig. 5. Appearance of the Aomori Vegetable Research Institute's sheet method of curing

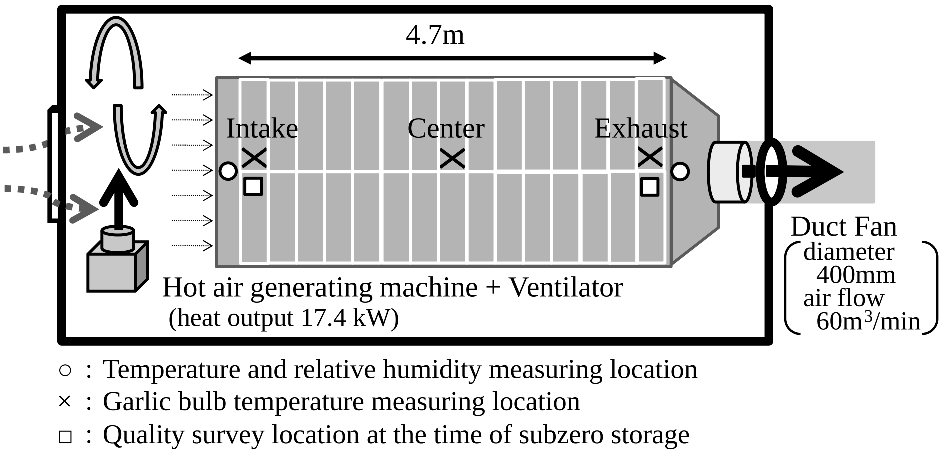

Fig. 6. Schematic diagram viewed from above the curing facility and the measurement points

31.4°C, the container's center area was 27.5°C, and the exhaust side was 24.9°C, and during the ventilation of ambient temperature air overnight, the inlet side was 21.6°C, the container's center area was 22.6°C, and the exhaust side was 23.0°C (Fig. 7). In other words, the temperature of air passing through the container in the tempering method zone was notably different from that in the continuous heating zone, especially during hot air ventilation, thereby raising a concern about uneven curing on the inlet and exhaust sides. Here, when you look at the rate of garlic weight reduction, the exhaust side was always lower when compared with the inlet side. In the continuous heating zone, the difference gradually decreased from 5.3% in the initial stage of curing to 2.7% in the later stage, and in the end, the air-intake side had a 27% loss rate before curing. Conversely, the difference in the tempering method zone decreased from 3.6% in the initial stage of curing to 1.7% in the later stage of curing, with the rate of weight loss being 25% on the inlet side. Similar to the continuous curing section, curing unevenness due to container position could be suppressed despite the above concern during the process of achieving complete curing. This was presumed to be a refining effect of the tempering method. The garlic bulbs in the tempering method zone took 35 days to fully cure, which was one week longer than the 28 days it took in the continuous heating zone (Fig. 8). However, the fuel cost was 24,200 yen (price of kerosene: 1,100 yen / 18 L) in the tempering method zone, compared with 50,200 yen in the continuous heating zone. The amount of energy per unit of water removed was 0.41 L / kg-H_2O in the tempering method zone, as compared with 0.79 L / kg-H_2O in the continuous heating zone. Thus, these results make it clear that although the tempering method requires a longer curing period compared with continuous heating, the tempering method is more energy efficient and greatly

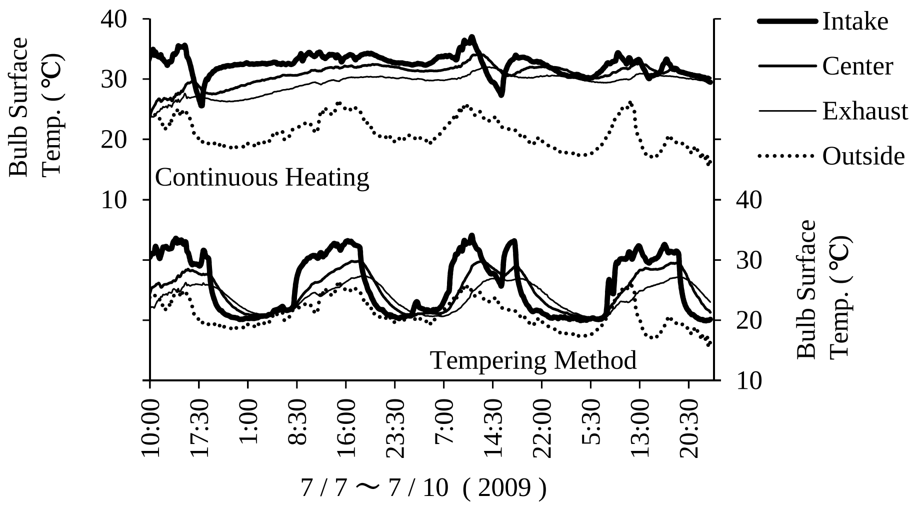

Fig. 7. Temperature of air passing through the loading container layer

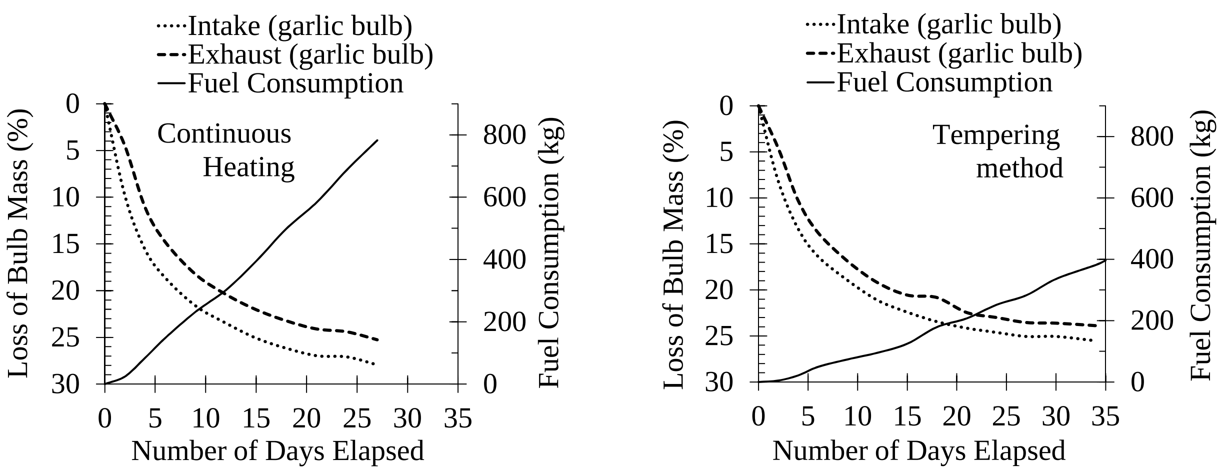

Fig. 8. Curing characteristics due to continuous heating and tempering method of the sheet method

contributes to the reduction of curing costs.

2. Moisture variations in different parts of curing garlic

Yamazaki et al. (2013a) investigated moisture variations in different parts of curing garlic. When garlic is harvested in Aomori Prefecture, the bulbs are regulated to have attached stems of about 10 to 15 cm, with parts above that height as well as roots being removed. Curing reduces the weight of garlic bulbs by 25-40% when compared to their pre-cured weight. In both the continuous heating and tempering method test zones, the outer layer cures first, followed by the bract, with moisture equilibrium being reached in about two weeks. In comparison, the basal plate slowly loses moisture and both test zones suddenly declined after 10 days of curing. Finally it became 11-15% w.b. and became the shape of a cork. Regardless of the curing of other parts, the scales retained more than 60% w.b. (Fig. 9). Using this information from the relationship of the equilibrium state of the weight reduction rate, the moisture of the peduncle can be used as a standard to judge the curing state, regardless of the curing method.

Examination of the tempering method at production sites and dissemination of technology

Niwata et al. (2010) and Yamazaki et al. (2013a) demonstrated the effects of the tempering method on a practical scale, and reported that compared with continuous heating at 33-35°C, the tempering method is less likely to cause damage after storage at subzero temperatures. However, curing using the peduncle moisture content as a standard took 29.7 days in the tempering method zone, which was about one week longer than the 21.3 days in the continuous heating zone (Table 1). Based on the above, we conducted a demonstration test of the tempering method at garlic

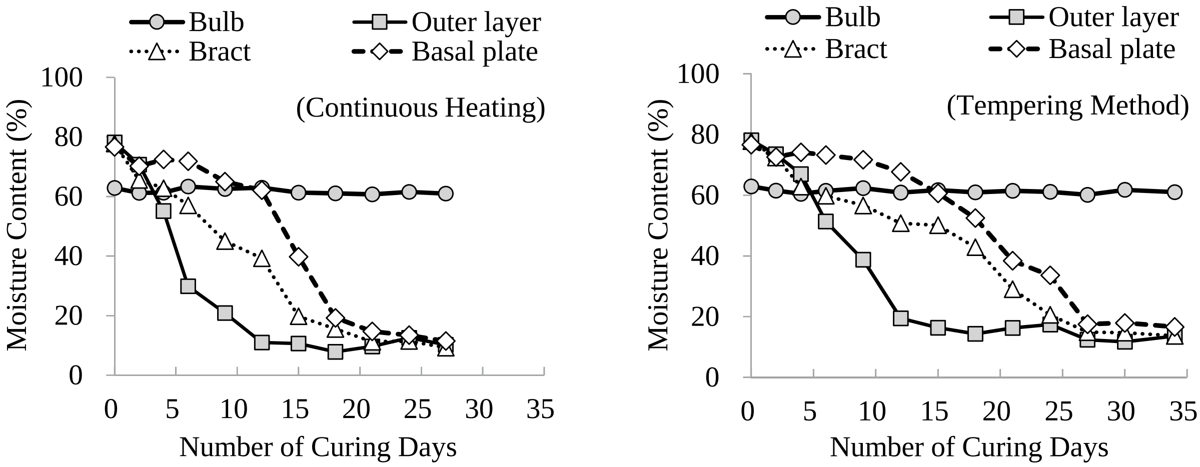

Fig. 9. Moisture change of bulbs in the curing process

Table 1. Occurrence of damage during post-harvest curing and storage at subzero temperatures on a practical scale (modified from Yamazaki et al. (2013a))

Curing Method	Measurement Location	Ave. Temp. (°C)	Saturation Deficit (kPa)	Damaged Bulbs (%)	Damage Level [x]	Comparison of Total Fuel Consumption (%) [y]	Curing Duration (in Days) [z]
Tempering Method	Intake	26.5	1.2	10.0	0.2	53.4	29.7
	Exhaust	26.0	1.0	6.7	0.2		
Continuous Heating	Intake	33.4	2.7	63.3	1.3	100.0	21.3
	Exhaust	31.9	2.2	56.7	1.1		

Numerical values are from actual data averaged over three years (2009-2011). The average saturation deficit was averaged over the two years from 2010-2011, due to missing data from 2009.

[x] The extent of damage regarding damaged scales within bulbs is 0: None, 1: Mild damage in less than 50% of bulbs, 2: Moderate damage in less than 50% of bulbs, 3: Moderate or greater damage in more than 50% of bulbs, and 4: Concavities accompanied by rarefaction of tissues. Damaged Bulbs and Damage Level were determined by visual confirmation.

[y] Total fuel consumption in comparison with continuous heating set at 100%

[z] Number of days for completion using garlic peduncle moisture as a standard

production sites in Aomori Prefecture from 2014 to 2016. This test made growers aware of the fact that the tempering method contributes to the year-round supply of garlic, and it is now recognized as being a new curing technique.

Conclusions

In long-term storage that makes a year-round supply of garlic possible, the suitable storage temperature for avoiding the occurrence of freezing and concavities, as well as suppressing the formation of sprouts and roots, is approximately −2°C.

Concavities on scales caused by long-term storage are closely related to the condition of curing before storage, and even when the storage temperature is −2°C, when the average temperature during curing is 31°C or more, concavities are likely to occur.

With the tempering method, the incidence of concavities after long-term storage is significantly lower than with continuous heating, along with less fuel consumption for curing.

The sheet system is widely used at growers due to the large amount of garlic capable of being processed as per the capacity of the curing facilities.

In the curing of the sheet system, curing unevenness on the air inlet side and the exhaust side is less in the tempering method as compared with continuous heating, with a smaller difference in the reduction rate of the bulbs.

The tempering method is now being recognized as a new curing technique through demonstration tests at production sites.

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