低温貯蔵を行った加工用ジャガイモのリコンディショニング中の品質変化

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著者	樋元, 淳一 Sasaki Tamaki, D. Perez, K. 伊藤, 和彦
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Effects of Reconditioning on the Quality of Different Processing Potato Cultivars after Low Temperature Storage

SASAKI TAMAKI Doris*, PEREZ Karin*, HIMOTO Jun-Ichi* and ITOH Kazuhiko*

* *Graduate School of Agriculture, Hokkaido University*
Kita 9, Nishi 9, Kita-ku, Sapporo 060-8589

The chemical composition and physical properties of four chipping potato cultivars (Toyoshiro, Hokkaikogane, North Chip and P982) that had been stored for 3 months at 2℃ and 6℃ were evaluated during reconditioning for 30 days at 20℃. The quality attributes of the tubers and the appearance of chips obtained from the tubers were evaluated every 5 days over a period of 30 days. The reconditioning process lowered the contents of reducing sugars of all of the tubers to acceptable levels for frying purposes. The potato chip color was improved during the reconditioning process regardless of the cultivar. Potato chips obtained from tubers that had been stored at 6℃ showed higher lightness values after the reconditioning process than those chips obtained from tubers that had been stored at 2℃. After 30 days of reconditioning, potato chips obtained from all of the cultivars showed an acceptable color for commercial purposes.

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Problems of sprout growth and losses in potato tubers due to disease and rotting can be partially resolved without using chemicals inhibitors by low-temperature storage[1].

However, potato tubers, like many other plant tissues, often undergo a phenomenon known as low-temperature sweetening (LTS) when exposed to a low temperature[2]. Large amounts of reducing sugars accumulate in tubers of most chipping cultivars stored at temperatures below 9～10℃[3),4], resulting in dark potato chips[5]. The color of fried products is a major factor determining their commercial acceptability. Dark or uneven-colored potato chips are unattractive to consumers[2]. The flavor and color of potato chips are determined by products of the Maillard reaction, which results in the formation of brown melanoidin pigments from reactions involving compounds with amino and carbonyl groups[6)～8]. The carbonyl component has been found in some studies to be rate-limiting[9].

Reducing sugars are reconverted to starch if potatoes that had been stored at lower temperatures are kept for two to four weeks at 10 to 20℃, a process known as reconditioning[10]. The length of the reconditioning process required to lower the contents of reducing sugars to acceptable levels is dependent on clone, storage temperature and length of storage prior to reconditioning[5]. The enzymatic changes associated with reconditioning have not been investigated in detail. The conversion of sugars to starch at high temperatures may suppress the activities of enzymes involved in sugar accumulation and, on the other hand, may induce activities of those that convert sucrose to starch[11]. During reconditioning, about 80% of the reducing sugars are converted back to starch, and the remaining 20% are lost through respiration[5]. The reconditioning process usually continues until the results of frying tests indicate that light-colored chips can be produced from the potatoes or the results of a reducing sugar test indicate that the level of reducing sugars is the desired level[12]. Reconditioning is currently used in the chipping industry when cultivars are stored at temperatures below 6℃[5].

The purpose of this study was to evaluate the changes in chemical composition and physical properties of four processing cultivars of potato

* E-mail : SASAKI TAMAKI Doris ; doris_sasaki@yahoo.com, HIMOTO Jun-Ichi ; himo@bpe.agr.hokudai.ac.jp, ITOH Kazuhiko ; kazu@bpe.agr.hokudai.ac.jp

tubers during reconditioning at 20℃ after 3 months of storage at 2℃ and 6℃.

Materials and Methods

1. Materials

Four chipping cultivars of potato tubers (Toyoshiro, Hokkaikogane, North Chip and P982) were evaluated in the winter of 2002 in this study. Low temperature-susceptible potato tubers from Toyoshiro and Hokkaikogane cultivars were harvested in Memuro, Hokkaido, and low temperature-resistant potato tubers from North Chip and P982 were harvested in Eniwa, Hokkaido.

2. Storage and Reconditioning Methods

Tubers of each cultivar were randomized into two lots. The tubers were stored in refrigerated chambers at 2℃ and 6℃ for 3 months. The relative humidity in both chambers was above 90% during the entire period of storage. After 90 days of storage, the tubers were reconditioned by increasing the storage temperature to 20℃ for an additional 30 days. Potato chip color was evaluated after 90 days of low-temperature storage. In these tests, tubers of the North Chip cultivar and P 982 showed an acceptable potato chip color and were not reconditioned for the present study.

3. Experimental Methods

(1) Potato chip color Chips were obtained by slicing tubers into 2-mm-thick slices and then frying in vegetable oil at 180℃. An oil bath (Yamato Chemical Co.) was used to fry the chips. Doneness was determined by the absence of bubbles in the frying oil. Chips were drained and crushed into fine pieces, and then the chip color was evaluated using a colorimeter (Minolta CR-200 b). L*, a* and b* values were measured at 5 different points. The color attributes of the potato chips are expressed in terms of lightness (L*) and chroma or saturation ($\sqrt{a^2+b^2}$).

(2) Reducing sugar content Fifty grams of potato tissue (n = 3) was blended with 50mℓ distilled water, and the homogenate was filtered through 150-mm filter paper. One mℓ of the supernatant obtained was collected and diluted with 4 mℓ acetonitrile. The resulting liquid was microfiltrated through a 0.45μm filter and injected into an HPLC system.

A Shimadzu LC-10 AD_{VP} HPLC system equipped with a refractive index detector (model RID-10 A) was used to separate and quantify the reducing sugars (fructose and glucose) in the potato samples. An amino column (NH 2 P-50, Shodex Asahipack) and a guard column of the same packing were used. The mobile phase was 75 : 25 (v/v) acetonitrile : distilled water, run at 40℃ and 1.0 mℓ/min. Measurements were carried out in triplicate.

(3) Firmness Firmness of the potato tubers was measured using a rheometer (model NRM-2002 J, Fudoh Co.).

Measurements were made 4 times at different locations on each of 5 tubers. A cylindrical adaptor with a diameter of 2 mm was used to measure tuber firmness, and the table speed was set at 30cm/min.

(4) Loss of weight Tubers were weighed every 5 days to determine their weight losses during reconditioning.

(5) Moisture content Three potato tubers were each cut into six equally sized portions, and two opposite portions (containing parts of the different structures of the tuber: cortex, inner and outer medulla) were used to determine the moisture content in the sample. Thirty-gram samples were used for measurements, and the samples were dried for 24 hours at 70℃ in an oven (PV-211 ESPEC Co.). The percentage of moisture content was determined from the difference in masses before and after drying.

(6) Specific gravity Intact potatoes were weighed in air and in water. The potatoes and water were allowed to reach the ambient temperature before the weights were measured. The ratio of the weights in air and in water was calculated.

(7) Ascorbic acid content Ten grams of potato tissue (n = 3) was blended with 10mℓ of 5% metaphosphoric acid solution, and then the homogenate was centrifuged at 1,000 g for 5 min and the supernatant was filtered through 150mm diammeter filter paper. One mℓ of the supernatant obtained was collected and microfiltrated through a 0.45μm Whatman filter and injected into an HPLC system.

A Shimadzu LC-10 AD_{VP} HPLC system equipped with an ultraviolet-visible detector (model SPD-10 A_{VP}) operated at 254nm was used to quantify the ascorbic acid contents in the potato samples. An amino column (NH 2 P-50, Shodex Asahipack) and a guard column of the same packing were used. The mobile phase was 20 mM NaH_2PO_4 + 30 mM H_3PO_4 (pH 2.2)/CH_3CN (20/80), run at 30℃ and 1.0 mℓ/min. The measurements were carried out in triplicate.

(8) **Statistical analysis** Data were analyzed using the statistical analysis software MS-Excel 2000 (Microsoft, Bothell, Wash.) Data were subjected to analysis of variance and a least difference test to determine significant differences ($P \leqq 0.05$) among treatments.

Results and Discussion

1. Potato Chip Color

After 3 months of storage at 2℃, tubers of all cultivars showed the effects of the low temperature sweetening (LTS)[13] and dark chips were obtained from these potato tubers after frying. These tubers were therefore subjected to a reconditioning process to improve their color characteristics, and chips of lighter color were obtained after 30 days of reconditioning. Fig. 1 and Fig. 2 show changes in the overall appearance of potato chips as a function of reconditioning period for the different cultivars. In the present study, L^* values below 50 were considered to be commercially undesirable.

Two different tendencies were observed in the lightness of potato chips produced from the potato tubers (Fig. 1). A significant difference was found at the beginning of the reconditioning period between potato chips made from tubers that had been stored at 2℃ and those that had been stored at 6℃. A higher L^* value after 3 months of storage was found in chips obtained from tubers that had been stored at 6℃.

After 30 days of reconditioning, chips obtained from potato tubers that had been stored at 6℃ (Toyoshiro and Hokkaikogane) showed a significant difference in lightness from that of chips obtained from tubers of the same cultivars that had been stored at 2℃. At the end of the reconditioning period, the lightness of chips obtained from tubers that had been stored at 6℃ ranged from 61.3~61.4, while the lightness of chips obtained from tubers that had been stored at 2℃ ranged from 55~58.6. These results suggest that there is a relationship between the temperature of storage prior to the reconditioning process[5] and the lightness value after the reconditioning process. No significant difference was found between lightness values of chips obtained from tubers of Hokkaikogane, North Chip and P982 cultivars that had been stored at 2℃ after the reconditioning treatment, though the lightness values of chips obtained from tubers of North Chip and P982 cultivars (low temperature-resistant cultivars) were slightly lower than the values of chips obtained from tubers of Toyoshiro and Hokkaikogane cultivars (low temperature-susceptible cultivars).

Fig. 2 shows changes in the chroma of chips obtained from potato tubers during the reconditioning process. In the present study, chroma values below 20 were considered to be commercially undesirable. A significant difference in chroma at the beginning of reconditioning was found between chips obtained from tubers that had been stored at 2℃ and chips obtained from tubers that had been stored at 6℃. A higher chroma value after 3 months of storage was found in chips obtained from tubers that had been stored at 6℃. At the end of the reconditioning period, an increase in more than 13 chroma units was seen in all chips. No significant ($P>0.05$) difference was found between chroma units of chips obtained from tubers of Toyoshiro, Hokkaikogane, Noth Chip and P 982 that had been stored at 2℃.

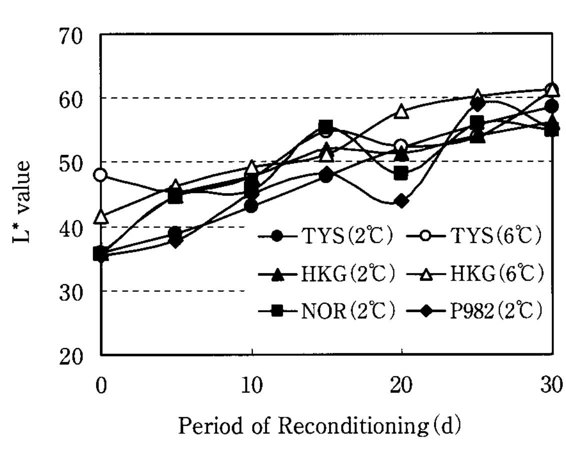

Fig. 1 Changes in L^* value during reconditioning

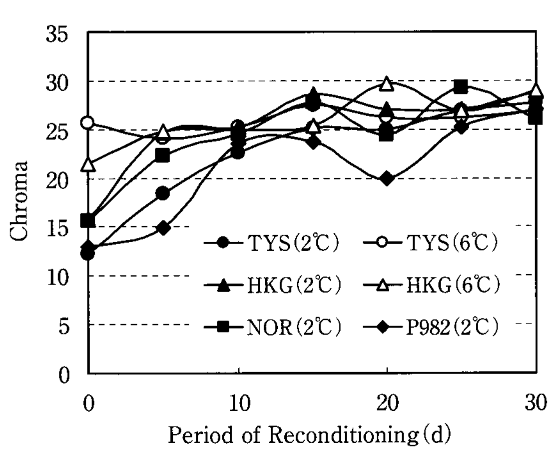

Fig. 2 Changes in chroma during reconditioning

2. Reducing sugars

Fig. 3 shows changes in contents of reducing sugars as a function of reconditioning period for the cultivars studied. After 3 months of low-temperature storage, considerably greater amounts of reducing sugars were found in all of the cultivars. Accumulations of reducing sugars were lower in the tubers that had been stored at 6 ℃ than in those that had been stored at 2 ℃ for all of the cultivars studied. The concentrations of reducing sugars in tubers of Hokkaikogane, North Chip and P982 that had been stored at 2 ℃ were significantly lower than the concentrations in Toyoshiro tubers that had been stored at the same temperature. All of the tubers that were affected by the low temperature during storage[14] showed a significant decrease in concentrations of reducing sugars, resulting in reduction of darkening during frying by the end of the reconditioning period. After only 20 days of reconditioning, all of the tubers, regardless cultivars or initial storage treatment, showed a considerable decrease in contents of reducing sugars to the desired levels.

Significant differences were found after 30 days of reconditioning at 20℃ between tubers that had been subjected to different low-temperature storage treatments. After the reconditioning period, tubers of the P982 (low temperature-resistant cultivar) that had been stored at 2 ℃ showed a lower reducing sugar content than those of the other cultivars. Tubers of the North Chip and Toyoshiro cultivars (stored at 2 ℃) showed the highest reducing sugar contents. Despite their higher reducing sugar content, potato chips obtained from tubers of both cultivars were considered to be acceptable for commercial purposes as shown on Fig. 1 and Fig. 2.

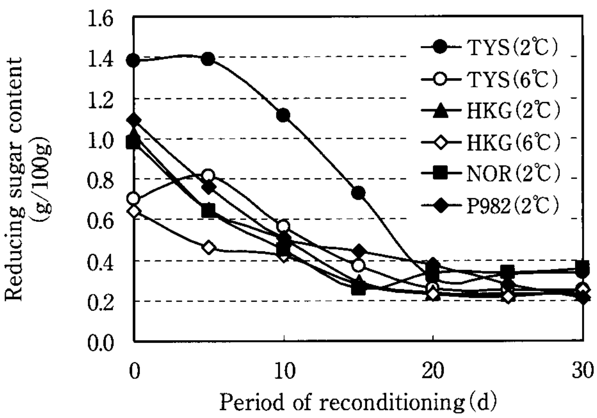

Fig. 3 Changes in reducing sugar content during reconditioning

3. Firmness

Fig. 4 shows changes in potato tuber firmness as a function of reconditioning period for the different cultivars studied.

One of the characteristics of potato tubers is slow rate of textural changes; the textural properties of potato tubers remain relatively stable for a long period, due to the low respiration rate of potato tubers, in comparison with other fruits and vegetables[15].

No significant difference in firmness was found during the 30 days reconditioning period among tubers that had been subjected to the same low-temperature storage treatment. However, a significant difference was found between the firmness of tubers of the North Chip cultivar and the firmness of tubers of the other cultivars. The lower degree of tubers of the North Chip cultivar might be related to the smaller weight loss during the storage and reconditioning periods.

4. Loss of Weight

Fig. 5 shows the weight losses of the potato tubers during the reconditioning process. The

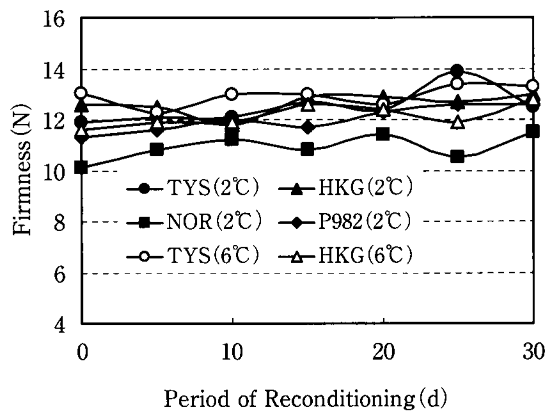

Fig. 4 Changes in the tuber firmness during reconditioning

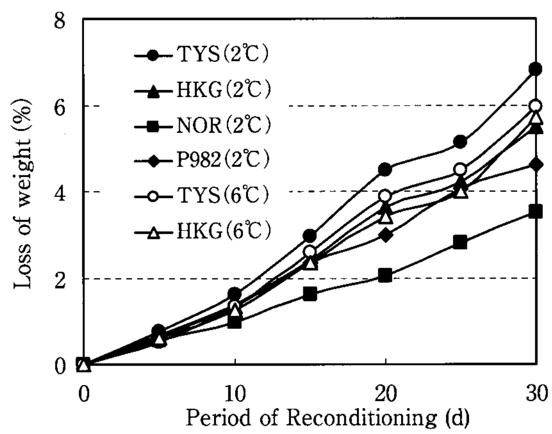

Fig. 5 Losses of weight during reconditioning

change from a low temperature for storage to a high temperature for reconditioning generally leads to a respiratory burst[16] and consequently to losses of reducing sugars, starch and water[6]. Moreover, the breaking of dormancy of all of the tubers by the 10th day of reconditioning influenced the weight loss during this process. This is because the water permeability of the epidermis of a potato sprout is about 100 times greater than that of the intact periderm of a mature tuber. Sprout growth could extend the surface area of the tuber, thus increasing evaporation losses[6].

A significant difference was found between weight losses of low temperature-resistant tubers (North Chip and P982) and weight losses of low temperature-susceptible tubers (Toyoshiro and Hokkaikogane) by the end of the reconditioning period. North Chip tubers showed the lowest loss of weight after 30 days of reconditioning (3.5%). No significant difference was found between weight losses of tubers of the same cultivar that had been stored at different temperatures. Weight losses as high as 10% after 4 months of storage at 5 ℃ and 40 days of reconditioning at 20℃ were found in a similar previous study for Danshakuimo cultivar[17].

5. Moisture Content

Important quality characteristics of potato cultivars used for production of potato chips are high dry matter content and low moisture content[18]. The higher the dry matter content is, the better the texture is. However, if the solid content is too high, the potato chips may become woody and difficult to bite[19].

Fig. 6 shows changes in potato moisture content as a function of reconditioning period for the cultivars studied.

A significant difference in moisture contents of tubers of the Toyoshiro cultivar (that had been stored at 2 ℃) before and after the reconditioning process. This difference is thought to be related to the larger weight losses of tubers of this cultivar during the reconditioning period. No significant differences were found between moisture contents of tubers of the four cultivars at the end of the reconditioning period.

6. Specific Gravity

In the chipping industry, specific gravity is directly related to processing efficiency, time and temperature[19].

Fig. 7 shows changes in specific gravity as a function of reconditioning period for the cultivars studied. No notable changes in specific gravity were observed during the reconditioning period for any of the cultivars. A significant difference was found between specific gravity of tubers of the North Chip cultivar and specific gravities of tubers of the other cultivars at the end of the reconditioning period.

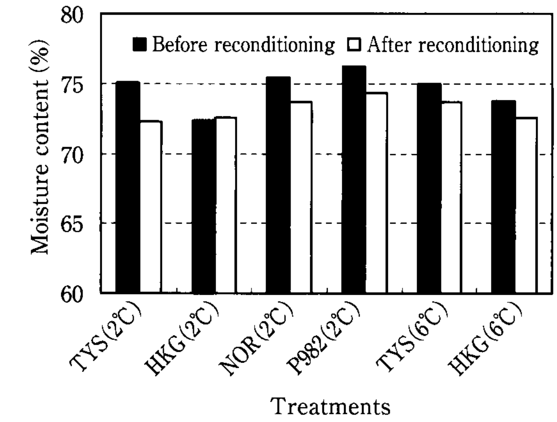

Fig. 6 Changes in moisture content during the reconditioning process

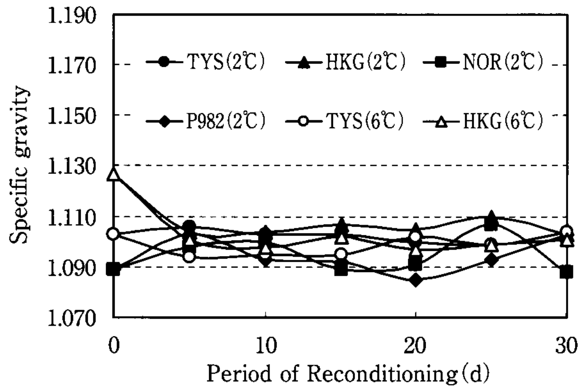

Fig. 7 Changes in specific gravity during reconditioning

7. Ascorbic Acid Content

Fig. 8 shows the ascorbic acid contents in the potato samples at the beginning and the end of the reconditioning period.

It has been reported that, losses in ascorbic acid content declines by as much 85% of the initial content during the chipping process[10]. Therefore, maintaining the ascorbic acid content in the potato tubers during the reconditioning process is highly desirable to minimize nutritional losses. After 3 months of low-temperature storage, ascorbic acid contents of tubers of the four potato cultivars in the present study ranged from 8.3~10.6mg/100 g. No notable changes in ascorbic acid were found at

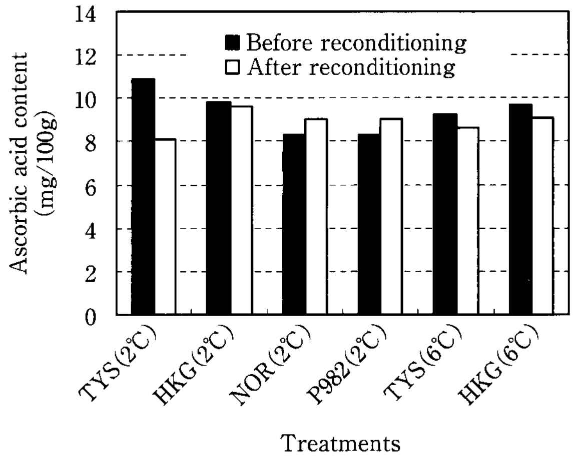

Fig. 8 Changes in ascorbic acid content during the reconditioning process

the end of the reconditioning period, and no significant ($P>0.05$) differences were found among the different cultivars.

Conclusions

The temperature of storage prior to the reconditioning process has a great effect on the quality of chips obtained from potato tubers after the reconditioning process. Potato chips obtained from tubers that had been stored at 6 ℃ were lighter in color after the reconditioning period than the color of chips obtained from that had been stored at 2 ℃. Regardless of the cultivar, a considerable decrease in contents of reducing sugars was observed and chips obtained after the 30-days reconditioning period were acceptable for commercial purposes.

No significant changes were found between degrees of firmness, moisture contents, specific gravities and ascorbic acid contents in of the cultivars studied during the reconditioning period.

Low temperature-susceptible cultivars showed a significant higher weight loss than low temperature-resistant cultivars by the end of the reconditioning process.

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低温貯蔵を行った加工用ジャガイモのリコンディショニング中の品質変化

ササキドリス*・ペレスカリン*
樋元淳一*・伊藤和彦*
* 北海道大学大学院農学研究科
(〒060-8589 北海道札幌市北区北9条西9丁目)

3カ月間2℃および6℃で貯蔵を行い，その後20℃でリコンディショニングを行った4種類の加工原料ジャガイモ（トヨシロ，ホッカイコガネ，ノースチップス，P 982）の成分値と物性値を測定した。加工原料ジャガイモの品質および原料から調製したポテトチップスの外観を貯蔵期間中5日ごとに測定した。リコンディショニングを行うことによって，すべての試料の還元糖含量が減少した。6℃で貯蔵した試料から調製したポテトチップスの明度は2℃で貯蔵し，その後リコンディショニングを行った試料から調製したポテトチップスの明度より高い値を示した。20℃で30日間リコンディショニングを行った試料から調製したポテトチップスは商品価値を保持していることが明らかになった。

(平成15年9月5日受付，平成16年3月20日受理)