Comparison of Keeping Quality between Pressure-processed Jam and Heat-processed Jam: Changes in Flavor Components, Hue, and Nutrients during Storage

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Products of strawberry jam prepared by a high hydrostatic pressure-processing method and a conventional heat-processing method were examined with regard to the changes of quality such as volatile flavor components, anthocyanins, browning index, furfural, sucrose contents, and vitamin C contents during storage at 5°C and 25°C for 1-3 months. The quality of pressure-processed jam immediately after manufacturing was superior to that of heat-processed jam in preserving the fresh flavor and natural color of raw fruits. The superior quality was maintained under low temperature storage for two to three months. However, room temperature storage resulted in rapid deterioration including off-flavor, discoloration, browning, and decomposition of sucrose and vitamin C. So, the commercial value of pressure-processed jam decreased within a brief period. On the other hand, heat-processed jam did not change in quality under room temperature storage for three months. It is supposed that dissolved oxygen and enzyme systems retained are the causative factors of rapid deterioration in pressure-processed jam.

We have developed a new method of fruit preparation by a high hydrostatic pressure-process instead of a heat-process, and introduced the first pressure-processed fruit products to the Japanese retail market in 1990.1) In the meantime, jellies, yogurt desserts, and fruit sauces were added to the line of the pressure-processed products, up to 15 items now.  
Maintaining the original fresh fruit color and flavor and simultaneously accomplishing commercial sterilization1-3) are excellent characteristics of the pressure-process method. However, a problem is that the superior quality of the pressure-processed products deteriorates rapidly during storage at room temperature. Accordingly, chilling is necessary for distribution of the products.  
Investigations about possible ways for keeping quality during storage are important for research for further development of the pressure-processed products. As to pressure-processed products, the deterioration of quality during storage has not been studied so far except for citrus fruit juice.4) We did a storage study, as a beginning, to examine quantitative changes in flavor components, hue, and nutrients in high hydrostatic pressure-processed jam and conventional heat-processed jam.

Materials and Methods

Materials. High hydrostatic pressure-processed strawberry jam (pressure-jam) and conventional heat-processed strawberry jam (heated jam) were taken from the manufacturing lines of the Meidi-Ya Food Factory and used as experimental materials. Processing methods and formulations for these strawberry jams were described in our previous paper.1) The raw strawberries were the Hoko cultivar. Pressured jam had a fruit content of 50% and a sugar content of 40 Brix, 725 g of which was sealed in a plastic container (laminated film of PP/EVOP2)PP, and then was pressurized (400-500 MPa, 10-30 min). Heated jam was prepared by heating under reduced pressure (70°C, 60 min), filled into bottles at about 90°C, and heat-sterilized (93°C, 20 min). It had a fruit content of 50% and a sugar content of 50 Brix, and the bottled content was 180 g. These two kinds of jam were stored in a thermostatic atmosphere of 5°C and 25°C. Samples were taken out from them after 30, 60, and 90 days, and measured.

Measurement of volatile flavor and furfural. The volatile components of the strawberry jams were identified by gas chromatography-mass spectrometry (GC-MS). GC-MS system consisted of a gas chromatography (Hewlett-Packard-5890A) and a mass spectrometer (Hitachi M-80B), trans-2-Hexenal, malonal, ethyl butyrate, 2-methylbutyric acid as flavor components and furfural as browning substance were analyzed quantitatively by gas chromatography (GC equipment described above). The GC conditions were: J&W DB-Bax column (0.32 mm i.d. x 60 m) was used; the initial oven temperature was held at 60°C for 5 min and then programmed at 3°C/min to 220°C. Injection port and detector (false ionization detector) were kept at 250°C; a 1.0 μl portion of sample solution was injected into GC equipment (split ratio 70:1); for mass units, the electron impact ionization method was used; ionization voltage was 20 eV.

Measurement of anthocyanins and browning index. Anthocyanin pigments of the strawberry jams were extracted in accordance with the AOAC procedure5) and absorbance of the extract solution at 515 nm was measured by a spectrophotometer. The browning index of the strawberry jams were measured by the procedure of Ifuku et al.6)

Measurement of sucrose and total vitamin C content. Sucrose contents of the strawberry jams were measured by high pressure liquid chromatography (HPLC). The HPLC system consisted of a pump (JASCO Tri Rotor-V), a detector (JASCO 830-R1), and a separation column (4.6 mm i.d. x 250 mm Asahipak NH2P-30). For HPLC conditions, the column temperature was 35°C, mobile phase was 10 mm tetra-n-propylammonium hydroxide (pH 10)/acetoniitrile = 25/75; flow rate was 1.0 ml/min; a 10-μl portion of sample solution was injected into the HPLC equipment.

Vitamin C (total ascorbic acid) contents of the strawberry jams were measured by HPLC after dehydroascorbic acid was reduced to ascorbic acid by the diithiothreitol reducing method of Tono and Fujita.7) The HPLC system consisted of a pump (JASCO Tri Rotor-V), a detector (JASCO UV-970), and a separation column (4.6 mm i.d. x 150 mm In-
For HPLC conditions, the column temperature was 40°C; the mobile phase was prepared as follows: 10 mM tetra-n-butylammonium hydroxide was added to 0.04 M potassium dihydrogen phosphate/methanol=95:5, and then adjusted to pH 4.8 with 10% phosphoric acid; flow rate was 1.0 mL/min; a 10-μl portion of sample solution was injected into the HPLC equipment.

**Measurement of dissolved oxygen.** The sample of strawberry jam (20 g) was weighed in a 300-ml beaker, 200 mL of water (boiled, oxygen-free) was added into the beaker, then it was stirred gently. The dissolved oxygen concentration of the mixture was measured by using an oxygen microanalyzer (Daido Sanso Co., Ltd., Model RO-880).

**Results and Discussion**

**Changes in flavor components during storage**

The gas chromatograms of volatile substances originated from the raw material mixture, pressured jam, and heated jam examined immediately after manufacturing are shown in Fig. 1. There is scarcely any difference in the gas chromatographic profile between the raw material mixture and pressured jam, but many peaks that are not detected in the pressured jam are observed on the chromatogram of heated jam. The former indicates that the flavor of raw fruit was not lost but retained intact in pressured jam during the manufacturing process, the latter means that a new aroma was formed in heated jam during the heating. Sugawara et al. also reported in detail that a sweet aroma was produced newly by heating strawberry jam.

\[ \text{(a) raw mixture} \]

\[ \text{(b) pressure-processed jam} \]

\[ \text{(c) heat-processed jam} \]

![Fig. 1. Gas Chromatogram of Volatile Flavor Components of Strawberry Jam.](image)

(a) raw mixture; (b) pressure-processed jam; (c) heat-processed jam. Peak identification: 1, ethyl butyrate; 2, hexanal; 3, trans-2-hexenal; 4, hexanol; 5, trans-2-hexenol; 6, acetic acid; 7, furfural; 8, linalool; 9, isobutyric acid; 10, butyric acid; 11, 2-methylbutyric acid; 12, hexanoic acid; 13, 4-hydroxy-2,5-dimethyl-3(2H)-furanone; 14, 4-vinylphenol; 15, 5-hydroxymethyl-2-furfural; std. benzy1 benzoate.

A number of substances were identified with flavor components such as esters, alcohols, carbonyl compounds, etc., by GC-MS analysis. Some of them increased, some decreased, and some new ones appeared and increased during storage.

Among flavor components of strawberry, trans-2-hexenol endows it with fresh and grassy flavor; linalool confers sweet and floral flavor; ethyl butyrate gives fresh fruit-like flavor; and 2-methylbutyric acid adds sour-sweet flavor. Each one of them is an important characteristic flavor of strawberries. Figure 2 shows changes of these four flavor components during storage. Much larger amounts of the flavor components are present in pressured jam than in heated jam immediately after manufacturing: trans-2-hexenol, about 80 times; linalool, about 5 times; ethyl butyrate, about 6 times; and 2-methylbutyric acid, about 7 times. During 5°C storage, the quantity of trans-2-hexenol, linalool, or 2-methylbutyric acid changes little, but ethyl butyrate decreases slowly in pressured jam. About 1.7 times as much ethyl butyrate is present in pressured jam than in heated jam after three months of 5°C storage. It is thus demonstrated that the fresh flavor of pressured jam is preserved during low temperature storage. During 25°C storage, flavor deterioration is enhanced in pressured jam. For example, ethyl butyrate markedly decreases and reaches the level of heated jam in one and a half months. Linalool also decreases a little. On the other hand, the four flavor substances of heated jam do not show recognizable changes during storage at 25°C.

**Changes in anthocyanins during storage**

The red color of strawberry jam comes from anthocyanins contained in strawberry fruits. Anthocyanins are a very unstable pigment and are readily decomposed by various factors. Changes in anthocyanins during storage are shown in Fig. 3.

Anthocyanins are rich in pressured jam at the beginning of storage, but they decrease linearly both in pressured jam and in heated jam even stored at 5°C. When stored at 25°C, both jams show a marked decrease in anthocyanins within a month. The color fading of pressured jam was particularly rapid during 25°C storage, so its commercial value in terms of hue is lost within a short period of time at room temperature. The decrease in anthocyanins slows down in both jams after a month during 25°C storage, and approaches the velocity of color decrease under 5°C storage.

**Changes in browning index and furfural during storage**

Change in browning index during storage is shown in Fig. 4. The amount of brown pigment is clearly small in pressured jam immediately after production. That is, though browning occurs in jam during the producing process of heated jam, it does not take place during the production of pressured jam. Although the change in the browning index is negligible in heated jam, as for 5°C storage, the browning index of pressured jam increases linearly and its slope is almost equal to the slope of heated jam stored at 25°C. It is shown that browning reactions in pressured jam under low temperature storage proceed at nearly the same speed as those of heated jam under room temperature storage. But the browning index of pressured jam stored at 5°C for
Fig. 2. Changes in Volatile Flavor Components of Strawberry Jam during Storage.
(a) trans-2-hexenol; (b) linalool; (c) ethyl butyrate; (d) 2-methylbutyric acid.
Peak area of GC was plotted against storage time (days) with pressure-processed jam stored at 5°C (○) and 25°C (●), and heat-processed jam stored at 5°C (■) and 25°C (■).

Fig. 3. Change in Anthocyanins during Storage of Strawberry Jam.
Anthocyanin content was plotted against storage time (days) with pressure-processed jam stored at 5°C (○) and 25°C (●), and heat-processed jam stored at 5°C (■) and 25°C (■).

Fig. 4. Change in Browning Index during Storage of Strawberry Jam.
Absorbance at 420 nm was plotted against storage time (days) with pressure-processed jam stored at 5°C (○) and 25°C (●), and heat-processed jam stored at 5°C (■) and 25°C (■).

Three months is lower than that of heated jam immediately after production. The browning index of pressured jam stored at 25°C increases rapidly, reaches the level of heated jam within a month of storage, and then proceeds parallel with the change in the browning index of heated jam stored at 25°C.

Furfural is an intermediate product appearing at the initial phase of non-enzymatic browning reactions. Changes in furfural during storage are shown in Fig. 5. In heated jam, furfural is already present in a significant amount.
immediately after production, and then increases slowly during storage. On the contrary, furfural in pressured jam is undetectable under 5°C storage for three months, but it is formed rapidly under 25°C storage and increases up to the level of heated jam within a month. This suggests that non-enzymatic browning reactions proceed rapidly in pressured jam under room temperature storage.

**Change in the ratio of residual sucrose during storage**

Decomposition of sucrose in pressured jam is great, as seen in the change in ratio of residual sucrose during storage (Fig. 6). It goes down to 0% under 25°C storage within a month, and decreases to about 10% under 5°C storage after two months. On the other hand, sucrose is decomposed slowly in heated jam. The residual amount of sucrose in heated jam is about 80% under 5°C storage and about 70% under 25°C storage after three months.

**Change in vitamin C content during storage**

Vitamin C in pressured jam and heated jam originates only from the strawberry fruit itself. The change in vitamin C content is shown in Fig. 7. As seen in the figure, vitamin C content immediately after production are slightly more than 30 mg% in pressured jam and a little less than 20 mg% in heated jam. As shown in our previous paper, the pressure-process results in no loss of vitamin C, but the heat-process causes loss of vitamin C.

During storage, vitamin C content does not change in heated jam, but that in pressured jam decrease slowly. But the vitamin C level in pressured jam under 5°C after three months is still higher than that in heated jam immediately after production.

**Changes in dissolved oxygen content during storage**

Changes in dissolved oxygen content during storage are shown in the Table. Dissolved oxygen content is about five times as high in pressured jam as in heated jam immediately after production. It goes down to about one third under 5°C storage and about one eleventh under 25°C storage after three months. On the other hand, the initial amount of dissolved oxygen is small in heated jam, and does not change much during storage.

The rapid decrease of oxygen dissolved in pressured jam conceivably suggests that various oxidative reactions, enzymatic and non-enzymatic reactions, by which quality of the jam deteriorates, proceed simultaneously during storage.

<table>
<thead>
<tr>
<th>Jam</th>
<th>Stored for (month)</th>
<th>Stored at (°C)</th>
<th>Dissolved oxygen content (mg/100 g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pressure-processed</td>
<td>0</td>
<td>25</td>
<td>1.96</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>5</td>
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</tr>
<tr>
<td></td>
<td>3</td>
<td>25</td>
<td>0.17</td>
</tr>
<tr>
<td>Heat-processed</td>
<td>0</td>
<td>25</td>
<td>0.39</td>
</tr>
</tbody>
</table>

**Fig. 5.** Accumulation of Furfural during Storage of Strawberry Jam.
Peak area of GC was plotted against storage time (days) with pressured-jam stored at 5°C (□) and 25°C (○), and heat-processed jam stored at 5°C (■) and 25°C (■).

**Fig. 6.** Changes in Sucrose Content during Storage of Strawberry Jam.
Sucrose residual rate was plotted against storage time (days) with pressured-jam stored at 5°C (□) and 25°C (○), and heat-processed jam stored at 5°C (■) and 25°C (■).

**Fig. 7.** Changes in Vitamin C Content during Storage of Strawberry Jam.
Vitamin C content was plotted against storage time (days) with pressured-jam stored at 5°C (□) and 25°C (○), and heat-processed jam stored at 5°C (■) and 25°C (■).
Consideration on the rapid deterioration of pressured jam during storage

The experimental results concerning changes in flavor components, anthocyanins, browning index, and furfural during storage are arranged as follows:

1. It is a superior characteristic of the pressure-processing method that the quantity of each flavor component from raw strawberries was retained in pressured jam immediately after manufacturing. Among 4 flavor components, 3 (trans-2-hexenol, linalool, and 2-methylbutyric acid) were scarcely changed in both pressured jam and heated jam during storage. Ethyl butyrate in pressured jam decreased rapidly during storage.

2. Fresh product samples of pressured jam had a bright red color, because more anthocyanins from the strawberries were present, but the anthocyanins in pressured jam decreased in the early stage of room temperature storage. It is presumed that the rapid color fading depended on influences of ascorbic acid and oxygen. This phenomenon, ascorbic acid and oxygen enhance decomposition of anthocyanins, was reported by Nakabayashi. Anthocyanins are said to turn into brown pigment as a result of decomposition.

3. The browning of pressured jam proceeded more promptly in comparison with that of heated jam. This probably took place for the reason that the browning in pressured jam was caused by enzymatic and non-enzymatic reactions, but the browning in heated jam was caused by non-enzymatic reactions alone.

4. The rapid increase of furfural content in pressured jam under room temperature storage means that non-enzymatic browning happened in the jam during the storage. The presence of furfural in heated jam immediately after manufacturing indicates non-enzymatic browning occurred during heat-processing.

The experimental results of changes in content of sucrose and vitamin C are arranged as follows:

5. Decomposition of sucrose in heated jam is caused by organic acids. The decomposing velocity in pressured jam was faster than that in heated jam, and this result indicates that the decomposition of pressured jam was brought about by not only organic acids but also enzymes.

6. Vitamin C content of pressured jam at the start of storage was higher than that of heated jam, and this means, damage to vitamin C in the manufacture of pressured jam was small, but velocity of the decrease of vitamin C in pressured jam during storage was faster than that in heated jam. It is considered that vitamin C in pressured jam was attacked by dissolved oxygen and enzymes that were not inactivated, if they had existed.

7. The measurements of dissolved oxygen were arranged as follows:

Rapid decrease of dissolved oxygen in pressured jam stored under room temperature indicates that the oxygen caused various chemical reactions and also that the oxygen was consumed by the reaction.

Degradation in heated jam resulted from chemical reaction, but degradation in pressured jam was from both chemical and enzymatic reactions, and dissolved oxygen accelerated the oxidizing reaction. Accordingly, the quality of heated jam immediately after manufacturing remained after room temperature storage for several months, but rapid deterioration was observed in pressured jam after room temperature storage.

The difference in keeping quality between heated jam and the pressured one is caused by differences in the manufacturing processes. That is, in case of heated jam, the enzymes from raw fruit are entirely inactivated by heat-processing, and air (oxygen) included in the raw material mixture is removed through the heat concentrating process, moreover, air does not enter into the jam through its processing after concentration. In the case of pressured jam, however, there is no heating process, so that residual enzymes and dissolved oxygen in finished product cause trouble in keeping quality.

It is difficult to inactivate enzymes in raw materials by pressurizing treatment used for production of food and this was described in many papers. There was a study for citrus juice, in which it was shown that pectin esterase remained after pressurization and caused deterioration of the juice. Our study also indicates that various enzymes in raw strawberry remain in pressured jam. For example, the rapid decomposition of ethyl butyrate, an ester flavor compound, is probably caused by existence of an esterase; sucrose participates possibly in decrease of sugar content; enzymes concerning to browning, such as peroxidase, phenolase, etc., probably act in the degradation of color in pressured jam.

There is no heating-process in the manufacturing of pressured jam, so dissolved oxygen in the raw mixture of jam stays into finished product. Moreover, when the raw mixture is filled up in a plastic container and the lid is heat-sealed, a small amount of air (oxygen gas) sometimes enters into the container. A packaging material used to pressured jam is made of a gas barrier composite film (PP/EVOH/PP), nevertheless a little oxygen is supplied also through the material of the container. The oxygen permeability of PP/EVOH/PP film is 4.8 cc/m²-d·atm. On the other hand, the glass used for heated jam is a perfect gas barrier. The difference between these gas barrier properties is one of the reason why the deterioration-velocity between pressure-processed jam and heat-processed jam is different. Such compounds oxidized easily, as ascorbic acid, phenolic compound, etc., are attacked by the dissolved oxygen, and those reactions bring about browning of pressured jam. The rapid decrease of dissolved oxygen in pressured jam shows that the oxygen causes various chemical reactions, so that the dissolved oxygen is consumed by those reactions.

As above-mentioned, in pressured jam, various enzymatic reactions and chemical reactions, which are caused by residual enzymes and dissolved oxygen, bring about the deterioration of quality in pressured jam during room temperature storage. Accordingly, to avoid the deterioration, pressured jam must be kept at low temperatures. There are more merits in the pressure-processing method than in heat-processing method, as described in our previous paper. Inactivation of enzyme systems and removal of dissolved oxygen are significant issues for the further development of the pressure-processed products.

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References


