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Abstract

This study was conducted to examine the effects of starch noodles (*dangmyeon*) with different starch sources and porcine intestines with different pH on the rehydration stability of Korean blood sausage (*sundae*). Mungbean starch noodle (SN3) and porcine intestine (PI3, pH 9.18) showed significantly higher values of 80.69-91.67% and 79.66-80.98%, respectively, regardless of the drying methods (hot air, vacuum and freeze drying). ($p<0.05$) A number of larger pores were observed only in the cross-section of the freeze dried SN and PI through SEM. SN2 (potato starch) and PI3 (pH 9.18) showed lower expansion ($^*\Delta L$ 6.90 mm) and higher expansion ratio ($^*\Delta L$ 26.29 mm), respectively, after rehydration of freeze dried sample ($p<0.05$). From the application of SN2 (potato starch) and PI (0.5-2.0% Na-pyrophosphate) to freeze dried *sundae* manufacturing, higher rehydration stability of more than 91.5% was obtained. These results suggested that potato starch noodle and treatment of porcine intestine with sodium pyrophosphate is useful for desirable rehydration stability of freeze dried *sundae.*

Key words: *sundae*, Korean blood sausage, starch noodle, porcine intestines, rehydration stability

Introduction

Sausages are a meat product that is usually made from ground meat (usually pork, but sometimes beef or poultry), salt, spices and other flavorings (Caldironi and Ockerman, 1982; Oh, 2012). Many countries produce similar types of sausages even though the materials and methods used are different (Caldironi and Ockerman, 1982; Oh, 2012). Among the many different sausage products, blood sausage (*sundae* in Korean) is a popular ready-to-eat food in Korea (Son et al., 1999; Choi et al., 2015), which is similar to western blood sausage, although the manufacturing methods differ (Silva et al., 2013).

Sundae is generally prepared by steaming porcine intestines stuffed with various ingredients such as minced pork, starch noodles, pork blood, and vegetables (Park, 2017). The many different *sundae* products tend to be named after their city of origin or main ingredient, i.e. Pyongando (starch noodles), Hamgyeongdo (bigger), Gaesung (pork), Byungcheon (rich ingredients), Baekam (ground ingredients), Ojingeosundae (squid) and chapssal sundae (glutinous rice), with each type having its own special characteristics and manufacturing method (Oh et al., 2012). However, when cooking *sundae* or rehydrating dried *sundae* as a convenient HMR (home meal replacement) product, swelling of the inner part and contraction of the outer part often occur simultaneously, resulting in an undesirable shape (Kim et al., 2019). These problems are attributable to the physicochemical properties of the inner starch noodles and outer porcine intestine with which *sundae* is made (Kim et al., 2019).

Starch noodles (SN), also called cellophane or glass noodles, are routinely used as one of the main ingredients of *sundae*, and are derived from sweet potatoes, called *dangmyeon* in Korea (Chen et al., 2002).

However, many kinds of starch noodles have also been made from corn, sweet potato, potato, and tapioca, which can have different physicochemical properties that influence the swelling or spreadability of *sundae* (Chen, 2003; Lee et al., 2002; Yook et al., 2001). In this study, starch noodle products from sweet potato, potato and mungbean were chosen as one of main experimental materials because they have different starch composition (Chen, 2003; Yook et al., 2001), which can show different expansion effect on the *sundae.*

Porcine intestine (PI), a natural casing material, is usually used to pack the inner material of s*undae*. Kim et al (2019) tried to change the contraction properties of PI by controlling its pH in order to reduce the contraction of PI that occurs when hot water is added to rehydrate dried *sundae*. Choi and Kim (2016) showed that the addition of natural vinegar to swelled pig skin increased moisture content and decreased hardness in *sundae*, though acid was commonly known to lower the quality of meat products (Kim and Lim, 1994). On the other hand, lower or higher pH from the pI (isoelectric point) of beef improved its water-retention capacity, followed by an increase in the yields and tenderness of marinated beef after cooking (Hong et al., 2013). Based on the above studies, it is expected that water retention capacity or tenderness of porcine intestine can be increased like pig skin or beef through adjustment of pH to acidic or alkaline.

The purpose of this study is to examine the rehydration stability of Korean blood sausage (*sundae*) according to the swelling and contraction characteristics of starch noodles (SN) and porcine intestine (PI), in the cooking, drying and rehydration.

Materials and Methods

Materials

The main ingredients of s*undae*, including pork, pork blood, porcine intestine, and starch noodles, were purchased from a local market in the Jeonju area of South Korea. Starch noodle products were classified into sweet potato (Ottogi, Anyang, Korea), potato

(Qingdao richsun trading Co, Qingdao, China), and mung bean (Qingdao richsun trading Co, Qingdao, China) ones. Samples of starch noodle products were cut into strips measuring 3-5 cm and boiled for 6 min, and then left to cool immediately.

The raw ingredients such as pork, porcine intestine and porcine blood were stored at -80℃ (RT50H6120SL, Samsung, Suwon, Korea) and defrosted before use. The porcine intestine was used after removing the fat layer and washing it with distilled water. Citric acid (Edentown FNB, Incheon, Korea) and sodium pyrophosphate (ESfood, Gunpo, Korea) were used for the pH control.

Manufacturing *Sundae*

Table 1 shows the recipe for *sundae*. The inner part ingredients were mixed and stuffed into the PI using a stuffing machine (SV-5, Newtech, Daegu, Korea). The diameter of the stuffing machine used to make the casing was 25 mm. The error range of the casing diameter of manufactured *sundae* was within 5%. The samples were heated at 80℃ for 50 min in a water bath (SB-9, Eyela, Tokyo, Japan) and then left to cool for 30 min at room temperature. The manufactured *sundae* was cut into the proper size and stored at -80℃ or freeze-dried under 20 Pa for 24 h.

Dry yields

Samples were freeze-dried (FDU-1200, EYELA, Japan), hot air-dried (HK-DO1000F, HANKUK S&I, Korea) and vacuum-dried (DRV622DA, ADVANTEC, Japan) for 24 h. Hot air drying and vacuum drying were performed at a temperature of 60℃ and 40℃, respectively, with the degree of the vacuum set at 80 kPa. Each sample was weighed before and after drying, and the dry yields were calculated as a percentage of the pre-drying weight.

SEM (Scanning Electron Microscopy)

SEM (Scanning Electron Microscopy, Hitachi S4700, Japan) was used to analyze the swelling effect of the samples treated by freeze, hot air and vacuum drying for 24 h. The samples were fixed to SEM stubs with double-sided tape, then coated with a layer of gold with a thickness of 10 nm. All of the samples were observed at an accelerating voltage of 20.0 kV with a magnification level of x1500.

Length and thickness

Vernier calipers (CD-15CPX, Mitutoyo, Japan) were used to measure changes in the length (ΔL) and thickness (ΔT) of the dried samples before and after heating them, and in the length ($^*\Delta L$) and thickness ($^*\Delta T$) of the freeze-dried samples before and after heating them.

pH

The PI samples were soaked in a pretreatment solution (distilled water, 2% citric acid and 0.5-2% sodium pyrophosphate) at 4℃ for 2 h at a ratio of 1: 10. The pH of each solution was measured using a pH meter (S210, Mettler Toledo, USA). The pretreated samples were washed 3 times with distilled water and then stocked at 4℃ until use in experiments. The pH of the PI was measured after homogenizing 5 g samples with 20 mL of distilled water at 12,000 rpm for 1 min in a homogenizer (PT1200E, Kinematica, Luzern, Switzerland)

Rehydration stability

The freeze dried *sundae* cut into a proper size was rehydrated in a beaker with 100 mLof boiling distilled water, and width of the porcine intestine part was measured every min for 3 min. The rehydration stability was expressed in relative ratio (%) of width of porcine intestine part before and after rehydration.

Statistical analysis

The experiment was replicated 3 times, and SPSS Statistics (ver. 23, IBM Co., Armonk, NY, USA) were used for the statistical analysis. One-way ANOVA was performed for the significant test between each sample, and Duncan's multiple range test was performed to determine whether there were any significant differences between the mean values ($P<0.05$).

Results and Discussion

Dry yields

The freeze, hot air and vacuum drying methods are well known as common and conventional techniques. Hot air drying is a technique by heated air (Celma et al., 2009) and vacuum drying is a method by reducing pressure and drying at low temperature (Long et al., 2007) while freeze drying (FD) is a technique for drying foods at low temperatures and under high vacuum. (Karam et al., 2016) These drying methods have their own characteristics, and may influence drying yields or quality according to drying conditions such as kinds of sample, temperature and time. Table 2 shows the dry yields of the SN and PI samples after freeze, hot air and vacuum drying. The dry yields of the SN ranged from 60.02 to 91.67%. Jung et al. (1991) reported a water-binding capacity of 77% for mung bean starch, 79% for potato starch, and 83% for sweet potato starch. In addition, the water content of starch when isolated from starch noodles was as follows: 11.6% for mung bean starch, 8.9% for potato starch, and 8.7% for sweet potato starch (Chen, 2003). In our results, however, SN3 (mung bean starch) showed a significant difference in dry yield, ranging from 80.69% to 91.67%, when compared to SN1 (sweet potato starch, 60.96-64.62%) and SN2 (potato starch, 60.13-60.96%), regardless of the drying method. This indicates that the different properties of the starch noodle products used in this experiment resulted in significant differences between the dry yields.

On the other hand, the dry yields of the PI samples ranged from 65.23-93.95%. There was a significant difference in PI2 (citric acid), PI3 (sodium pyrophosphate) and PI1 (control, distilled water), regardless of the drying method. These results indicate that the water-holding capacity and degree of expansion of the PI2 and PI3 samples are relatively higher than the control (PI1) due to the pH shifting from the isoelectric point (Kim et al., 2000). Hong et al (2013) showed that shifting of pH from pI (isoelectric point) of beef improved the water-holding capacity by as much as 9-15%, followed by an increase in the yield and tenderness of marinated beef meat after cooking.

Therefore, the above results correlate with the high water-holding capacity resulting from the pH shift from the isoelectric points and the humectant effect achieved by reducing water loss during drying.

pH

pH is an important factor that affects the quality of meat, including its freshness, water-holding capacity, tenderness, binding ability, color and texture (Hong et al., 2013; Yim et al., 2016). The pH value of PI2 with 2% citric acid was 2.37, and that of PI3 with 2% sodium pyrophosphate was 9.18, while that of PI1 with distilled water was 6.13 (data not shown), suggesting different levels of water-holding capacity or tenderness. The accumulation of met-myoglobin is faster in meat with a low pH than in meat with high pH condition (Owen and Lawrie, 1975; Ledward, 1986).

In general, the pH value of raw meat used to make ham and sausages is 5.8-6.2, so it is very difficult to produce satisfactory products in terms of quality when meat with a pH of

5.7 or less is used (Kim and Lim, 1994). Hong et al. (2013) indicated that lower or higher pH than the pI (isoelectric point) of beef improved the water-holding capacity, yield and tenderness of marinated beef after cooking.

Therefore, PI3 (pH 9.18) was expected to be the most advantageous in terms of improving the rehydration stability of *sundae.*

Length and thickness

The degree of expansion of the SN and the degree of contraction of the PI, which differently used of SN products and the respective PI treatments, were compared by observing changes in the length and thickness of boiled and rehydrated SN and PI samples after freeze-drying. As shown in Table 3, SN3 (ΔL 7.72 mm) showed a significant difference from SN1 (ΔL 5.03 mm) and SN2 (ΔL 5.39 mm) after boiling; and this pattern was also similar to the changes of length observed when SN samples were rehydrated after freeze-drying where SN3 (ΔL* 6.90 mm) was significantly longest, compared to SN1 (ΔL* 1.81 mm) and SN2 (ΔL* 1.47 mm), respectively. This means that SN3 has a stronger expansion property than SN1 and SN2. On the other hand, a significant difference was not observed in the changes of thickness among the SN samples after boiling or after rehydration of the freeze-dried samples. These results may be due to the relatively lower changes.

In the case of the PI samples (Table 4), after soaking treatment, the length of PI3 was observed to expand significantly more (42.15 mm) than PI1 and PI 2 at 24.77 mm and 25.90 mm, respectively. These expansion levels were also maintained in the freeze-drying step. On the other hand, when the freeze-dried PI samples were rehydrated with hot water, PI3 contracted to 26.29 mm in length, while PI1 and PI2 contracted to 15.63 mm and 21.02 mm, respectively. Even though the PI3 samples showed a relatively higher degree of contraction, the overall length of PI3 (16.29 mm) is relatively longer than that of PI1 (5.63 mm) and PI2 (11.02 mm). These results are interesting and may seem controversial, but if *sundae* is manufactured under the same conditions, the PI3 sample with a higher expansion capability is expected to be advantageous in terms of maintaining the shape of freeze-dried *sundae* during rehydration.

SEM

SEM images were analyzed to observe a cross section of SN composed of different starch and PI samples were treated by various drying methods. As shown in Fig. 1, freeze-dried SN (A-a, B-a, C-a) retained a number of pores regardless of the type of starch noodles, while hot air dried (A-b, B-b, C-b) and vacuum dried (A-c, B-c, C-c) SN showed different closed patterns, instead of pores on the surface of the noodles. Among the freeze-dried samples, SN1 (A-a) retained more pores than SN2 (B-a) or SN3 (C-a), and showed a different pattern from the other two samples. Wang et al. (2010) reported that potato starch noodles were tighter, and thus absorbed less water. From the above results, it seems advantageous to use potato (SN2, B-a) or mung bean (SN3, C-a) starch noodles for their rehydration stability because they are able to inhibit the swelling of starchy tissues due to their reduced water absorption.

Overall, the freeze-dried PI samples also show a similar pattern to the SEM images of the dried SN ones. However, the size of the pores of the PI2 (E-a) and PI3 (F-a) samples is relatively larger than that of the PI1 (D-a, distilled water treatment) samples. The water-holding capacity of meat is lowest at pH 5.4-5.6 near the isoelectric point (pI), and increases as the pH shifts further away from the isoelectric point (Korea Food Research Institute, 2020; Hong et al., 2013; Kim et al., 2000). The tissue of PI treated with citric acid and sodium pyrophosphate is supposed to become looser and cause concomitant swelling, and keeps tissue in a loose state even after drying. As shown in Fig. 1, the larger pores are observed from the PI2 (E-a) and PI3 (F-a). This means that citric acid or sodium pyrophosphate affects the water-holding capacity of PI, which is responsible for the production of pores after freeze-drying. On the other hand, no clear pores were observed in the cross sections of any of the samples after air-drying and vacuum drying. Son et al. (2014) reported that the better the water-holding capacity of a sample, the better its rehydration stability after freeze-drying.

From the above results, the freeze-drying method seems to be advantageous for the production of dried *sundae* with improved rehydration stability.

Rehydration stability

Based on the above results, freeze-dried *sundae* was manufactured using SN2 composed of potato starch and PI treated with various concentrations of sodium pyrophosphate in order to obtain the optimum concentration available for commercial use.

In consideration of the Korean Food Standard Codex (2020), the PI was treated at a maximum concentration of up to 2.0% sodium pyrophosphate and the rehydration stability of *sundae* was measured by the relative width changes of PI, compared to control.

As shown in Table 5, unlike the control (S1) showing a lower rehydration level (72.5% by 180 s), all of the treated samples maintained a rehydration stability of more than 91.5%, and this increased to 95.5 % at 180 s when the concentration of sodium pyrophosphate was increased to 2.0%.

Judging from the above mentioned results, it is concluded that SN2 made with PI treated with more than 0.5% sodium pyrophosphate is advantageous for the production of *sundae* with desirable rehydration stability.

Conclusion

Expansion of starch noodles (SN) and contraction of porcine intestine (PI) were influenced by starch sources and pH difference, respectively. The starch noodle from potato (SN2) and alkaline porcine intestine with sodium pyrophosphate (PI3, pH 9.18) showed relatively lower expansion and higher expansion ratio during rehydration, respectively. The rehydration stability was achieved more than 91.5% through application of SN2 and SN3 to *sundae* manufacturing. Therefore, use of potato starch noodle and porcine intestine treated with sodium pyrophosphate seems to be advantageous for strengthening rehydration stability of freeze dried *sundae.*

Conflicts of Interests

The authors declair no potential conflict of interest.

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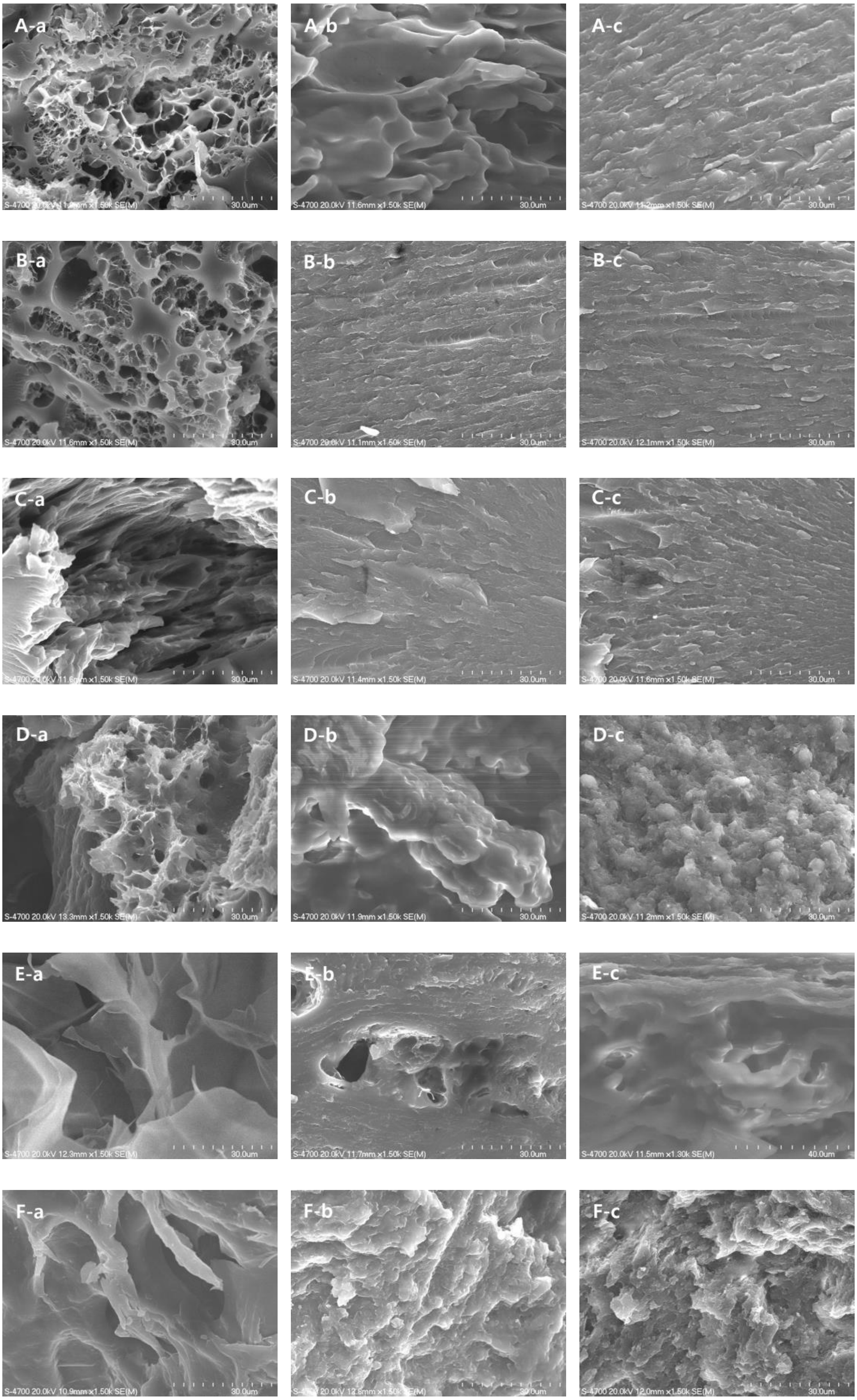

Fig. 1. SEM images of dried SN and PI

A : SN1, B : SN2, C : SN3, D : PI1, E : PI2, F : PI3
a: Freeze dried; b: Hot air dried; c: Vacuum dried
[1)]SN1, sweet potato starch; SN2, potato starch; SN3, mung bean starch.
[2)]PI1, distilled water; PI2, 2% citric acid; PI3, 2% sodium pyrophosphate.

Table 1. Formulation of *Sundae*

Ingredients	Contents (%)
Pork	44.5
Porcine intestine	16.0
Starch noodles	7.5
Pork blood	2.5
Starch	5.0
Isolated soybean protein	4.0
[1)]Vegetable	17.3
[2)]Seasoning	3.2
Total	100

[1)]Vegetable included the following: onion, 6.0%; green onion, 5.0%; carrot, 5.0%; garlic, 1%; and ginger, 0.25%.
[2)]Seasoning included the following: salt, 1.0%; sugar, 1.0%; condiment, 1.0%; and pepper, 0.25%.

Table 2. Dry yield of SN and PI according to various dry methods

Samples		Dry yield (%)
Freeze drying	[1)]SN1	62.02±5.75^{b}
	SN2	60.35±7.14^{b}
	SN3	80.69±2.29^{a}
	[2)]PI1	67.12±0.45^{c}
	PI2	91.98±0.23^{a}
	PI3	79.66±2.66^{b}
Hot air drying	SN1	64.62±6.00^{b}
	SN2	60.96±5.12^{b}
	SN3	91.67±8.33^{a}
	PI1	67.62±0.19^{c}
	PI2	92.18±0.41^{a}
	PI3	80.98±1.40^{b}
Vacuum drying	SN1	60.96±5.69^{b}
	SN2	60.13±4.51^{b}
	SN3	90.00±8.82^{a}
	PI1	65.23±1.40^{c}
	PI2	93.95±5.27^{a}
	PI3	79.68±2.73^{b}

[1)]SN1, sweet potato starch; SN2, potato starch; SN3, mung bean starch.
[2)]PI1, distilled water; PI2, 2% citric acid; PI3, 2% sodium pyrophosphate.
$^{a\text{-}c}$ Means on the same column with different letters are significantly different ($p<0.05$).

Table 3. Relative changes in the length and thickness of SN

Samples	Relative change (mm)			
	ΔL	*ΔL	ΔT	*ΔT
[1)]SN1	5.03±0.41^{b}	1.81±2.01^{b}	0.03±0.02^{a}	0.22±0.03^{a}
SN2	5.39±1.53^{b}	1.47±0.41^{b}	0.03±0.02^{a}	0.20±0.16^{a}
SN3	7.72±1.48^{a}	6.90±0.05^{a}	0.05±0.01^{a}	0.14±0.01^{a}

[1)]SN1, sweet potato starch; SN2,potato starch; SN3, mung bean starch.
$^{a\text{-}b}$ Means on the same column with different letters are significantly different ($p<0.05$).

Table 4. Changes in the length of PI at each step of treatment

Samples	Treatment steps (mm)					Remarks
	Before treatment	Soaking	Boiling	Freezing drying	Rehydration	Overall length change
$^{1)}$PI1	10.00^{a}	24.77±3.81^{ax}	24.16±3.81^{bx}	21.97±4.73^{bx}	15.63±1.69^{bx}	+5.63±1.69^{x}
PI2	10.00^{a}	25.90±2.37^{abx}	25.31±2.39^{abx}	23.64±1.65^{abx}	21.02±3.76^{bxy}	+10.96±3.76^{xy}
PI3	10.00^{a}	42.15±6.67^{by}	41.23±6.60^{cy}	37.35±6.43^{cy}	26.29±5.54^{cy}	+16.29±5.54^{y}

$^{1)}$PI1, distilled water; PI2, 2% citric acid; PI3, 2% sodium pyrophosphate.
$^{a-c}$ Means on the same row with different letters are significantly different ($p<0.05$).
$^{x-y}$ Means on the same column with different letters are significantly different ($p<0.05$).

Table. 5. Relative rehydration stability of *sundae* formulated with various levels of sodium pyrophosphate based on the length changes of PI

Samples	Relative rehydration (%)			
	0 s	60 s	120 s	180 s
$^{1)}$S1	100^{a}	76.2±5.7^{bx}	74.8±4.5^{bx}	72.5±4.4^{bx}
S2	100^{a}	92.6±4.8^{aby}	91.7±4.4b^{y}	91.5±4.5^{by}
S3	100^{a}	93.0±4.5^{by}	92.7±1.6^{by}	92.5±1.9^{by}
S4	100^{a}	95.5±3.5^{y}	95.0±3.3^{y}	95.0±3.3^{y}
S5	100^{a}	96.9±2.1^{aby}	95.7±1.8^{by}	95.5±2.0^{by}

$^{1)}$S1: *Sundae* (PI with 0% Na-pyrophosphate); S2: *Sundae* (PI with 0.5% Na-pyrophosphate); S3: *Sundae* (PI with 1.0% Na-pyrophosphate); S4: *Sundae* (PI with 1.5% Na-pyrophosphate); S5: *Sundae* (PI with 2.0% Na-pyrophosphate). $^{a-b}$ Means on the same **row** with different letters are significantly different ($p<0.05$). $^{x-y}$ Means on the same column with different letters are significantly different ($p<0.05$).