The preparation and food applications of divalent cation–substituted potato starch

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Abstract  Potato starch is characterized by discernibly high content of starch-bound phosphate monoester groups, and metal cations are attached to the phosphate groups by ion forces. A high level of divalent cations appears to lead to good viscosity stability of potato starch by ionically cross-linking starch phosphate esters. However, potato starches manufactured in factories in Hokkaido, the northernmost island of Japan, do not show good viscosity stability due to high potassium content and low divalent cation content. To overcome this, potato starches substituted with divalent cations, such as calcium, magnesium, and iron, have been produced by treating potato starches with solutions containing divalent cations. This review paper provides an overview of the preparation methods and physicochemical properties of divalent cation–substituted potato starch. Moreover, food applications of divalent cation–substituted potato starch are also discussed.

Keywords  potato starch, phosphorus, divalent cations, food

Introduction  Starch is a critical functional food biopolymer that is widely utilized in various food and non-food applications. It is a mixture of two types of α-glucans: linear amylase and branched amylopectin. Additionally, it also contains minor non-carbohydrate constituents, such as proteins, lipids, and minerals. Phosphorus is one of the main minerals present in starch molecules. In starches from tuber and root crops, it usually exists as phosphate monoesters, which are covalently attached to the amylopectin molecules. Potato, the key crop worldwide, including Japan, constitutes an important source of carbohydrates, predominantly starch, which is the major component of potato tubers. Potato starch has been produced extensively in local factories in Hokkaido, the northernmost island of Japan. As compared to starches from other tuber and root crops, potato starch is highly phosphorylated [1–4]. More importantly, potato starch contains metal cations that are linked to phosphate monoester groups by ion forces [5–9]. As starch granules are heated in the presence of excess water, viscosity in starch slurry changes drastically. Starch viscosity characteristics can be studied using Rapid Visco Analyzer (RVA), which then provides peak viscosity (an increase in viscosity during initial heating) and breakdown (the degree of the disintegration of granules or pasting stability) [10–12]. Mineral components have great impact on starch viscosity characteristics. Potato starch exhibits unique viscosity properties, having noticeably higher peak viscosity than other starches because of higher levels of phosphate ester groups [2–4]. It has been well-established that starch with higher phosphorus content displays increased peak viscosity within potato starches from different cultivars [7, 13, 14]. Moreover, high levels of divalent cations, such as calcium and magnesium, are associated with low peak viscosity and breakdown, suggesting that divalent cation–substituted potato starch displays good viscosity stability by ionically cross-linking starch phosphate esters [6, 15, 16]. It has been reported that potato starches manufactured in Hokkaido factories generally have high potassium content and low divalent cation content [8, 9, 17]. Therefore, the factory-made potato starch does not display good viscosity stability, which may limit the applications of the native potato starch in a variety of food products. The dietary roles of some divalent cations for health promotion have been widely recognized. Calcium and magnesium can help to decrease the risk of type 2 diabetes [18, 19] and osteoporosis [20]. Iron is essential for red blood cell formation, and iron deficiency affects approximately two billion people worldwide [21]. It may be interesting to research the modification of metal cations in potato starch that changes its nutritional charac-
teristics as well as its physicochemical characteristics.

Recently, our group has established effective and practical ways to prepare potato starches substituted with divalent cations, such as calcium [22, 23], magnesium [22], and iron [24], by immersion in solutions containing divalent cations. This review paper aims to summarize the latest progress of research on preparation methods and physicochemical properties of divalent cation–substituted potato starch. Additionally, the current status of research and development on food applications of divalent cation–substituted potato starch is also described [23].

**Previous studies on the preparation of divalent cation–substituted potato starch**

Potato starch has high ability to bind cations due to the high level of phosphate ester groups in potato amylopectin molecules. Therefore, potato starch would be an adequate carrier of vital cations, in which humans are frequently deficient. In the starch extracted from potato tubers with distilled water in the laboratory, potassium is markedly higher than other cations [6, 9, 25, 26]. This is presumably because potassium is the principal cation in potato tubers [27]. Yagi and Yoshioka [5] and Wiesenborn et al. [7] reported that the potato starch extracted in tap water, probably containing a high level of calcium, contained relatively high calcium (207 to 281 ppm). These studies suggest that some of the potassium is replaced by calcium through an ion-exchange process. As the tap water used for starch production usually contains extremely low levels of divalent cations, the degree of replacement appears to be small. Thus, in general, factory-made potato starch contains a low level of divalent cations. To overcome the inherent deficiency of divalent cations in potato starch, some research involved immersing potato starch in solutions containing divalent cations. According to an early study by Kainuma et al. [6], calcium-substituted potato starches (calcium content 351 to 784 ppm) were obtained using potato starches from different cultivars; however, their method involved the treatment of the control potato starch sequentially with 0.05 mol/L HCl, distilled water, saturated Ca(OH)2 solution, and distilled water. Yamamoto et al. [25] also prepared calcium-substituted potato starches (calcium content 370 to 523 ppm) by suspension sequentially in 0.05 mol/L H2SO4, distilled water, 0.1 mol/L CaCl2 solution, and distilled water. Thus, the methods for preparing calcium-substituted potato starches in their studies were laborious and not appropriate for the industrial production of calcium-substituted potato starch. Recently, Fortuna et al. [16] reported that treating the control potato starch with a mixture of 1% (w/w) MgCl2 and saturated Mg(OH)2 solution in a volume ratio of 1:1 led to enhanced magnesium content (322.6 ppm). Rożnowski et al. [28] prepared potato starch with a higher content of iron (585.8 ppm) by immersing the control potato starch in an FeSO4 aqueous solution. However, Fortuna et al. [16] and Rożnowski et al. [28] did not investigate the optimum condition for the reaction of magnesium and iron substitution, respectively.

**Our studies on the preparation of divalent cation–substituted potato starch**

We reported calcium- and magnesium-substituted potato starches obtained by immersion in various concentrations of CaCl2 (0.005–1%) and MgCl2·6H2O (0.02–2%) solutions, respectively [22]. The pasting properties, i.e., peak viscosity and breakdown, of all of the starches prepared above were measured using RVA. Additionally, the gelatinization properties and in vitro digestibility of the representative calcium- and magnesium-substituted starches were determined. The control potato starch had high contents of phosphorus (801 ppm) and potassium (663 ppm), whereas it contained manifestly lower calcium (99 ppm) and magnesium (89 ppm). The calcium contents of the potato starches treated with a CaCl2 aqueous solution are presented in Fig. 1. The calcium content of the treated potato starches increased from 99 to 484 ppm with the increase of the CaCl2 concentration up to 0.1%. However, increasing CaCl2 concentrations from 0.25% to 1% caused an almost constant calcium content in the treated starches (640 to 686 ppm). The magnesium content of the potato starches treated with a MgCl2 aqueous solution is shown in Fig. 2. The magnesium content of the treated starch increased from 89 to 363 ppm with the increase in MgCl2·6H2O concentrations up to 0.2%. Above a 0.5% MgCl2·6H2O concentration, the magnesium content of the treated starch was relatively constant (382 to 421 ppm). The potassium levels of calcium- and magnesium-substituted potato starches were extremely decreased (0 to 16 ppm), implying that potassium in the control potato starch was replaced by calcium and magnesium during suspension in CaCl2 and MgCl2 aqueous solutions, respectively. The molar ratios of calcium and magnesium to phosphorus were about two-thirds for calcium- and magnesium-substituted potato starches, respectively. More importantly, as shown in Figs. 1 and 2, remarkably lower values of peak viscosity and breakdown were found in calcium- and magnesium-substituted potato starches, respectively, than in the control potato starch. Starch gelatinization parameters were analyzed by differential scanning calorimetry, and onset temperature and peak temperature as well as enthalpy were recorded. The calcium- and magnesium-fortified potato starches exhibited significantly but slightly higher onset temperature (62.9 to 63.1°C) and peak temperature (67.1 to 67.2°C) than the control potato starch (62.6°C for onset temperature and 66.7°C for peak temperature). Enthalpy was significantly but slightly lower in the calcium- and magnesium-fortified potato starches (15.9 to 16.1 J/g) than in the control potato starch.
For the determination of resistant starch content, each raw potato starch was digested with pancreatic α-amylase and amyloglucosidase for 16 h at 37°C. The calcium- and magnesium-fortified potato starches as well as the control potato starch had extremely high resistant starch content (93.0 to 95.5%) and no significant difference in resistant starch content was found among these starches. Thus, calcium and magnesium substitution had no or only slight influences on the gelatinization temperature and enthalpy as well as the starch digestibility.

It is crucial for manufacturing calcium- and/or magnesium-substituted potato starches to employ natural water, instead of food additive-containing solution, because the use of natural water can appeal to consumers as being safe and comforting. Some natural mineral waters, what you would call “extremely hard water,” contains high amounts of calcium and/or magnesium. Next, we attempted to prepare calcium-substituted potato starch by immersion in calcium-rich mineral water without using food additives such as CaCl₂ and to examine the influences of calcium enrichment on starch properties [23]. We prepared calcium-substituted potato starch by immersion in natural mineral water containing an extremely high level of calcium (468 ppm). The calcium content of the substituted potato starch produced by use of the mineral water was as high as 813 ppm, while the calcium content of the control potato starch was 99 ppm. RVA data revealed that the calcium-substituted potato starch had markedly lower peak viscosity and breakdown than did the control potato starch. Moreover, as shown in Fig. 3, calcium substitution led to a great reduction in starch swelling power.

We also reported iron-substituted potato starch obtained by immersion in various concentrations of FeSO₄·7H₂O (0.0125–1%) solution [24]. To determine the impact of iron substitution on the characteristics of potato starch, all of the starches prepared through the process mentioned above were analyzed for their pasting properties, color, gelatinization properties, and resistant starch content. The iron content of the potato starches treated with an FeSO₄ aqueous solution is shown in Fig. 4. The iron content of the treated potato starches increased drastically with the enhancement of the FeSO₄·7H₂O concentration up to 0.1%.

[Figure 1] The calcium content (A) and RVA pasting properties (B) of the potato starches treated with CaCl₂ aqueous solution. For each RVA parameter (peak viscosity or breakdown), bars labeled with the same letter are not significantly different (p < 0.05). This is taken from Noda et al. [22].
Increasing FeSO₄·7H₂O concentrations from 0.2 to 1% caused a slight increase in iron content in the treated starches (782 to 890 ppm). As shown in Fig. 5, the representative iron-substituted potato starch treated with a 0.5% FeSO₄·7H₂O solution had small amounts of sodium, magnesium, and calcium. Furthermore, the potassium content, which was the predominant cation of the control potato starch, was very small in the iron-substituted potato starch. The iron-substituted potato starch had high molar ratio of iron to phosphorus (0.616). During iron substitution, pasting properties were dramatically altered by decreasing the peak viscosity and breakdown. Iron substitution resulted in slightly decreased whiteness (slightly lower L*-value) and increased yellowish color (higher b*-value). In contrast,
iron substitution had little influence on the gelatinization temperature and enthalpy. Additionally, no significant change in the resistant starch content, which indicates the starch digestibility, was found due to iron substitution.

Cross-links between phosphate esters in potato starch by divalent cations

Here, we will describe the molecular mechanism of the cation-substituted potato starch paste. Viscosity characteristics of potato starch are strongly influenced by differences in the monovalent cations and divalent cations bound to the phosphate ester groups. As suggested by Kainuma et al. [6] and Bergthaller et al. [15], divalent cations have the capacity to cross-link adjacent phosphate groups, leading to improved viscosity stability (Fig. 6). Previous reports revealed that peak viscosity and breakdown decreased distinctly due to the fortification of potato starch with calcium [6, 15] and magnesium [16]. In contrast, the fortification of potato starch with potassium [6, 15] and sodium [6, 15] enhanced peak viscosity and breakdown. In line with these findings, our data demonstrated that the exchange of potassium for divalent cations, such as calcium [22, 23], magnesium [22], and iron [24], in factory-made potato starch markedly decreased peak viscosity and breakdown. Thus, divalent cation–substituted potato starch obtained in the previous research and our own showed good viscosity stability. Furthermore, it was proven that calcium substitution in potato starch led to a decrease in starch swelling power [6, 23, 25]. According to a recent study by Reyniers et al. [29], cross-links between phosphate esters in potato starch by calcium are suggested to have a pronounced negative effect on starch swelling.

Food applications of calcium-substituted potato starch

To date, applications of potato starch in a variety of food systems have been received significant attention. Especially in Japan, potato starch is commonly cheaper (120–200 JPY/kg) than wheat flour (160–240 JPY/kg), and wheat flour–
based foods, such as different forms of noodles, are manufactured with the addition of potato starch with the intention of improving their quality and/or reducing the cost of imported wheat flour. The utilization of potato starches extracted from several cultivars was examined for making instant noodles [30] and Korean-style cold noodles [31] with blends of wheat flour and potato starch. Little research has been conducted on the usability of potato starch for bakery products. As described above, we have obtained divalent cation–substituted potato starches with largely altered viscosity characteristics. Thus, we investigated the suitability of calcium-substituted potato starch prepared by immersion in calcium-rich mineral water for making pound cakes and breads [23].

The characteristics of pound cakes made from wheat flour supplemented with each of the two potato starches and those made from wheat flour only are presented in Table 1. Reductions in the height and specific volume of cakes during the baking process are associated with undesirable characteristics. The height and specific volume of pound cakes were evidently decreased from 72.0 to 63.8 mm and from 2.27 to 2.01 cm³/g, respectively, by the replacement of wheat flour with the control potato starch. Contrary to this, the values of height and specific volume of pound cakes made from wheat flour blended with calcium-substituted potato starch were as high as 76.0 mm and 2.25 cm³/g.

### Table 1 Effect of substitution of wheat flour with the control potato starch and with the calcium-substituted potato starch on characteristics of pound cakes

|                        | None    | Control potato starch | Calcium-substituted potato starch |
|------------------------|---------|-----------------------|-----------------------------------|
| Height (mm)            | 72.0    | 63.8                  | 76.0                              |
| Specific volume (cm³/g)| 2.27    | 2.01                  | 2.25                              |
| Sensory evaluation (n = 7) |        |                       |                                   |
| Appearance             | 3.0 ± 0.0ª | 2.4 ± 0.8ª          | 3.1 ± 0.7ª                       |
| Color                  | 3.0 ± 0.0ª | 3.0 ± 0.6ª          | 2.7 ± 0.5ª                       |
| Flavor                 | 3.0 ± 0.0ª | 2.9 ± 0.4ª          | 2.9 ± 0.7ª                       |
| Texture                | 3.0 ± 0.0ª | 2.7 ± 0.5ª          | 2.7 ± 0.8ª                       |

On sensory evaluation, seven panelists were asked to rate the appearance, color, flavor, and texture of samples on a 1–4 scale (1 corresponding to bad, 2 to slightly bad, 3 to good, and 4 to very good). 100% wheat flour sample was regarded as “None”, and the panelists were required to rank it “3 (good).” The rate of substitution of one of the potato starches for wheat flour was 40%. In the data of sensory evaluation, the data are averages ± standard deviation of seven evaluations, and the same letter does not show significant difference among samples at P < 0.05. This is taken from Noda et al. [23].

### Table 2 Effect of substitution of wheat flour with the control potato starch and with the calcium-substituted potato starch on characteristics of breads

|                        | None    | Control potato starch | Calcium-substituted potato starch |
|------------------------|---------|-----------------------|-----------------------------------|
| Specific loaf volume (cm³/g)| 5.98   | 5.29                  | 5.40                              |
| Calcium content (ppm)  | 90      | 82                    | 195                               |
| Sensory evaluation (n = 9) |        |                       |                                   |
| Appearance             | 3.0 ± 0.0ª | 2.3 ± 0.5ª          | 2.6 ± 0.5ª                       |
| Inner phase            | 3.0 ± 0.0ª | 2.7 ± 0.7ª          | 2.7 ± 0.7ª                       |
| Flavor                 | 3.0 ± 0.0ª | 2.4 ± 0.7ª          | 2.1 ± 1.2ª                       |
| Taste                  | 3.0 ± 0.0ª | 2.7 ± 0.7ª          | 2.6 ± 0.9ª                       |
| Texture                | 3.0 ± 0.0ª | 2.7 ± 0.7ª          | 2.9 ± 0.9ª                       |

On sensory evaluation, nine panelists were asked to rate the appearance, inner phase, flavor, taste, and texture of samples on a 1–4 scale (1 corresponding to bad, 2 to slightly bad, 3 to good, and 4 to very good). 100% wheat flour sample was regarded as “None”, and the panelists were required to rank it “3 (good).” The rate of substitution of one of the potato starches for wheat flour was 30%. In the data of sensory evaluation, the data are averages ± standard deviation of nine evaluations, and the same letter does not show significant difference among samples at P < 0.05. This is taken from Noda et al. [23].
respectively, which were similar to those made from wheat flour only. From the sensory analysis data, all of the sensory attributes of pound cakes were not significantly different among the three samples examined. However, pound cakes made from wheat flour substituted with the control potato starch indicated a slightly lower score for appearance (2.4) than those made from wheat flour only (3.0) and those made from wheat flour supplemented with the calcium-substituted potato starch (3.1). Next, the characteristics of breads made from wheat flour supplemented with the control potato starch and with the calcium-substituted potato starch, as well as those made from wheat flour only, were also studied, and the results are shown in Table 2. Potato starch–free breads showed the highest specific loaf volume (5.98 cm$^3$/g). The specific loaf volume of breads made with the addition of calcium-substituted potato starch was slightly higher (5.40 cm$^3$/g) than that of those made with the addition of the control potato starch (5.29 cm$^3$/g). Thus, the replacement of wheat flour with calcium-substituted potato starch slightly improved the specific loaf volume of the breads, as compared to the bread with the control potato starch. The sensory analysis results of breads demonstrated no significant differences in all of the attributes—appearance, inner phase, flavor, taste, and texture—among the three samples examined.

**Conclusion**

Potato starches substituted with divalent cations, such as calcium, magnesium, and iron, were successfully prepared by immersion in solutions containing divalent cations. Divalent cation–substituted potato starch exhibited good viscosity stability by ionically cross-linking starch phosphate esters. Calcium-substituted potato starch was found to be suitable for making pound cakes with good volume. Further research on the physicochemical properties and food applications of calcium-substituted potato starch is currently underway.

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**References**

1. Hizukuri S, Tabata S, Nikuni Z. Studies on starch phosphate: Part 1. Estimation of glucose-6-phosphate residues in starch and the presence of other bound phosphate(s). Starch/Stärke. 1970; 22: 338–43.
2. Hoover R. Composition, molecular structure, and physicochemical properties of tuber and root starches: a review. Carbohydr Polym. 2001; 45: 253–67.
3. Srichuwong S, Sunarti TC, Mishima T, Isono N, Hisamatsu M. Starches from different botanical sources II: Contribution of starch structure to swelling and pasting properties. Carbohydr Polym. 2005; 62: 25–34.
4. Noda T, Takigawa S, Matsuura-Endo C, Suzuki T, Hashimoto N, Kottearachchi NS, Yamauchi H, Zaidul ISM. Factors affecting the digestibility of raw and gelatinized potato starches. Food Chem. 2008; 110: 465–70.
5. Yagi T, Yoshioka S. Studies on the preparation of potato starch. J Jpn Soc Starch Sci. 1973; 20: 13–6 (in Japanese with English Abstract).
6. Kainuma K, Miyamoto S, Yoshioka S, Suzuki S. Studies on structure and physico-chemical properties of starch: Part 3. Changes in physical properties of high phosphate potato starch by substitution of cations. J Jpn Soc Starch Sci. 1976; 23: 59–66 (in Japanese with English Abstract).
7. Wiesenborn DP, Orr PH, Casper HH, Tacke BK. Potato starch paste behavior as related to some physical/chemical properties. J Food Sci. 1994; 59: 644–8.
8. Noda T, Takigawa S, Matsuura-Endo C, Kim SJ, Hashimoto N, Yamauchi H, Hanashiro I, Takeda Y. Physicochemical properties of amylopectin structures of large, small and extremely small potato starch granules. Carbohydr Polym. 2005; 60: 245–51.
9. Md Zaidul IS, Norulaini N, Mohd Omar AK, Yamauchi H, Noda T. Correlations of the composition, minerals, and RVA pasting properties of various potato starches. Starch/Stärke. 2007; 59: 269–76.
10. Deffenbaugh LB, Walker CE. Comparison of starch pasting properties in the Brabender Viscoamylograph and the Rapid Visco-Analyzer. Cereal Chem. 1989; 66: 493–9.
11. Suh DS, Jane JL. Comparison of starch pasting properties at various cooking conditions using the Micro Visco-Amylograph and the Rapid Visco-Analyzer. Cereal Chem. 2003; 80: 745–9.
12. Zaidul ISM, Nik Norulaini NA, Mohd Omar AK, Yamauchi H, Noda T. RVA analysis of mixtures of wheat flour and potato, sweet potato, yam and cassava starches. Carbohydr Polym. 2007; 69: 784–91.
13. Noda T, Tsuda S, Mori M, Takigawa S, Matsuura-Endo C, Saito K, Mangalika WHA, Hanaoka A, Suzuki Y, Yamauchi H. The effect of harvest date on the starch properties of various potato cultivars. Food Chem. 2004; 86: 119–25.
14. Noda T, Tsuda S, Mori M, Takigawa S, Matsuura-Endo C, Hashimoto N, Yamauchi H. Properties of starches from several potato varieties grown in Hokkaido. J Appl Glycosci. 2004; 51: 241–6.
15. Berghaller W, Witt W, Goldau HP. Potato starch technology. Starch/Stärke. 1999; 51: 235–42.
16. Fortuna T, Galkowska D, Bączkowiak M, Szkarab K, Tartanis I, Labanowska M, Kuzdziel MA. Effect of potassium and magnesium treatment on physicochemical and rheological properties of potato, corn and spelt starches and on thermal generation of free radicals. Starch/Stärke. 2013; 65: 912–22.
17. Noda T, Matsuura-Endo C, Ishiguro K. Physicochemical properties of potato starches manufactured in Hokkaido factories. J Food Sci Technol. 2019; 56: 2501–7.
18. Liu S, Choi HK, Ford E, Song Y, Klevak A, Buring JE, Manson JE. A prospective study of dairy intake and the risk of type 2 diabetes in women. Diabetes Care. 2006; 29: 1579–84.
19. Villegas R, Gao YT, Dai Q, Yang G, Cai H, Li H, Zheng W, Shu XO. Dietary calcium and magnesium intakes and the risk of type 2 diabetes: The Shanghai woman’s health study. Am J Clin Nutr. 2009; 89: 1–9.
20. Nieves JW. Osteoporosis: the role of micronutrients. Am J Clin Nutr. 2005; 81: 1232S–1239S.
21. Zimmermann MB, Hurrell RF. Nutritional iron deficiency. Lancet. 2007; 370: 511–20.
22. Noda T, Takigawa S, Matsuura-Endo C, Ishiguro K, Nagasawa K, Jinno M. Preparation of calcium- and magnesium-fortified potato starches with altered pasting properties. Molecules. 2014; 19: 269–76.

8 J Biorheol (2021) 35(1):2–9
23. Noda T, Takigawa S, Matsuura-Endo C, Ishiguro K, Nagasawa K, Jinno M. Properties of calcium-fortified potato starch prepared by immersion in natural mineral water and its food application. J Appl Glycosci. 2015; 62: 159–64.

24. Noda T, Matsuura-Endo C, Ishiguro K. Preparation of iron-fortified potato starch and its properties. J Food Sci Technol. 2018; 55: 1360–5.

25. Yamamoto K, Sawada S, Onogaki T. Gelatinization properties of classified potato starches. J Jpn Soc Starch Sci. 1981; 28: 227–34 (in Japanese with English Abstract).

26. Sasaki T. Influence of anionic, neutral, and cationic polysaccharides on the in vitro digestibility of raw and gelatinized potato starch. J Sci Food Agric. 2020; 100: 2435–42.

27. Rivero RC, Hernández PS, Rodríguez EMR, Martín JD, Romero CD. Mineral concentrations in cultivars of potatoes. Food Chem. 2003; 83: 247–53.

28. Rożnowski J, Fortuna T, Przetaczek-Rożnowska I, Łabanowska M, Bączkowicz M, Kurdziel M, Nowak K. Effect of enriching potato and corn starch with iron-ions on selected functional properties. Starch/Stärke. 2014; 66: 1049–59.

29. Reyniers S, De Brier N, Matthijs S, Brijs K, Delcour JA. Impact of mineral ions on the release of starch and gel forming capacity of potato flakes in relation to water dynamics and oil uptake during the production of snacks made thereof. Food Res Int. 2019; 122: 419–31.

30. Noda T, Tsuda S, Mori M, Takigawa S, Matsuura-Endo C, Kim SJ, Hashimoto N, Yamauchi H. Effect of potato starch properties on instant noodle quality in wheat flour and potato starch blends. Starch/Stärke. 2006; 58: 18–24.

31. Noda T, Fujikami S, Miura H, Fukushima M, Takigawa S, Matsuura-Endo C, Kim SJ, Hashimoto N, Yamauchi H. Effect of potato starch properties on the textural properties of Korean-style cold noodles made from wheat flour and potato starch blends. Food Sci Technol Res. 2006; 12: 278–83.