Chapter 21

Starch Properties and Uses as Food for Human Health and Welfare

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Abstract Sago palm is a highly efficient starch-producing plant found in humid tropical zones. In the areas where sago palms are cultivated, its plantation methods and food cultures have been conveyed from generation to generation. Recently, it is increasingly seen as an important agricultural product and crop whose cultivation can lead to more fulfilling lives for local people. However, there are very few food uses for sago starch as a main ingredient in Japan. In order to increase sago starch usage across Japan, it is exceedingly important to introduce high-quality sago starch. Also it is crucial to publicize its attractiveness, positive characteristics, and its specific and potential usages. Accordingly, in this report, the physicochemical characteristics and optimal cooking properties of sago starch were examined through investigating sago starch usage in the cooking processes of *udon*, Chinese noodles, Chinese vermicelli, *kuzukiri (fen pi)*, *gomadofu*, *kamaboko*, *warabimochi*, *kuzuzakura nama-yatsushashi*, *mushiyokan*, pie filling, blancmange, and biscuits.

In terms of gelatinization behavior, sago starch was found to be similar to potato, cassava, and sweet potato starch. Also, in terms of retrogradation and amylose content, sago starch was close to cornstarch. It was proved that sago starch could be used in various types of cooking and food manufacturing by replacing other starches. Sago starch gel has satisfactory elasticity, softness, flexibility, and less adhesiveness. Furthermore, sago starch usability in puffed foods was proven. In sensory evaluations for all foodstuffs in this report, the sago starch-replaced foods had superior physical properties and were valued to have favorable tastes and textures in sensory evaluations. The possibility of further development of sago starch became apparent. In Japan, the appeal of the up-to-now unused resource, that is, sago starch, is being widely disseminated, and its potential use in cooking and manufacturing foodstuffs is being further considered.

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21.1 Introduction

The sago palm (*Metroxylon sagu* and *M. rumphii*) is a highly efficient starch-producing plant found in humid tropical zones (Sato et al. 1979). Sago starch accumulates in the trunk of the sago palm. It takes over 10 years from the period of planting for sago starch to accumulate and be ready for harvest. However, this long maturation period can be countered through placing a sago palm plantation under proper sucker management to enable harvesting to be carried out more frequently (Kainuma 1982).

Sago starch has been used in a variety of ways across sago-producing areas. For example, it can be kneaded into a porridge (*kurupun*) or paste-like state (*papeda*, *rendang*), and it can be baked in a similar fashion into cakes and breads (*lempeng*, *keropo*, *sinoli*). It is also processed to make sago pearls (Hirao and Takahashi 1996), noodles (*mie sagu*), and crackers (*kerupuk*, *sagu*) as secondary products (Takahashi and Hirao 1992). In recent years, in addition to conventional usage of sago starch as a staple food and in desserts (Hirao et al. 2008; Nishimura 2008; Yamamoto et al. 2008), new usages in different food products are being considered (Bujang and Ahmad 2000; Puchongkavarin et al. 2000). Also, in the areas in which sago starch is cultivated, it is increasingly being seen as an important agricultural product and as a crop whose cultivation can lead to a more fulfilling life for local people. Accordingly, local people are trying to pass sago starch food culture down to their younger generations.

In Japan, sago starch is mainly imported from Indonesia and Malaysia with modified sago starch being largely used as dusting flour for noodles such as *udon*, *ramen*, and *soba* or for dumpling skins such as *gyoza* and *shumai* (Kondo 2015). However, in Japan there are very few foods that use sago starch as a main ingredient.

A possible reason for this could be that Japan is blessed with a multitude of starches which all have their own conventional unique food cultures. Examples of this include potato starch and sweet potato starch, both of which have a desirable degree of whiteness and are affordable, and kudzu starch and bracken starch which are a bit more expensive. It must also be mentioned that the usage of cornstarch extracted from imported corn is becoming more common in Japan.

In order to increase the usage of sago starch across Japan, in addition to the acquisition of high-quality sago starch, promotion of the attractiveness and positive characteristics of sago starch and its specific and potential usages is exceedingly important. Accordingly, it was decided that the physicochemical, cooking, and processing properties of sago starch were to be investigated in this report.

21.2 The Physiochemical Characteristics of Sago Starch

1. The shape, surface construction, and color of sago starch.

One of the unique characteristics of sago starch is the shape of its particles, which are elliptical or bell-shaped with part of the ellipse missing. The relatively large particle size of 10 ~ 65 μm (average of 35 μm) is similar to that of tuber-root starches such as sweet potato and potato.

Furthermore, observations using an X-ray photoelectron spectrometer and an atomic force microscope have shown that the structure of the outermost surface of sago starch particles has a myriad of small protuberances, thus resembling the surface structure of potato starch (Hatta et al. 2002).

Due to the fact that harvested sago palm logs are often stored in water for prolonged periods of time before starch extraction, damage and discolorization of the particles, possibly related to microbial growth or enzymatic reactions during storage, are frequent occurrences (Takahashi et al. 1981).

In terms of whiteness, when a plate of magnesium oxide (MgO) is set at 100, cornstarch and potato starch have ratings of 100 and 95.3, respectively. Comparatively, the whiteness rating of 80.1 for sago starch is low.

Recently, the number of new modern starch factories has increased. Accordingly, improvements in hygiene have been observed, and the whiteness rating of sago starch has risen to 83 or above.

2. Amylose content and amylopectin chain length distribution of sago starch.

The amylose content, determined by amperometric titration, is 24.5% for sago starch and 19.7% for potato starch. Due to the fact that the physicochemical properties of sago starch depend not only on its type but also on its cultivation environment, a high amylose content rating of 26%, similar to that of cereal starches such as corn and mung bean, could also be attained.

Furthermore, the long-chain fraction Fr. II in the amylopectin chain length distribution, which was obtained by the gel filtration method, and Fr. III/Fr. II, which are considered to be very important physical properties, closely resemble those of cassava starch (Takahashi and Hirao 1994).

3. Swelling power and solubility.

Swelling power refers to how many grams of water are absorbed by 1 g of dry starch at 60 ~ 90 °C. Solubility refers to the amount of starch that dissolves in hot water. Compared to potato starch which has a high swelling power of 100 as well as a high solubility of 100% at 90 °C, cornstarch, with a swelling power of 22 and a low solubility of 26%, swells and dissolves with difficulty even at 90 °C. The swelling power and solubility of sago starch are 40 and 53%, respectively, meaning sago starch can be valued between tuber-root starches and cereal starches (Takahashi et al. 1995).

4. The gelatinization and retrogradation properties of starch.

(i) Viscosity measured by a Rapid Visco Analyzer (RVA)

The changes in viscosity caused by heating and cooling of various starch types using an RVA (Newport Scientific Pty. Ltd) are shown in Fig. 21.1.

Sago starch (commercial sago, spineless sago palm, and spiny sago palm) showed a temperature at which viscosity begins to rise of 71 ~ 74 °C and a maximum viscosity of 195 ~ 248 RVU. When cooling at 50 °C, its final viscosity was 115 ~ 165 RVU. The viscosity of sago starch was the second highest behind potato starch and showed a similar viscosity to kudzu starch. In contrast to this, sugar palm

Fig. 21.1 Rapid Visco Analyzer (RVA) curves of various starches (Source: Hamanishi 2002)

starch (represented in this study by *Arenga pinnata*), which like sago starch is derived from tropical palm trees, showed the lowest viscosity with results similar to wheat starch (Hamanishi et al. 2002a).

(ii) Gelatinization behavior observed by photopastigraphy

The transmittance change of starch slurry during heating was determined using photopastigraphy (Hirama Scientific Machinery ART-3). After declining for a while, the transmittance then increased again (Fig. 21.2). It was concluded that this decline was due to the starch particles starting to swell with water. The gelatinization temperature at which the increase of transmittance occurred was 56 °C for potato starch, 58 °C for sago starch, 64 °C for cornstarch, and 65 °C for mung bean starch (Takahashi et al. 1995).

(iii) Degree of gelatinization determined by β -amylase-pullulanase method (BAP method) and thermal analysis

When using the BAP method to determine the degree of gelatinization (Kainuma et al. 1981), it was found that the rate for sago starch quickly increased at around 70 °C. This, being the lowest temperature after potato starch, proved that sago starch

Fig. 21.2 Photopastegram of sago, mung bean, potato, and cornstarches (Source: Takahashi et al. 1981)

gelatinizes easily. After that, as the temperature rose, sago starch showed a slow gelatinization process resembling that of corn and mung bean starch (Takahashi et al. 1983). Based on the DSC determinations of the various types of starch at a sample concentration of 30%, the onset temperature of gelatinization for sago starch was 60.4 °C, and the peak and finishing temperatures of gelatinization and the heat of gelatinization (ΔH) were similar to that of potato starch.

(iv) Dynamic viscoelasticity of starch gel

According to static viscoelasticity measurements attained by a creep meter (Yamaden Plc.), when compared to sweet potato starch, sago starch was softer and had higher viscosity. By the same measurements, sago starch gel showed lower fluidity than that of potato starch gel.

According to dynamic viscoelasticity measurements using Rheograph Gel (Toyoseiki Plc.), the E' and E'' (corresponding to hardness and viscosity, respectively) ratings of sago starch were the lowest, indicating it is softer than potato, sweet potato, and cornstarch gels. Also, sago starch gel had a strong internal viscosity element with a large $\tan \delta$ (E'/E''), as opposed to the small $\tan \delta$ of cornstarch, which was found to have elasticity elements (Takahashi and Hirao 1994).

(v) Physical properties of sago starch gel

Fig. 21.3 Gel hardness and adhesiveness of various starches measured by Tensipresser (Source: Miyazaki 1999)

Texture measurements for hardness, cohesiveness, and adhesiveness were conducted using a Tensipresser (Taketomo Electric TTP-50BX). As shown in Fig. 21.3, the hardness of sago starch gel was similar to potato, sugar palm, and kudzu starch gels. Immediately after preparation, the physical property of the gel was soft but became hard after being cooled at 5 °C for 2 h (Miyazaki 1999). Furthermore, by cooling the gel for 2 h at 5 °C, its adhesiveness greatly decreased, and its cohesiveness, which shows the degree of internal binding force, did not change from the original large value (Hamanishi 2002).

(vi) Changes of syneresis and whiteness in starch gels

The retrogradation of starch is followed by determining the change of syneresis and whiteness of the gel. Mung bean starch and cornstarch gels, which contain a higher amount of amylose, showed the largest amount of syneresis. Sago starch gel was second only to potato starch gel in terms of low syneresis (Fig. 21.4). Potato

Fig. 21.4 Syneresis of starch gels determined by released water (Source: Takahashi et al. 1981)

starch gel proved to have low whiteness showing less change from immediately after preparation until 4 h later. Sago starch gel had high transparency and little change in whiteness, being second only to potato starch gel. Cornstarch gel, however, immediately after preparation, showed apparently higher whiteness which increased as time passed (Takahashi et al. 1981).

Based on the above, it can be seen that the good points of sago starch are that it is a transparent, soft, and flexible gel with low adhesiveness and a low syneresis. Furthermore, sago starch contains a similar amount of amylose as cornstarch and its physical properties are similar to those of potato, sweet potato, kudzu, and bracken starches. Due to this evidence, it is thought that sago starch can be used in food products that contain the aforementioned starch types.

21.3 Sago Starch as an Ingredient in Cooking

1. *Udon* (Japanese noodles)

Udon was prepared using five types of starch: sago, potato, sweet potato, kudzu, and cassava. The starches were mixed to a ratio of 50% with non-glutinous rice flour. For comparison, *udon* made from 100% non-glutinous rice flour and from wheat flour was processed and examined. *Udon* made using non-glutinous rice flour was softer than wheat flour *udon*. However, adding starch to non-glutinous rice flour *udon* caused firmness to increase producing a firmer noodle than when using wheat flour. Cassava *udon* was the hardest followed by sago *udon*. In the sensory evaluation, *udon* made using sago starch was preferred in the parameters of smoothness and stickiness and overall evaluation. When the appropriate amount of substitution (with non-glutinous rice flour) of cassava and sago starch was investigated, it was

found that as the substituted amount was increased, the *udon* became harder. In the sensory evaluation, *udon* made using a replacement rate of 50% sago starch and 50 or 70% cassava starch was favored the most (Yokota et al. 2015).

2. Chinese noodles

In the preparation of Chinese noodles, starch was used as a partial substitute for wheat flour, and the effects of this replacement were investigated. The boiled Chinese noodles increased in hardness and became stretchy as the substituted amount of starch was increased. When comparing Chinese noodles made using sago starch and potato starch, the former was found to be harder and expanded to a greater degree. Furthermore, it was clearly found that by making Chinese noodles using sago starch, the amount of solid material lost in the water during the boiling period decreased dramatically. Based on sensory evaluation, it was proved that replacing wheat flour with sago starch to a degree of 10 or 20% produced Chinese noodles that were more transparent, were less sticky, and had a more favorable taste compared to the reference sample (0% starch) (Kondo et al. 2013).

3. Bread and muffins

Bread and muffins were prepared to investigate the potential usage of sago starch in puffed foods. Muffins made using sago starch were found to expand better and have a more uniform texture and more springiness than muffins made using cornstarch or potato starch. It was found that when sago starch replaced 30% of the bread flour and vital gluten (10% of the bread flour and sago starch) was added, the bread expanded to a degree of 1.3 ~ 1.5 times. In the sensory evaluation, sago bread was found to be springier and have more uniform texture than bread made with other starches (Ohya and Takahashi 1987). Based on the above evidence, it can be concluded that sago starch is a perfectly viable ingredient in puffed foods.

4. Chinese vermicelli

Based on its physiochemical properties, sago starch was considered to have excellent noodle-making qualities and was therefore used in the production of Chinese vermicelli (cellophane noodles) using the pressurized extrusion method (Takahashi et al. 1985). Chinese vermicelli made from sago starch was found to be transparent, desirably firm, and nonsticky. In the sensory evaluation, sago starch vermicelli was rated higher than commercially available vermicelli in terms of appearance, texture, and overall evaluation. Due to this, sago starch can be considered as a viable ingredient in Chinese vermicelli. The addition of soybean protein isolate (5%) to sago starch had further positive effects. It was found to inhibit solubility and produce noodles that resembled commercially available Chinese-made vermicelli (Takahashi and Hirao 1992).

5. *Kuzukiri/fen pi*

Fen pi is a mung bean starch sheet that is used in Chinese cooking. In Japan it is known as *kuzukiri* or *suisen* and is eaten as a chilled dessert with black honey or roasted soybean flour. Generally, kudzu, potato, or sweet potato starches are used as

primary ingredients with characteristics such as quality of texture, chewiness, and ability to blend well with required toppings or seasonings. Based on this information, *fen pi* made from sago starch, which gels easily and has a strong internal binding force, was investigated. The product was found to have a hardness that was similar to potato starch *fen pi*, harder than kudzu starch *fen pi*, and approximately half that of mung bean *fen pi*. In the sensory evaluation, it was favored in terms of adhesiveness, ease of expansion, and in the overall evaluation (Ohya et al. 1990).

6. *Gomadofu* (sesame curd)

Gomadofu is made of kudzu starch and ground sesame seeds, which are heated and gelatinized. It is one of the most essential dishes for a vegetarian diet. Samples were prepared with sago starch or kudzu starch and 30% soybean flour, instead of ground sesame seeds. It was found that sago starch was a good substitute for kudzu starch (Takahashi and Hirao 1994).

7. *Kamaboko* (boiled fish paste)

In order to determine the effects of heating on the physical properties of gel, sago starch and potato starch were added to frozen Alaska pollack paste and prepared in two ways – heating at 80 °C for 20 min and heating at 30 °C for 30 min and then 80 °C for 20 min. The network structure of fish paste gel was investigated using a low vacuum scanning electron microscope. In the gel containing sago starch, the starch particles could be observed, but they were smaller than those of potato starch. This proved that the ability of sago starch to gelatinize is lower than that of potato starch (Sompongse et al. 2006a).

Sago starch frozen fish paste gel was additionally examined by comparing two two-step cooking methods (90/80 °C). At 90 °C the gel was harder and the starch particles in the gel were larger than when heated at 80 °C. Due to this, it was clearly determined that when sago starch is added to frozen fish paste, it should be heated at a final temperature of 90 °C in order to attain a gel with a similar structure to that of frozen fish paste containing potato starch (Sompongse et al. 2006b).

8. *Warabimochi* (bracken starch pastry)

Warabimochi is a Japanese dessert that is popular for its transparent appearance and its smooth texture both on the tongue and when swallowing. Traditional *warabimochi* is made from bracken starch. However, due to its recent rise in price, nowadays commercially sold bracken starch consists mostly of sweet potato starch. For this reason it was decided to use sago starch to prepare *sagomochi*. The end product had better color, cutting quality, firmness, and biting quality than traditional *warabimochi*. As previously mentioned, transparency is an important aspect of *warabimochi*, and in this parameter too, sago starch was superior to sweet potato starch as its distinctive pink tinge went well with the yellowish soybean flour which is sprinkled on top of the dessert. *Sagomochi* can be readily prepared at home. The key point in preparation of *sagomochi* from sago starch is to keep stirring it at high temperatures to promote gelatinization so that the end product has favored characteristics such as high viscoelasticity, good texture on the tongue, and slow retrogradation (Takahashi and Hirao 1994; Hamanishi et al. 2002a).

9. *Kuzuzakura* (kudzu starch pastry)

Kuzuzakura is a transparent dessert that is eaten in early summer. It is necessary for the starch pastry to be easy to make and for it to form well around the adzuki bean paste filling. Usually kudzu starch is used in making *kuzuzakura*; however, as has previously been reported, by mixing kudzu starch and potato starch to a ratio of 3:1, a highly workable *kuzuzakura* can be produced (Teramoto and Matsumoto 1966). Using the aforementioned *kuzuzakura* as a reference, it was decided to make *kuzuzakura* using 100% sago starch. The sago starch product was found to be superior in terms of ease of production, formability, and shape retention. In the sensory evaluation, sago starch was found to produce a *kuzuzakura* that was smoother and springier than the reference and highly preferred in terms of transparency, color, and cutting quality. The low fluidity and syneresis plus the high viscoelasticity and transparency of sago starch give it the maneuverability, formability, and shape retention that are required for *kuzuzakura* production. Sago starch forms a soft gel that achieves the right balance of firmness between the pastry and the filling (Takahashi and Hirao 1994).

10. *Nama-yatsushashi* (raw cinnamon-flavored dumplings)

Yatsushashi is a popular confection in Kyoto. There are two basic forms, *nama-yatsushashi* which has a soft mouth feel and *yaki-yatsushashi*, which is baked *yatsushashi* and is hard and cookie-like. *Nama-yatsushashi* are thin squares of cinnamon-scented sticky rice dough with non-glutinous rice flour or glutinous rice flour being key ingredients. The effect of partially substituting these ingredients with sago starch was investigated. It was found that as the amount of substituted sago starch was increased, a harder gel was created with both non-glutinous rice flour and glutinous rice flour. It was also found that when sago starch replaced 30% of non-glutinous rice flour and 50% of glutinous rice flour, a product with more adhesiveness resulted. Furthermore, in the sensory evaluation, when 50 or 70% of non-glutinous rice flour was replaced with sago starch, differences in color, firmness, and elasticity were revealed, and it was preferred in terms of elasticity and overall evaluation. This clearly proved that the usage of sago starch in *nama-yatsushashi* is effective (Kondo et al. 2013).

11. *Mushiyokan*

Mushiyokan, which is made from kudzu starch or wheat flour mixed with adzuki bean paste, is enjoyed for its thick texture. *Mushiyokan* made using sago starch is softer and less sticky than that made of kudzu starch and rated on a par with kudzu *mushiyokan* in terms of color, sweetness, taste, springiness, and overall assessment (Hamanishi et al. 2002b).

12. Pie filling

Pie filling refers to the contents that are poured into baked piecrust. It requires good shape retention and it is important for it to be able to be cut cleanly. Conventionally, cornstarch or wheat flour is used to gain these characteristics, but

they have a shortcoming for fast retrogradation and syneresis during low-temperature storage. Due to these facts, the potential for sago starch to be used as a substitute for cornstarch and wheat flour was investigated. Filling made from sago starch with the addition of egg yolk powder (equivalent to 20% of sago starch) had low syneresis and good shape retention. Furthermore, it rated better than cornstarch filling in terms of firmness, springiness, and overall evaluation, thus proving that sago starch can also be reliably used as an ingredient in pie filing (Hirao et al. 2005).

13. Blancmange

The English-style blancmange is a pudding made of a mixture of cornstarch, sugar, and milk which is heated and gelatinized. When sago starch was substituted for cornstarch, it gave the blancmange less syneresis, better shape retention, less stickiness, and a better feel on the tongue (Hirao et al. 1998). Immediately after preparation, the sago gel was soft, was supple, and lacked adhesiveness. However, by cooling the gel at 5 °C for 24 h, it retained its shape to a much more sufficient degree (Hirao et al. 2002, 2003a). The addition of cocoa or green tea powder improved shape retention of the sago starch blancmange, and its taste, hardness, smoothness, and overall rating in sensory evaluation were valued highly (Hirao et al. 2003b).

14. Biscuits

Biscuits are a baked confection with flour, butter, sugar, and milk used as basic ingredients. Some biscuits are made with starch acting as a partial replacement for flour. When 50% of the flour was replaced with sago starch, the biscuits exhibited higher swelling ability, softness, and fracturability than potato or cornstarch biscuits. These characteristics intensified as the ratio of sago starch increased, with 50% showing the highest improvement. Sensory evaluation found that biscuits with partial sago starch substitution were more crumbly than wheat-only biscuits and were given significantly higher preference in terms of form, taste, hardness, fracturability, feeling on the tongue, and overall evaluation. The 50% substitution was especially preferred. Furthermore, even when a low amount of butter was used, as the amount of substituted sago starch used was increased, the biscuit became less crumbly. This condition was maintained until the amount of butter used was reduced by as much as half. Sago starch cookies using egg instead of baking powder and milk were found to have the same level of hardness but were 3–4 times more crumbly (Hirao et al. 2004).

21.4 Conclusion

In terms of its gelatinization behavior, sago starch was found to be similar to potato, cassava, and sweet potato starch. In terms of retrogradation and amylose content, sago starch was similar to cornstarch. It was clearly proved that sago starch could be used in various types of cooking and food manufacturing, as when it was used as a replacement for other starch types, the products attained had an agreeable taste. Gel

made from sago starch had satisfactory degrees of elasticity, softness, flexibility, and adhesiveness. Furthermore, the usability of sago starch in puffed foods was clearly proven. In all the foodstuffs in this study, the sago starch versions had superior physical properties and in sensory evaluations were valued to have favorable tastes and textures. The possibility of the further development of sago starch-based foodstuffs is increasing (Hirao 2015). Presently, in Japan, sago starch is imported and used in the production of foodstuffs such as oxidized starch and as a dusting powder for various noodle types. However, research on the usage and effects of processed sago starch is now underway.

Sago palm and sago starch are now being widely seen as a valuable natural food resource and a plant resource that can help maintain the natural environment of planet earth. Sago is being increasingly considered to be an essential plant for overcoming many twenty-first century problems such as global warming, environmental destruction, and rampant deforestation in the tropic regions and for combatting hunger problems that frequently occur in developing countries and due to rapid world population increase (Kainuma 2015; Yamamoto 2015).

In Japan too, the appeal of the up-to-now unused resource, that is, sago starch, is being widely spread, and its potential use in cooking and manufacturing foodstuffs is being further considered (Kondo 2014; Hirao 2016). Sago starch is an ingredient that has the potential to make the lives of people all over the world more fulfilling and colorful. Research into sago starch deserves to be continued.

References

- Bujang KB, Ahmad FB (2000) Production and utilization of sago starch in Malaysia. *Sago Comm* 11:1–6
- Hamanishi T (2002) Studies on physicochemical properties of sago starch obtained at different growth stages of the trunk and cooking characteristics of sago starch. Kyoritsu Women's University ph. D. Thesis, pp 73, 95 (in Japanese)
- Hamanishi T, Hirao K, Nishizawa Y et al (2002a) Physicochemical properties of sago starch compared with various commercial starches. In: Kainuma K, Okazaki M, Toyoda Y, Cecil JE (eds) *New frontiers of sago palm studies: proceedings of the international symposium on sago*. Universal Academy Press, Tokyo, pp 289–292
- Hamanishi T, Matsunaga N, Hirao K et al (2002b) Cooking and processing properties of the traditional Japanese confection, kudzumushbiyokan, made from sago starch. *J Cook Sci Jpn* 35:287–296. (in Japanese)
- Hatta T, Nemoto S, Hamanishi T et al (2002) Uppermost surface structure of sago starch granules. In: Kainuma K, Okazaki M, Toyoda Y, Cecil JE (eds) *New frontiers of sago palm studies: proceedings of the international symposium on sago*. Universal Academy Press, Tokyo, pp 349–354
- Hirao K (2015) Development of sago starch foods using sensory evaluation. *Jpn J Sens Eval* 19:2–11. (in Japanese)
- Hirao K (2016) The physicochemical properties and cooking aptitude of the sago starch. *Sugar Starch Info* 45(6):40–51. (in Japanese)
- Hirao K, Takahashi S (1996) Studies on cooking of pearl-type starch. Part 3. Cooking method of sago pearls. *Sago Palm* 4:14–20 (in Japanese)

- Hirao K, Igarashi Y, Takahashi S (1998) Cooking and processing quality of sago starch gel. Part 3. Effects of ingredients ratio of soybean protein isolate and soybean oil on the rheological properties of starch gel. *Sago Palm* 6:1–9 (in Japanese)
- Hirao K, Hamanishi T, Igarashi Y, Takahashi S (2002) Effect of the ingredient ratio of sago starch, soybean protein isolate and soybean oil on the physical properties and sensory attributes of blanchmange. *J Home Econ Jpn* 53:659–669 (in Japanese)
- Hirao K, Watanabe T, Takahashi S (2003a) Effects of added soybean protein isolate and soymilk powder on the physical properties and sensory evaluation of a blanchmange type of starch gel (part 1) effects of additive concentration and addition method. *J Home Econ Jpn* 54:457–468 (in Japanese)
- Hirao K, Watanabe T, Takahashi S (2003b) Effects of added soybean protein isolate and soymilk powder on the physical properties and sensory evaluation of a blanchmange type of starch gel (part 2) effects of adding cocoa and powdered green tea. *J Home Econ Jpn* 54:469–476 (in Japanese)
- Hirao K, Kanamori K, Yoneyama Y, Takahashi S (2004) Physical and sensory properties of biscuits containing partially replaced sago starch. *J Home Econ Jpn* 55:715–723. (in Japanese)
- Hirao K, Takei F, Yoneyama Y, Takahashi S (2005) Effect of adding egg yolk powder on the physiochemical properties of sago starch. *J Home Econ Jpn* 56:49–54. (in Japanese)
- Hirao K, Tanaka H, Konoo S et al (2008) The present condition of sago starch using method and processed foods in Riau, Indonesia. In: *Proceedings of the 17th conference of the society of sago palm studies*, pp 75–78 (in Japanese)
- Kainuma K (1982) Utilization of sago palms in Sarawak, South Kalimantan and Papua New Guinea. *Jpn J Trop Agri* 26:177–186
- Kainuma K (2015) Potential use of sago starch. In: *The sago palm, the food and environmental challenges of the 21st century*. Kyoto University Press, Tokyo, pp 289–295
- Kainuma K, Matsunaga A, Itakawa M, Kobayashi S (1981) New enzyme system - β -amylase and-pullulanase—to determine the degree of gelatinization and retrogradation of starches or starch foods. *J Jpn Soc Starch Sci* 28:235–240 (in Japanese)
- Kondo T (2014) Properties of sago starch and utilization to prepared foods of sago starch. *Prep Foods Techn* 20:65–79 (in Japanese)
- Kondo T (2015) Utilization of sago palm starch. In: *The sago palm, the food and environmental challenges of the 21st century*. Kyoto University Press, Tokyo, pp 259–289
- Kondo T, Hirao K, Takahashi S (2013) Effect on Chinese noodles of using sago starch. *J Cook Sci Jpn* 46:93–99 (in Japanese)
- Miyazaki T (1999) Cooking characteristics of sago starch: its physical properties by sago starch types and the breaking properties of sago noodles. Kyoritsu Women's University Faculty of Home Economics 1999 graduation thesis
- Nishimura Y (2008) Present sago palm situation in Mindanao, Philippines. *Proceeding of the 17th conference of the society of sago palm studies*, pp 31–36 (in Japanese)
- Ohya C, Takahashi S (1987) Application of sago starch to baked foods. *J Cook Sci Jpn* 20:362–370. (in Japanese)
- Ohya C, Takahashi S, Watanabe T (1990) Texture evaluation of fenpi made of sago starch by physical and sensory method. *J Cook Sci Jpn* 23:293–301. (in Japanese)
- Puchongkavarin H, Shonbsngob S, Nuyim et al (2000) Production of alkaline noodles produced from the partial substitution of wheat flour with sago starch. *Sago Comm* 11:7–14
- Sato T, Yamaguchi T, Takamura T (1979) Cultivation, harvesting and processing of sago palm. *Jpn J Trop Agri* 23:130–136. (in Japanese)
- Sompongse W, Morioka K, Yamamoto Y, Itoh Y (2006a) Comparison of the effect of sago starch and potato starch on the texture properties of gels cooked from walleye pollack frozen surimi. *Sago Palm* 14:45–52
- Sompongse W, Morioka K, Yamamoto Y, Itoh Y (2006b) Effect of the heating temperature on the of textural properties of sago starch-containing gels cooked from walleye pollack frozen surimi. *Sago Palm* 14:53–58

- Takahashi S, Hirao K (1992) Food-cultural studies on cooking and processing properties of sago starch. *Bull Facul Home Econ, Kyoritsu Women's University* 38:17–23 (in Japanese)
- Takahashi S, Hirao K (1994) Studies on the physical and the chemical properties of sago starch, and its performance when used in the preparation of Japanese sweets. *Bull Facul Home Econ, Kyoritsu Women's University* 40:59–64 (in Japanese)
- Takahashi S, Kitahara H, Kainuma K (1981) Chemical and physical properties of starches from mung bean and sago. *J Jpn Soc Starch Sci* 28:151–159 (in Japanese)
- Takahashi S, Kobayashi R, Watanabe T, Kainuma K (1983) Effects of addition of soybean protein on gelatinization and retrogradation of starch. *J Food Sci Techn* 30:276–282 (in Japanese)
- Takahashi S, Hirao K, Kawabata A, Nakamura M (1985) Effect of preparation methods of starches from mung beans and broad beans and preparation method of noodles on the physico-chemical properties of harusame noodles. *J Jpn Soc Starch Sci* 30:257–266 (in Japanese)
- Takahashi S, Hirao K, Kainuma K (1995) Physicochemical properties and cooking quality of sago starch. *Sago Palm* 3:72–82 (in Japanese)
- Teramoto Y, Matsumoto F (1966) Studies on the cooking quality of various starch (pt.1) kudzu dumpling. *J Home Econ Jpn* 17:384–388. (in Japanese)
- Yamamoto Y (2015) Preface. In: *The sago palm, the food and environmental challenges of the 21st century*. Kyoto University Press, Tokyo, pp 29–32
- Yamamoto Y, Yoshida T, Yanagidate I et al (2008) Sago palm and its utilization in Ambon and Seram Island, Maluku Province, Indonesia. In: *Proceedings of the 17th conference of the society of sago palm studies*, pp 17–22 (in Japanese)
- Yokota T, Kondo T, Hirao K, Takahashi S (2015) Physical properties and sensory attributes of Japanese udon noodles made from sago starch, the 12th international symposium 2015. *Sago Palm* 23:46

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