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Quality improvement of boba from sago flour supplemented with inulin using electron beam

Leelawat, B.[1*], Thongwattananun, S.[1] , Jaroenjun, N.[1] and Sajjabut, S.[2,]

[1]Division of Food Science and Technology, Faculty of Science and Technology, Thammasat University, Center of Excellence in Food Science and Innovation, Pathumthani 12121, Thailand; [2]Nuclear Technology Research and Development Center, Thailand Institute of Nuclear Technology, Nakhon Nayok, Thailand.

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Abstract The results indicated that increasing the proportion of sago flour led to increase in hardness and gumminess, as well as increased in redness (a*) and yellowness (b*). In terms of sensory evaluation, the 70:30 formula were not significantly differed from the control formula in all attributes. The addition of inulin at various levels was then studied, including 2.5%, 5%, 7.5%, and 10% by flour weight. The higher ratios of inulin addition resulted to increase hardness, lightness, (L*), and water activity. The 7.5% inulin addition received the highest overall liking score from the sensory test. Afterward, the 70:30 formula with 7.5% inulin was subjected to electron beam irradiation at doses of 2, 4, 6, 8, and 10 kGy. As the dose increased, it increased in both hardness and gumminess. The doses at 6 kGy decreased in the total plate count (TPC) of untreated Boba. The Boba texture was improved by investigating the incorporation of modified starch (MS) at 5%, 10%, 15%, and 20% by flour weight along with the 6 and 8 kGy irradiation. The hardness and gumminess of Boba with 10% and 20% MS at 6 kGy and 20% MS at 8 kGy were not significantly differed from the control ($p > 0.05$) and the Boba with 20% MS at 8 kGy received the highest liking score.

Keywords: Milk tea, Boba, Sago, Electron beam, Irradiation, Inulin

Introduction

Bubble milk tea is a popular beverage worldwide, originating from Taiwan. Thailand has the highest consumption of bubble milk tea in Southeast Asia, with an average of 6 cups per person per month. However, bubble milk tea contains BobaBoba, or tapioca pearl made from cassava flour composed of mainly carbohydrate. These flours are mixed with hot water, kneaded to form round balls approximately 1 centimeter in diameter, and generally require a relatively long cooking time of about 20-30 minutes (Leelawat *et al.,* 2020).

[*] **Corresponding Author:** Leelwat, B. ; **Email:** jafood@hotmail.com

Sago palm is an economic plant in ASEAN, it is predominantly found in the southern region of Thailand. Sago palm serves as a source of carbohydrates and also contains dietary fiber, minerals, and vitamins as nutritional components that provide energy to consumers. Sago palm contains a high percentage of starch (approximately 88%) and its content of amylose ranges from 21.4% to 30%. It has excellent foaming capacity, a high gelatinization temperature, and low viscosity; therefore, it provides good stability to the product (Zhu, 2019). However, raw sago flour contains initial levels of various pathogenic bacteria such as *Escherichia coli*, *Salmonella sp., Bacillus cereus, S. aureus* , and *L. Monocytogenes* as high as 2.5×10^5 cfu/g (Shipton *et al*., 2013).

Prebiotic is a type of dietary fiber derived from natural sugars, which is beneficial to health by stimulating and promoting the growth of probiotic bacteria. Consumption of some probiotic foods has been associated with the absorption of micronutrients like calcium and iron from ingested foods. This research is interested in using inulin to enhance the nutritional value of BobaBoba. Inulin plays a role in increasing viscosity, acts as a gelling agent, and helps improve sensory attributes. Additionally, it has the potential to reduce blood sugar levels, lower cholesterol, and decrease blood fat levels. (El-Kholy *et al*., 2020).

Food irradiation is one of the food preservation methods of non thermal processing , also known as the "cold process". This technique can better preserve the nutritional value of food products compared to using high heat. The World Health Organization (WHO) has certified that irradiated food is safe for consumption and is an effective method of food preservation. Food irradiation is the use of energy from electromagnetic waves, whether packaged or not, to achieve specific objectives, such as extending shelf life, reducing the quantity of food-degrading and disease-causing microorganisms, and inhibiting sprouting, among other purposes. The Food and Drug Administration (FDA) currently permit the use of three types of radiation in food: gamma, X-ray, and electron beam, in quantities specified according to the intended purpose of use (Tilokkul *et al*., 2021).

Based on the benefits of sago flour, prebiotic, and the irradiation process mentioned above, this research on the development of quality improvement of Boba from sago flour supplemented with inulin using an electron beam has commenced. The objectives were to enhance the nutritional value and to reduce the microbial load in sago flour.

Materials and methods

Organic sago flour (Phatthalung province, Thailand), Cassava starch (Thai fish 5 stars brand), Inulin (Krungtephchem Co., Ltd), Syrup (Mitr Phol brand), Modified starch (Kreation® NE from Questex Co., Ltd.) and Taiwan milk tea powder (Red Leaf brand) were used in the experiments.

Preparation of Boba

60 grams of cassava starch was mixed with 45 ml of boiling water (100°C) using mixer (Kenwood KVL4100S, China) at speed 2 until it formed a uniform dough. Then, the dough was fed into an automatic Boba-forming machine (LD-88A/8 mm, China) to form fresh Boba with an approximate diameter of 0.8 millimeters. Afterward, the Boba was dried at 65 °C for 40 minutes and kept at 4°C in the refrigerator before analysis (Tilokkul *et al.,* 2021).

Boiling Boba before analysis

The dried Boba was cooked in boiling water at approximate 90°C for 20 minutes. Then, turn off the heat and let it stand in a pot with a closed lid for another 10 minutes. The Boba was strained and washed under running water. Afterward, it was steeped in syrup (36 °Brix) to prevent the Boba from sticking to one another and to increase their sweetness (Ketphet and Vatthanakul, 2021).

Determination of the optimum ratio of cassava starch and sago flour

The Boba from the mixture of cassava starch and sago flour was prepared by following the method of Boba preparation as mentioned above. The 5 ratios of cassava starch and sago flour were studied as 100:0, 70:30, 60:40, 50:50, and 0:100 by weight, as shown in Table 1. The optimum formulation was selected based on texture profile analysis, color (L*, a*, b*), and sensory evaluation using 9-point hedonic scale.

Table 1. Quantity of cassava starch, sago flour and water for Boba preparation

Ratio	Quantity (grams)		
	Cassava starch	Sago flour	Water
100 : 0	60	-	45
70 : 30	42	18	45
60 : 40	36	24	45
50 : 50	30	30	45
0 : 100	0	60	45

Determination of the optimum percentage of inulin supplementation

The Boba with the optimum ratio of cassava starch and sago flour was selected to find the optimum percentage for inulin supplementation. The formulation demonstrated in Table 2 was used to study the four inulin ratios of 2.5%, 5%, 7.5%, and 10%. The optimum formulation for inulin supplementation was selected from texture profile analysis, water activity (a_w) using water activity meter (CX2, Aqua Lab, USA), and sensory evaluation using 9-point hedonic scale.

Table 2. Quantity of cassava starch, sago flour, water and inulin for inulin supplementation of Boba

The percentage of inulin content	**Quantity (grams)**			
	Cassava starch	Sago flour	water	Inulin
2.5	42	18	45	1.5
5	42	18	45	3
7.5	42	18	45	4.5
10	42	18	45	6

Effect of electron beam radiation dose on Boba properties

The dried Boba was placed in a laminated bag made of PET and PE and stored at a freezer temperature of -18 °C for 24 hours before being exposed to radiation (Tilokkul *et al*., 2021). The radiation treatment was conducted by Thailand Institute of Nuclear Technology (Public Organization), located in Pathum Thani, Thailand. The Boba was irradiated by electron beam at levels of 2, 4, 6, 8, and 10 kGy. The optimum level of electron beam was chosen from the texture profile analysis, color (L*, a*, b*), water activity (a_w), total plate count (TPC), and sensory evaluation using 9-point hedonic scale.

Determination of the optimum percentage of modified starch

Boba samples were prepared according to the optimum ratio of cassava starch, sago flour, and the inulin obtained from the previous experiments. The cassava starch was substituted with 4 levels of modified starch (0-20%) to improve the Boba texture, as shown in Table 3, and then subjected to electron irradiation using the optimum dose of electron beam irradiation from previous experiment. The optimum percentage of modified starch was selected by considering from the texture profile analysis and the sensory evaluation using 9-point hedonic scale.

Determination of textural properties

The texture of Boba sample was performed by Texture Profile Analysis as described by Tilokkul *et al.* (2021) with modification, using a TA-XT2i (Stable

Micro Systems, UK), equipped with cylinder probe P/50. The TPA settings were pre-test, test, and post-test speed of 1, 5, 5 mm/s, respectively with 50% strain. Hardness, springiness, cohesiveness and gumminess were obtained from the TPA curves for each sample.

Table 3. Quantity of cassava starch, sago flour, inulin and modified starch for texture improvement of Boba

The percentage of modified starch content	Quantity (grams)			
	Cassava starch	Sago flour	modified starch (MS)	Inulin
0	42.0	18	0	7.5
5	39.9	18	2.1	7.5
10	37.8	18	4.2	7.5
15	35.7	18	6.3	7.5
20	33.6	18	8.4	7.5

Determination of Boba color

Color of Boba samples was measured using colorimeter (Hunter Lab model, CX2687, Hunter Lab, USA). The color measurements were determined according to the CIELAB system. Color was expressed as L* (100 = white; 0 = black), a* (+, redness; -, greenness), and b* (+, yellowness; -, blueness). Each experiment was repeated three times.

Sensory evaluation

The sensory evaluation was performed using the 9-Point Hedonic Scale method using 34 panelists. Samples were evaluated to rate the liking of quality attributes according to appearance, color, flavor, taste, texture, and overall acceptability using a 9-point hedonic scale (1 = dislike extremely and 9 = like extremely). Each sample consisted of 2 pieces of Boba and 10 mL of syrup (36 ^{o}Brix) and was placed in plastic cups. A three-digit code number was assigned for each sample.

Determination of total plate count

The analysis of Total Plate Count was conducted according to U.S. Food and Drug Administration BAM Chapter 3 (2001) by the Chemistry and Microbiology Laboratory of Bureau Veritas AQ Lab Thailand Co., Ltd.

Results

The physical properties of Boba from various ratios of cassava starch and sago flour, including color (L*, a*, and b*) and texture properties, were shown in Table 4. It was found that an increase in the proportion of sago flour led to a significant increase ($p \leq 0.05$) in the values of the redness (a*) and yellowness (b*) color parameters. These changes were visually observable and can be attributed to the original color of sago flour, which has a brownish hue. In terms of texture properties, it was observed that an increase in the proportion of sago flour resulted in a significant increase ($p \leq 0.05$) in both hardness and gumminess. The ratio of cassava starch to sago flour of 0:100 had the highest hardness and gumminess.

Table 4. Physical properties of Boba from various ratios of cassava starch and sago flour

CS: SF[/1]	Color			Texture properties	
	L*	a*	b*	Hardness (g_f)	Gumminess (g_f)
100:0	$11.61^b \pm 0.01$	$-0.20^d \pm 0.01$	$-1.53^d \pm 0.10$	$91.21^e \pm 0.18$	$78.08^d \pm 1.31$
70:30	$8.52^d \pm 0.01$	$1.24^c \pm 0.01$	$0.34^c \pm 0.12$	$126.33^d \pm 1.01$	$111.09^c \pm 2.13$
60:40	$8.77^d \pm 0.01$	$1.47^c \pm 0.01$	$0.57^c \pm 0.01$	$168.26^c \pm 3.36$	$144.42^b \pm 2.31$
50:50	$9.21^c \pm 0.01$	$2.90^b \pm 0.01$	$1.89^b \pm 0.01$	$188.95^b \pm 7.66$	$152.37^b \pm 8.10$
0:100	$12.66^a \pm 0.01$	$4.54^a \pm 0.01$	$3.95^a \pm 0.01$	$244.77^a \pm 3.32$	$209.77^a \pm 7.30$

[a,b,c] Mean values in a column with different letters are significantly different ($p \leq 0.05$)

[/1] CS = Cassava starch, SF = Sago flour

The 9-point hedonic scale sensory evaluation of Boba from various ratios of cassava starch and sago flour is shown in Figure 1. The 70:30, 60:40, 50:50 and 0:100 Boba formula received lower liking scores in all aspects than the control formula (100:0). The 70:30 Boba formula, which had received the highest overall acceptability score of 7.21 (like moderately to like very much), gave higher liking scores in all aspects than the 60:40, 50:50, and 0:100. The 70:30 Boba formula was therefore chosen to be further investigated in inulin supplementation experiments owing to its resemblance to the hardness and gumminess of the control formula, along with the sensory assessment result.

The color (L*, a*, and b*) and texture properties of the 70:30 Boba formulation with different percentages of inulin are shown in Table 5. The brightness values (L*) significantly increased with the increase of inulin addition, whereas the redness values (a*) showed no significant difference, and the yellowness values (b*) did not exhibit a trend of change with inulin addition. Regarding texture properties, the increase in inulin addition significantly increased Boba's hardness ($p \leq 0.05$), but there was no obvious pattern for gumminess. Boba with 10% inulin addition had the highest hardness and gumminess value.

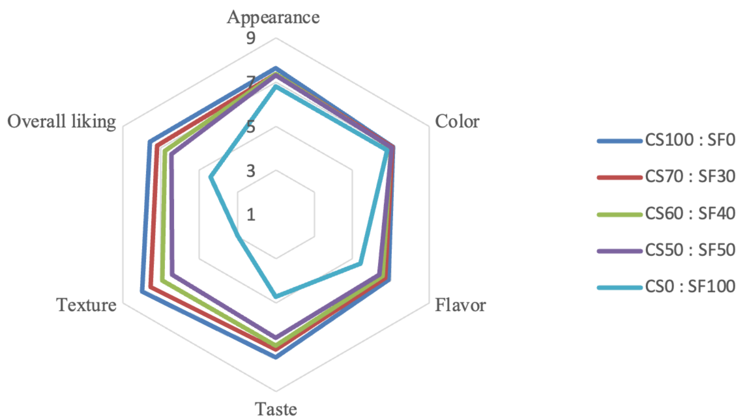

Figure 1. Sensory evaluation of Boba from various ratios of cassava starch and sago flour

Table 5. Color and texture properties of the 70:30 Boba formulation with different percentages of inulin

Inulin	Color			Texture properties	
	L*	a* ns	b*	Hardness (g_f)	Gumminess (g_f)
2.5%	15.84[c] ± 0.10	4.88 ± 0.12	3.35[d] ± 0.20	150.17[c] ± 1.45	130.78[c] ± 1.31
5%	16.28[c] ± 0.14	4.45 ± 0.49	8.51[a] ± 0.33	168.01[b] ± 6.25	139.42[b] ± 2.13
7.5%	17.34[b] ± 0.20	4.61 ± 0.33	7.34[b] ± 0.08	168.14[b] ± 5.34	137.95[bc] ± 2.31
10%	20.27[a] ± 0.50	4.34 ± 0.28	4.79[c] ± 0.45	180.03[a] ± 2.72	147.48[a] ± 8.10

[a,b,c] Mean values in a column with different letters are significantly different ($p \leq 0.05$)
[ns] Mean values are not significantly different ($p > 0.05$)

The water activity (a_w) of the 70:30 Boba formulation with different percentages of inulin are shown in Table 6. there was no significant difference among the Boba with different percentages of inulin ($p > 0.05$).

Table 6. Water activity (a_w) of the 70:30 Boba formulation with different percentages of inulin

Inulin	Water activity ns (a_w)
2.5%	0.983 ± 0.01
5%	0.984 ± 0.01
7.5%	0.986 ± 0.01
10%	0.987 ± 0.01

[ns] Mean values are not significantly different ($p > 0.05$)

The sensory evaluation of the 70:30 Boba formulation with different percentages of inulin is shown in Figure 2. The panelists rated the appearance, color, taste, and texture of the 2.5-7.5% inulin addition as not significantly different ($p > 0.05$). The Boba with a 10% inulin addition received the lowest flavor score of 5.21 (neither liked nor disliked). According to the highest overall liking score of 7.23 (from like moderately to like very much) of Boba with 7.5% inulin addition, this formulation was selected for further study in the determination of the optium dose for electron irradiation.

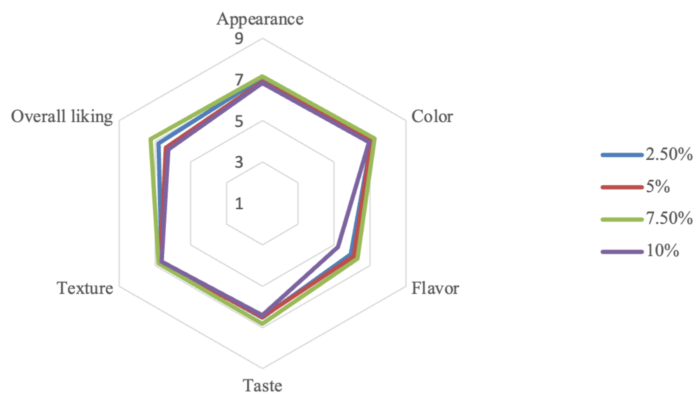

Figure 2. Sensory evaluation of of the 70:30 Boba formulation with different percentages of inulin

The results of texture properties and the analysis of Total Plate Count (TPC) with the various doses of electron irradiation (0 - 10 kGy) of the 70:30 Boba formulation with 7.5% inulin addition are shown in Table 7. It was found that as the amount of irradiation increased, the hardness and gumminess of Boba significantly increased ($p \leq 0.05$). The Boba that was irradiated at 10 kGy demonstraed the highest hardness and gumminess. However, the Boba with 2 kGy electron beam irradiation was not significantly different from the control one ($p > 0.05$). From the analysis of total plate count (TPC), it was found that as the dose of irradiation increased, the total number of microorganisms tended to decrease. The initial TPC in Boba before the electron irradiation was 1.8 x 10^7 cfu/g; the TPC of Boba was noticeably reduced to less than 10 cfu/g at the maximum dose of 10 kGy.

The sensory evaluation of 70:30 Boba formulation with 7.5% inulin addition irradiated with electron beam at various levels is shown in Figure 3. It was found that the appearance, color, flavor, taste, texture, and overall acceptance attributes were scored highest at the dose of 2 kGy with an overall acceptability score of 6.44 (liked slightly), which is consistent with the analysis results of texture properties in that the texture properties of 2 kGy Boba did not significantly differ from the control formulation.

Table 7. Texture properties and Total plate count (TPC) of the 70:30 Boba formulation with 7.5% inulin addition at different doses of electron irradiation

Irradiation Dose (kGy)	Texture properties		TPC (cfu/g)
	Hardness (g_f)	Gumminess (g_f)	
Control	$160.43^{e} \pm 5.43$	$131.81^{e} \pm 2.12$	1.8×10^{7}
2	$169.91^{e} \pm 2.39$	$123.89^{e} \pm 4.95$	1.8×10^{6}
4	$217.10^{d} \pm 4.75$	$174.62^{d} \pm 5.92$	3.4×10^{6}
6	$333.85^{c} \pm 6.87$	$262.49^{c} \pm 3.99$	7.2×10^{3}
8	$349.62^{b} \pm 7.76$	$294.90^{b} \pm 7.80$	8.7×10^{2}
10	$453.20^{a} \pm 6.76$	$325.54^{a} \pm 5.72$	< 10

[a,b,c] Mean values in a column with different letters are significantly different ($p \leq 0.05$)
[ns] Mean values are not significantly different ($p > 0.05$)

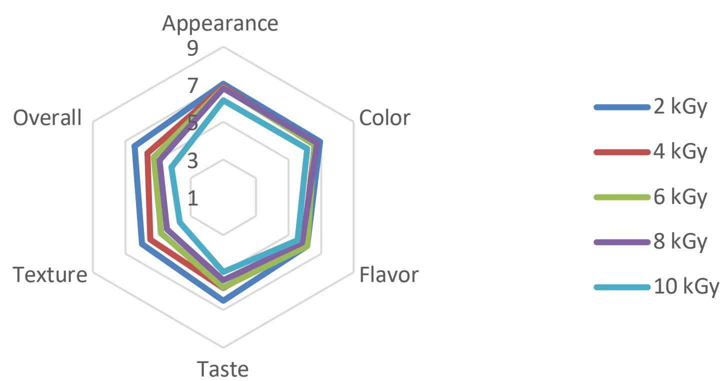

Figure 3. Sensory evaluation of the 70:30 Boba formulation with 7.5% inulin addition at different doses of electron irradiation

The results of the texture profile analysis (TPA) of the 70:30 Boba formulation with 7.5% inulin addition at different levels of modified starch (MS) with 0, 6 and 8 kGy of electron irradiation are shown in Table 8. It was found that the hardness and gumminess of the Boba with 10% modified starch at 6 kGy irradiation, 20% modified starch at 6 kGy irradiation, and 20% modified starch at 8 kGy irradiation were not significantly different from the control formulation ($p > 0.05$). Additionally, it became apparent that the hardness and gumminess values of Boba with 0-15% MS at the same irradiation dose reduced as the proportion of MS increased. However, the increase in the MS at the 20% level caused a highly significant increase in both hardness and gumminess. Furthermore, it was observed that the Boba with 20% modified starch at 6 and 8 kGy irradiation showed no significant differences with the control formulation ($p > 0.05$).

Table 8. Texture properties of 70:30 Boba formulation with 7.5% inulin addition at different levels of modified starch (MS) with 0, 6 and 8 kGy of electron irradiation

[/1]MS (%)	Dose (kGy)	Texture properties	
		Hardness (g_f)	Gumminess (g_f)
0*	0*	160.43^{e} ± 5.43	131.81^{de} ± 3.23
0	6	333.86^{b} ± 6.87	262.49^{b} ± 3.89
0	8	349.62^{a} ± 7.46	294.90^{a} ± 7.80
5	6	196.53^{d} ± 6.57	132.14^{de} ± 7.59
5	8	315.03^{c} ± 15.85	194.01^{c} ± 10.31
10	6	165.11^{e} ± 3.60	120.42^{e} ± 12.62
10	8	137.46^{f} ± 8.61	92.18^{f} ± 15.24
15	6	124.57^{g} ± 4.66	95.76^{f} ± 1.71
15	8	92.93^{h} ± 4.33	62.42^{g} ± 3.99
20	6	166.41^{e} ± 3.72	129.80^{de} ± 15.67
20	8	165.09^{e} ± 3.56	149.23^{e} ± 21.01

[a,b,c] Mean values in a column with different letters are significantly different ($p \leq .05$)

[/1] MS = Modified Starch, * = the control formulation

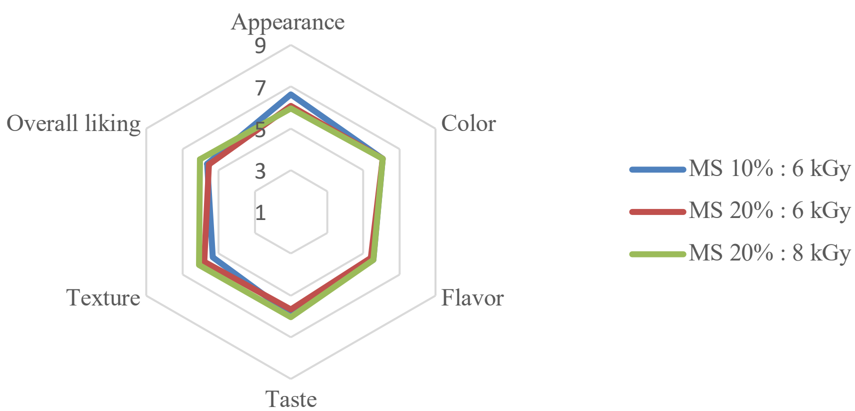

Figure 4. Sensory evaluation of 70:30 Boba formulation with 7.5% inulin addition and different percentages of modified starch at electron irradiation of 6 and 8 kGy

The sensory evaluation was taken into consideration in addition to the textural characteristics (hardness and gumminess) of the samples as the criteria in selecting the Boba samples. To conduct the sensory evaluation, the Boba with 10% modified starch at 6 kGy irradiation, 20% modified starch at 6 kGy irradiation, and 20% modified starch at 8 kGy irradiation were selected based on the textural properties. The sensory evaluation results are shown in Figure 4. The panelists rated the color, flavor, taste, and overall acceptibility of the 3 samples as not significantly different (p > 0.05). The Boba with 10% modified starch at 6 kGy irradiation received the highest appearance score of 6.63 (liked slightly). The Boba with 20% modified starch at 8 kGy irradiation received the highest texture acceptance score of 6.08 (liked slightly) and the highest overall liking score of 6.04 (light slightly). Therefore, the Boba with 20% modified starch with 8 kGy irradiation was chosen as the optimum formulation from sago flour supplemented with inulin.

Discussion

In order to find the best formulation for developing Boba from sago flour, the 5 ratios of casava starch to sago flour (100:0, 70:30, 60:40, 50:50, and 0:100) were investigated using color, texture properties, and sensory evaluation as criteria. The result revealed that adding more sago flour proportion caused an increase in hardness and gumminess of the Boba samples. It can be explained that sago flour contained more amylose than cassava starch, as reported by Pongsawatmanit *et al.* (2002), in that the average amylose content in cassava starch is 17%, and by Ahmad *et al.* (1999), who reported the amylose content in sago flour as 22–31%. While the Boba was boiling, the amylose molecules leached into the surrounding water. During cooling, the amylose molecules were reordered with hydrogen bonds between molecules, which was called retrogradation. This results in the formation of a strong network structure in the gel (Tongdang and Meenun, 2005). Therefore, the Boba with a higher proportion of sago flour, which contains more amylose, can be better retrograded to a stronger gel than the Boba with a lower sago flour content. The hardness and gumminess of Boba with a greater amount of sago flour are therefore higher than the lower one. In terms of color, the Boba with a higher proportion of sago flour showed higher values of redness (a*) and yellowness (b*). This can be explained by the fact that sago flour is a powder extracted from the pith, or spongy core tissue, of various tropical palm stems, which has been reported by Kamal *et al.* (2017) in that it is not white, provided that it has a low L* value, a low a* value, and a significantly high b* value. All the Boba made from five ratios of cassava starch and sago flour was subjected to sensory evaluation. The sensory score of the 70:30 formulation showed no significant difference from the control formulation (100:0) in all attributes, which is in accordance with the textural properties in that this formulation is closest to the control formulation. Hence, the 70:30 formulation was chosen to be further investigated for inulin supplementation.

The results from the inulin supplementation at 2.5%, 5%, 7.5%, and 10% revealed that hardness had significantly increased ($p \leq 0.05$) with an increase in inulin content. Inulin is a natural soluble dietary fiber that comes from roots of the chicory plant. It is a carbohydrate composed of many units of fructose joined together (a polysaccharide). Both starch and inulin are polysaccharides, which compete for water molecules. In the formulation with a lower inulin percentage, there was a sufficient quantity of water for both polysaccharides so that the starch could completely gelatinize. As the concentration of inulin increases, the water content becomes insufficient, resulting in not being fully hydrated. This causes the gel texture of the higher inulin formulation to be harder than the lower one because of the incomplete gelatinization of starch and the inulin not being fully hydrated. (Krystyjan *et al*., 2015). In terms of the effect of inulin addition on the Boba color, it was found that the values of brightness (L*) significantly increased with an increase in inulin, whereas redness (a*) and yellowness (b*) did not show a clear trend of change. This can be explained by that fact that hydroxyl groups in the structure of inulin facilitate the formation of hydrogen bonds with water molecules. This led to the formation of a gel that can effectively retain water, allowing it to bind with free water, which caused a brighter color of Boba (Mohammadi *et al*., 2022). The sensory evaluation results showed that the 10% inulin addition received the lowest flavor score, but the 7.5 % inulin addition had the highest overall liking score and was therefore selected for further study for the optimum dose for electron irradiation. Products made from inulin mostly comprise short-chain molecules that can increase the sweetness of sucrose by up to 35%, making them suitable for replacing some of the sweetness of sucrose molecules (Shoai *et al.*, 2016). Considering the fact that the panelists commented on the oversweetness of the Boba sample, this may be the cause of the 10% inulin addition receiving the lower flavor score.

The optimum dose of electron beam for irradiating Boba with 7.5% inulin addition was investigated, and it was discovered that an increase in the radiation dose resulted in an increase in both hardness and gumminess. According to Pimpa *et al.* (2007), the formation of gel strength can be explained by the radiation that can break the glycosidic bonds between glucose in amylopectin, resulting in shorter polysaccharides and their recombination to form linear glucan. The initial number of microrganisms from the analysis of total plate count (TPC) in Boba was 1.8×10^7 cfu/g, the TPC showed a decrease to less than 10^6 after applying the electron beam at greater than 6 kGy irradiation. It can be explained by the fact that when the cells of bacteria are exposed to radiation, it causes chemical bonds to break and molecular structures to be disrupted, resulting in changes to DNA and RNA molecules, which are essential for cell growth and division. This also affects the cell wall structure, making it unable to transport the necessary nutrients required for the growth and development of bacterial cells (Chaiprasop, 2015). By using sensory evaluation, the Boba that was subjected to various electron beam irradiation dosages was assessed. The result revealed that the Boba with 2 kGy was rated highest for appearance, color, flavor, taste, texture, and overall acceptance, which is in accordance with the texture properties, indicating that the 2 kGy and the control formulation were not significantly different ($p > 0.05$). Nevertheless, the Boba with 6 and 8 kGy irradiation was chosen to investigate the optimum percentage of the modified starch to enhance the Boba's textural properties because these doses were capable of lowering the microorganisms below to the required level of less than 10^6 cfu/g for safety (Department of Medical Sciences, 2017). To improve the texture properties of Boba that was irradiated with 6 and 8 kGy, the modified starch was chosen to be tested by comparing it with the control formulation (no irradiation or 0 kGy). The hardness and gumminess decreased as radiation dose increased for the Boba with 0-15% MS, however this effect reversed back for the Boba with 15-20% MS. The change of Boba's texture profile after being exposed to radiation, probably as a result of the radiation's degrading of the crystalline structure and amorphous region of the starch granules, which causes an increase or reduction in crystallinity (Tilokkul *et al.*, 2021). The Boba with 10% modified starch at 6 kGy irradiation, 20% modified starch at 6 kGy irradiation, and 20% modified starch at 8 kGy irradiation were chosen to perform sensory evaluation. The result indicated that the Boba with 20% modified starch at 8 kGy irradiation received the highest texture acceptance score and the highest overall liking score, which was the same as the result from texture properties in that this Boba had no significant differences with the control formulation.

In summary, the optimum formulation for producing Boba from sago flour was found to be 70:30 (cassava starch: sago flour) supplemented with 7.5% inulin addition. The Boba was exposed to an electron beam irradiation of 8 kGy to reduce the microorganisms to meet the safety standard of less than 10^6 cfu/g. The 20% modified starch was found to be the optimum percentage for Boba texture improvement.

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