Physicochemical, antioxidant, and sensory properties of low-fat ice cream using purple sweet potato maltooligosaccharides as a fat replacer

Elisa Julianti[1,2,1*], *Mimi* Nurminah[1,2], *Edy* Syahputra Harahap[1,2], *Titi* Candra Sunarti[3], and *Intan* Mustika Sari[1]

[1]Department of Food Technology, Faculty of Agriculture Universitas Sumatera Utara, 20155 Medan, Indonesia
[2]Centre of Tuber and Root Crops Study, Universitas Sumatera Utara, 20155 Medan, Indonesia
[3]Department of Agroindustrial Engineering, Faculty of Engineering and Technology IPB University, 16680 Bogor, Indonesia

Abstract. The increasing prevalence of overnutrition in Indonesia has encouraged the development of healthier foods, including ice cream. This study evaluated purple sweet potato maltooligosaccharide (MOS) as a fat replacer in low-fat ice cream. A Completely Randomized Design with different levels of full cream milk substitution by MOS (0–50%) was applied, and the best formulation was selected using TOPSIS. MOS substitution significantly affected overrun, melting rate, color index, anthocyanin content, antioxidant activity, fat content, and sensory attributes (color, texture, taste, and overall acceptability) ($p<0.01$), but not aroma ($p>0.05$). The optimal formulation contained 50% MOS, producing ice cream with low fat content (3.35%), high antioxidant activity (75.47%), and good sensory acceptance. These results indicate that purple sweet potato MOS is a promising fat replacer for functional low-fat ice cream.

1 Introduction

Growing consumer demand for low-fat foods is driven by the association between high fat intake and chronic diseases such as cardiovascular disease and diabetes. However, fat plays a key role in the texture, flavor, and mouthfeel of food products. Its reduction often causes quality defects, including iciness, coarseness, and poor structure in ice cream. Therefore, effective fat replacers are needed to maintain product quality while meeting consumer demand for healthier foods [1].

Purple sweet potato (*Ipomoea batatas* L.) cv. Ayamurasaki is a source of maltooligosaccharides (MOS), which possess prebiotic properties and antioxidant activity due to their anthocyanin content [2]. MOS can also function as a fat mimetic by binding water and forming viscous structures that improve texture and mouthfeel [3]. As a safe

* Corresponding author: elisa1@usu.ac.id

carbohydrate-based fat replacer, MOS can enhance viscosity, creaminess, and sensory quality while reducing caloric content [4]. Given that ice cream typically contains 10–16% milk fat [5], effective fat substitutes are needed. However, information on the physicochemical, antioxidant, and sensory properties of low-fat ice cream containing purple sweet potato MOS remains limited. Therefore, this study aimed to evaluate the effects of MOS substitution on the physicochemical, antioxidant, and sensory properties of low-fat ice cream and determine the optimal formulation.

2 Materials and methods

Purple sweet potato (*Ipomoea batatas* L.) cv. Ayamurasaki was obtained from Pakpak Barat, North Sumatra, Indonesia. α-Amylase (Liquozyme Supra 2.2X®, Novozymes, Denmark; 135 KNU/g) was used for enzymatic hydrolysis. The ingredients of the ice cream are presented in Table 1.

Purple sweet potato tubers were peeled, steamed (100 °C, 10 min), mashed, and blended with distilled water (1:1, w/w). The slurry (pH 6.0) was hydrolyzed using α-amylase (2 U/g) at 60±1 °C for 60 min (150 rpm), followed by enzyme inactivation (95 °C, 10 min). MOS was analyzed for total sugar, reducing sugar, Dextrose Equivalent (DE) and Degree of polymerization (DP) [6], total anthocyanin [7], and antioxidant activity (DPPH) [8].

Low-fat ice cream was prepared according to Balthazar et al. [9], with formulations shown in Table 1. MOS replaced full cream milk powder at levels of 0–50%. The mix was pasteurized (70 °C, 20 s), homogenized, aged (4 °C, 20 h), frozen (30 min), and hardened (−20 °C, 24 h).

Table 1. Formulation of low-fat ice cream with MOS substitution (% w/w).

Ingredient (g)	Substitution of full cream milk powder with MOS (M)					
	M_1= 0%	M_2= 10%	M_3= 20%	M_4= 30%	M_5= 40%	M_6= 50%
Liquid skim milk	500	500	500	500	500	500
Full cream milk powder	35.0	31.5	28.0	24.5	21.0	17.5
MOS	0.0	3.5	7.0	10.5	14.0	17.5
Sugar	150	150	150	150	150	150
Glucose syrup	25	25	25	25	25	25
Vegetable oil	15	15	15	15	15	15
Vanila	10	10	10	10	10	10
Carboxyl methyl cellulose	1.5	1.5	1.5	1.5	1.5	1.5
Gelatin	1.0	1.0	1.0	1.0	1.0	1.0

Physicochemical properties, including overrun, melting rate [10], color (°Hue) [10], fat content [6], anthocyanin [7], antioxidant activity [8], and sensory attributes (30 panelists), were evaluated. The experiment followed a Completely Randomized Design (n=4), and data were analyzed using ANOVA and DMRT ($p<0.05$). The best formulation was selected using TOPSIS [11].

3 Results and discussion

3.1 Chemical characteristics of purple sweet potato maltooligosaccharide

As shown in Table 2, purple sweet potato MOS contained high anthocyanin levels (90.91 mg/100 g wet basis and 234.06 mg/100 g dry basis), indicating good retention of bioactive compounds. Differences from previous studies may reflect variations in moisture content, as indicated by the dry-basis values of fresh and paste samples (209.38 and 284.7 mg/100 g) [12].

Table 2. Chemical characteristics of purple sweet potato MOS.

Parameter	Amount
Total anthocyanin (mg/100 g)	90.91±0.27
Antioxidant activity (% inhibition)	86.44±1.70
Total sugar (%)	20.02±0.31
Reducing sugar (%)	9.34±0.27
Degree of Polymerization (DP)	2.14±0.04
Dextrose Equivalent (DE)	46.67±0.78

Note: Values are expressed as mean±standard deviation of three replications.

MOS exhibited high antioxidant activity (86.44%), closely related to anthocyanin levels, indicating enhanced phenolic extractability during hydrolysis. Increased total sugar (20.02%) and reducing sugar (9.34%) confirmed starch breakdown into smaller saccharides. The low degree of polymerization (DP=2.14) and high dextrose equivalent (DE=46.67) indicate predominance of short-chain oligosaccharides with high solubility and water-binding capacity. These characteristics support fat mimetic functionality, as carbohydrate-based replacers improve texture and mouthfeel through hydration and viscosity enhancement [13].

3.2 Effect of MOS on the physicochemical properties of low-fat ice cream

The effect of MOS substitution on the physical and chemical properties of low-fat ice cream is presented in Table 3. Statistical analysis showed that MOS substitution significantly affected ($p<0.05$) all evaluated parameters. Increasing MOS reduced overrun due to lower fat content and higher viscosity, which limited air incorporation, similar to the effects reported for inulin and maltodextrin as fat replacers [8]. However, unlike conventional fat replacers such as inulin and maltodextrin, MOS also contributed antioxidant activity through its anthocyanin content [2]. Despite fat reduction, melting resistance improved with increasing MOS, likely due to enhanced water retention and structural stability [13]. The inverse relationship between overrun and melting rate supports this mechanism.

Table 3. Effect of purple sweet potato maltooligosaccharide (MOS) substitution on the physical and chemical characteristics of low-fat ice cream.

Parameter	Percentage of purple sweet potato maltooligosaccharide					
	M1 (0%)	**M2 (10%)**	**M3 (20%)**	**M4 (30%)**	**M5 (40%)**	**M6 (50%)**
Overrun (%)	33.09±2.08^{a}	30.26±1.39^{b}	28.35±1.90^{b}	23.87±0.71^{c}	19.60±1.70^{d}	17.45±0.99^{d}
Melting rate (s)	921.00±21.49^{e}	961.25±12.45^{e}	1036.25±19.26^{d}	1116.50±24.06^{c}	1255.00±36.29^{b}	1452.75±76.51^{a}
Color index (°Hue)	95.25±0.35^{a}	88.27±0.93^{b}	75.60±4.62^{c}	40.60±1.94^{d}	31.50±4.14^{e}	10.18±1.40^{f}

Anthocyanin content (mg/100 g)	0.00± 0.00[f]	2.75± 0.95[e]	4.44± 0.83[d]	6.77± 1.01[c]	9.01± 0.74[b]	14.28± 1.14[a]
Antioxidant activity (% inhibition)	30.98± 2.25[d]	41.07± 5.26[c]	47.05± 5.99[c]	60.18± 5.12[b]	72.27± 1.79[a]	75.47± 2.27[a]
Fat content (%)	4.94± 0.09[a]	4.66± 0.26[b]	4.32± 0.38[c]	3.98± 0.37[c]	3.55± 0.19[d]	3.35± 0.12[d]

Note: Values are presented as mean ± standard deviation of four replications. Different letters within the same row indicate significant differences based on Duncan's Multiple Range Test (p<0.05).

Higher MOS levels decreased hue angle, producing a red-purple color due to increased anthocyanin, although dilution by milk reduced intensity [14]. Anthocyanin and antioxidant activity increased proportionally with MOS, despite partial degradation during processing [12]. Fat content decreased significantly (4.94% to 3.35%), while texture and stability were maintained, demonstrating that MOS effectively functions as a fat replacer through water binding and network formation [15].

3.3 Sensory characteristics and optimization

MOS significantly improved most sensory attributes except aroma (Table 3). Color preference increased due to anthocyanin pigmentation, while taste and texture improvements were attributed to the sweetness and viscosity-enhancing properties of MOS [3, 12]. Consequently, overall acceptability increased significantly.

Table 3. Effect of purple sweet potato maltooligosaccharide (MOS) substitution on the sensory characteristics of low-fat ice cream.

Parameter	Percentage of purple sweet potato maltooligosaccharide					
	M1 (0%)	**M2 (10%)**	**M3 (20%)**	**M4 (30%)**	**M5 (40%)**	**M6 (50%)**
Color	2.53± 0.06[e]	2.98± 0.03[e]	3.41± 0.04[d]	3.78± 0.07[c]	4.52± 0.05[b]	4.80± 0.13[a]
Aroma	4.51± 0.18	4.55± 0.03	4.59± 0.04	4.60± 0.14	4.65± 0.09	4.67± 0.04
Taste	4.39± 0.04[c]	4.41± 0.05[c]	4.50± 0.04[b]	4.53± 0.05[b]	4.63± 0.03[a]	4.66± 0.03[a]
Texture	3.83± 0.05[e]	3.99± 0.08[d]	4.18± 0.04[c]	4.43± 0.11[b]	4.70± 0.02[a]	4.77± 0.05[a]
Overall acceptability	4.22± 0.06[e]	4.40± 0.06[d]	4.50± 0.10[cd]	4.56± 0.01[bc]	4.62± 0.04[b]	4.80± 0.04[a]

Note: Values are presented as mean±standard deviation of four replications. Different letters within the same row indicate significant differences based on Duncan's Multiple Range Test (p<0.05).

These findings are consistent with studies showing that carbohydrate-based fat replacers enhance creaminess and mouthfeel by reducing friction and increasing lubrication in the oral cavity [3]. Using the TOPSIS method, the optimal formulation was identified as M6 (50% MOS), which achieved the best balance between physicochemical properties and sensory acceptance.

4 Conclusion

Purple sweet potato-derived maltooligosaccharide (MOS) showed potential as a fat replacer in low-fat ice cream by improving structural stability, antioxidant activity, and sensory quality while reducing fat content. These findings demonstrate its potential as a carbohydrate-based fat mimetic for functional low-fat dairy products. Future studies should evaluate shelf-life stability, process scalability, and consumer acceptance to support industrial application.

The authors gratefully acknowledge the financial support provided by the Equity Research Funding 2024, Universitas Sumatera Utara, under Contract No. 87/UN5.2.3.1/PPM/KPEP/2023.

References

1. J. Tang, S. Yang, W. Li, J. Chang, Fat replacers in frozen desserts: functions, challenges, and strategies. Compr. Rev. Food Sci. Food Saf. **24**, e70191 (2025). https://doi.org/10.1111/1541-4337.70191
2. E. Julianti, M. Nurminah, B. Nathania, Effect of purple sweet potato paste (*Ipomoea batatas* L.) addition on yoghurt quality. IOP Conf. Ser.: Earth Environ. Sci. **1445**, 012014 (2025). https://doi:10.1088/1755-1315/1445/1/012014
3. I. Bourouis, Z. Pang, X. Liu, Recent advances on uses of protein and/or polysaccharide as fat replacers: textural and tribological perspectives: a review. J. Agric. Food Res. **11**, 100519 (2023). https://doi.org/10.1016/j.jafr.2023.100519
4. I. Nikolić, D. Šoronja-Simović, J. Zahorec, L. Dokić, I. Lončarević, M. Stožinić, J. Petrović, Polysaccharide-based fat replacers in functional food products. Processes. **12**, 2701 (2024). https://doi.org/10.3390/pr12122701
5. S. Adapa, H. Dingeldein, K.A. Schmidt, T.J. Herald, Rheological properties of ice cream mixes and frozen ice creams containing fat and fat replacers. J. Dairy Sci. **83**, 2224–2229 (2000). https://doi.org/10.3168/jds.S0022-0302(00)75106-X
6. A. Apriyantono, D. Fardiaz, N.L. Puspitasari, S. Sedarnawati, S. Budiyanto, Food analysis: Laboratory manual (PAU Pangan dan Gizi IPB, Bogor, 1989)
7. M. Giusti, R. Wrolstad, Characterization and measurement of anthocyanins by UV-visible spectroscopy. Curr. Protoc. Food Anal. Chem. (2001). https://doi.org/10.1002/0471142913.FAF0102S00
8. F. Xiao, T. Xu, B. Lu, R. Liu, Guidelines for antioxidant assays for food components. Food Front. **1**, 60–69 (2020). https://doi.org/10.1002/fft2.10
9. C.F. Balthazar, H.L.A. Silva, R.M.S. Celeguini, R. Santos, G.M. Pastore, C.A. Conte Junior, M.Q. Freitas, L.C. Nogueira, M.C. Silva, A.G. Cruz, Effect of galactooligosaccharide addition on the physical, optical, and sensory acceptance of vanilla ice cream. J. Dairy Sci. **98**, 4266–4272 (2015). https://doi.org/10.3168/jds.2014-9018
10. A. Rahim, S. Laude, Asrawaty, Akbar, Physicochemical and sensory properties of pumpkin ice cream with taro flour addition as a stabilizer. J. Agrol. **24**, 89–94 (2017)
11. A.H. Hasugian, M.A. Irawan, Application of the TOPSIS method to determine palm oil quality. J. Teknol. Sist. Inf. Apl. **7**, 942–950 (2024). https://doi.org/10.32493/jtsi.v7i3.40815
12. N.E. Husna, M. Novita, S. Rohaya, Anthocyanin content and antioxidant activity of fresh purple sweet potato and its processed products. Agritech **33**, 296–302 (2013)
13. V. Aswathy, P. Chalwa, A comprehensive review: Carbohydrate-based fat replacers and their role in food formulation. Pharma Innov. J. **12**, 2380–2383 (2023)

14. A. Oktafiyani, D.U.M. Susilo, Production of purple sweet potato ice cream with variation in churning–freezing cycles. J. Pertan. Pangan **1**, 20–26 (2019)
15. S.M. Nento, M. Limona, L. Ahmad, Physicochemical and organoleptic characteristics of pineapple ice cream with modified glutinous corn starch addition. Jumbura J. Food Technol. **5**, 231–242 (2023)