Development and Feasibility Study of Coconut Sugar Tablets with Cocoa-Malt Flavor: Physical Properties and Consumer Acceptance

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Abstract. Despite the growing demand for natural and value-added confectionery products, no standardized formulation for coconut sugar tablet has been developed. This study aimed to develop and evaluate coconut sugar tablets using formulation optimization and feasibility assessment. A Plackett–Burman experimental design was applied to evaluate factors affecting tablet hardness. Maltodextrin, magnesium stearate, and compression force were identified as significant variables and further optimized. Ten formulations were developed by varying ingredient composition and compression conditions based on the significant factors identified from the Plackett–Burman design. The formulations were evaluated for hardness and water activity, and formula J was selected as the optimal formulation based on physicochemical properties. The optimized tablets exhibited hardness of 100.92 N and water activity of 0.44. Sensory evaluation with 50 untrained panellists using a 9-point hedonic scale showed good consumer acceptance, with an overall liking score of 7.43. During 28 days of storage at ambient conditions, both hardness and water activity significantly increased. The estimated production cost was 5.19 THB per sachet that contained 15 tablets, indicating economic feasibility.

1 Introduction

The global confectionery market is projected to grow at a compound annual growth rate (CAGR) of 5.8%, increasing from USD 121.25 billion in 2026 to USD 169.82 billion by 2032 [1]. In recent years, there has been growing interest in using natural and local ingredients into value-added confectionery products [2]. Tablet products offer advantages such as portion control, portability, and structural uniformity, which make them attractive for developing sugar-based products [3].

Coconut sugar is produced from the sap of *Cocos nucifera*. It has been recognized as an alternative sweetener with higher nutritional and functional advantages compared with

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sucrose [4]. Unlike cane sugar, coconut sugar has lower glycemic index [5,6]. Coconut sugar also contains phenolic compounds such as vanillic acid, catechin, ferulic acid, gallic acid, and quercetin, which are associated with antioxidant activity and may contribute to its potential functional properties [7].

Despite these advantages, developing coconut sugar tablets remains technically challenging. Its powder characteristics can affect compressibility and tablet hardness, which is important for product stability [8,9]. Moreover, no standardized formulation for coconut sugar tablet has yet been established. Therefore, this study aimed to optimize the formulation of coconut sugar tablets, and evaluate their physicochemical properties, sensory acceptance, shelf-life stability, and economic feasibility.

2 Materials and Methods

2.1 Materials

Coconut sugar powder was obtained from Three Point Management Co., Ltd. Cocoa powder was purchased from Sangha Panich Ltd., Part. Maltodextrin, PVP K30, silicon dioxide, and magnesium stearate were purchased from Bangkok Chemical Co., Ltd. Malt extract powder was purchased from Yok Intertrade (Chiang Mai) Co., Ltd.

2.2 Preparation of Coconut Sugar Tablets

Coconut sugar tablets were prepared using the direct compression method. Coconut sugar powder, cocoa powder, malt extract powder, maltodextrin, PVP K30, silicon dioxide, and magnesium stearate were weighed according to the experimental design formulation in Section 2.4. The dry ingredients were blended using a mixer. After blending, the powder mixture was compressed using an electric single-punch tablet compression machine. The compression force was adjusted according to the experimental design levels in Section 2.4. The target tablet weight was 1.2–1.3 g per tablet, with a diameter of 20 mm and a thickness of approximately 4.0 mm. The prepared tablets were stored in sealed polyethylene bags at ambient temperature prior to further analysis.

2.3 Plackett–Burman Design

To identify the formulation and processing variables influencing tablet mechanical strength, a Plackett–Burman experimental design was used to screen the variables with significant effects on hardness (Table 1). Each factor was investigated at two levels including high and low.The response variable was tablet hardness (N). The experimental results were analyzed using analysis of variance (ANOVA) to determine significant factors. A confidence level of 80% ($p < 0.20$) was used for screening purposes. Statistical analysis was conducted using SPSS software version 16.0.

Table 1. Factors and levels for producing coconut sugar tablet products.

Factor	High Level (+)	Low Level (-)
A: Coconut sugar powder (%)	50	30
B: Cocoa powder (%)	30	10
C: Maltodextrin (%)	55	14
D: Magnesium stearate (%)	10	1
E: PVP-K30 (%)	3	2
F: Silicon dioxide (%)	1.5	1
G: Compression Force (tons)	1.5	1

2.4 Optimization of Ingredients and Formulation Development

Following the Plackett–Burman experiment results, the variables that showed significant effects on tablet hardness were selected for further investigation. These significant ingredients were varied to determine their optimal levels for formulation development. Ten experimental formulations (A–J) were prepared and the formulation compositions are presented in Table 2.

Table 2. Ingredient formulas after obtaining the results from placket-burman design.

Ingredients	Formula									
	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**
Coconut sugar powder (%)	29.92	29.92	29.92	29.92	30.03	40.03	50.03	30.00	30.00	40.00
Cocoa powder (%)	9.87	9.87	9.87	9.87	10.31	10.31	10.31	7.00	12.98	7.00
Malt extract powder (%)	-	-	-	-	-	-	-	3.33	25.00	6.98
Maltodextrin (%)	54.30	54.30	54.30	54.30	57.65	47.65	37.65	57.65	30.00	44.00
PVP-K30 (%)	2.76	2.76	2.76	2.76	-	-	-	-	-	-
Silicon dioxide (%)	1.46	1.46	1.46	1.46	1.50	1.50	1.50	1.50	1.50	1.50
Magnesium stearate (%)	0.50	0.50	1.00	1.00	0.52	0.52	0.52	0.52	0.52	0.52
Compression force (tons)	1.5	1.0	1.0	1.5	1.0	1.0	1.0	1.0	1.0	1.0

Tablet hardness and water activity (a_w) were determined for each formulation. The selection of the optimal formulation was based on physicochemical properties. The selected

formulation was considered for further sensory evaluation, shelf-life stability study, and cost analysis.

2.5 Determination of Physicochemical Properties

2.5.1 Hardness measurement

Tablet hardness was measured using a texture analyzer (TA.XTplus, Stable Micro Systems, UK). The values were evaluated using compression mode. A 25 mm diameter cylindrical probe (P/25) was used. The pre-test speed, test speed and post-test speed were all set as 2 mm/s. The compression distance was 8.5 mm.

2.5.2 Water Activity measurement

Water activity (a_w) was measured using AquaLab 4TE water activity meter (Meter Group, Inc., Pullman, WA, USA). Tablet samples were finely crushed and placed into the sample chamber, and measurements were recorded once equilibrium was achieved.

2.6 Sensory Evaluation

Consumer acceptance of the optimized coconut sugar tablet was evaluated by 50 untrained panelists. A 9-point hedonic scale was used for the test and the attributes included color, hardness, malt flavor, cocoa flavor, sweetness, and overall liking based on the degree of preference ranging from dislike extremely to like extremely. In addition, a 5-point Just-About-Right (JAR) scale, based on a different evaluation principle, was applied to assess whether the intensity of specific sensory attributes was perceived as too weak, too strong, or just-about-right by the panelists. The JAR results were further analyzed using penalty analysis. The evaluation was conducted using SU Sense software (Version 2013; v3.790).

2.7 Shelf-Life Stability

Tablets of optimized formulation were kept in polyethylene sachets and stored at ambient conditions for 28 days. Physicochemical properties of the samples were analyzed at 0, 7, 14, 21, and 28 days to evaluate shelf-life stability. The evaluated parameters included hardness, water activity (a_w), and color (L*, a*, b*).

2.8 Cost Determination

The economic feasibility of the optimized formulation was evaluated. Cost analysis was calculated for the sachet which contains 15 tablets. The total production cost included raw material cost, packaging cost, labor cost, utility cost (electricity), machine depreciation, and estimated production loss. A fixed percentage (10%) was used to calculated material loss during processing.

2.9 Statistical analysis

All experiments were conducted in triplicate. Statistical analysis was performed using one-way analysis of variance (ANOVA) to determine significant differences among treatments.

Duncan's multiple range test was used for post-hoc comparison at a significance level of $p < 0.05$. Statistical analyses were carried out using SPSS software version 16.0.

3 Results and Discussions

3.1 Screening of Factors Affecting Hardness

The seven evaluated factors included formulation ingredients and processing conditions that may influence tablet hardness. Coconut sugar powder served as the main ingredient, while cocoa powder contributed to flavor characteristics. Maltodextrin and PVP-K30 functioned as binding agents, magnesium stearate as a lubricant, and silicon dioxide as a glidant. Compression force was included as a processing parameter affecting tablet mechanical strength. Among the seven evaluated factors, maltodextrin (C), magnesium stearate (D), and compression force (G) showed potential effects on hardness at a confidence level of 80% ($p < 0.20$) (Table 3). Maltodextrin showed the highest positive coefficient with a p-value of 0.069, indicating that increase in maltodextrin content significantly enhanced tablet hardness. Maltodextrin was also reported to have significant effect on mixed fruit tablet hardness [10]. This result suggests that maltodextrin could increase particle binding capacity and structure formation during compression [11]. In contrast, magnesium stearate showed a negative coefficient, indicating that higher levels reduced tablet hardness. This might be due to its lubricant effect, which can reduce particle bonding and affect hardness [12]. Compression force also showed a positive effect, which means that higher compression pressure can increase mechanical strength. Based on these results, maltodextrin, magnesium stearate, and compression force were selected for further optimization of tablet formulation.

Table 3. Analysis of variables affecting tablet hardness from Plackett-burman.

Variables	Coefficients	t-value	p-value	Confidence Level (%)
A: Coconut sugar powder	-4.724	-0.865	0.436	56.4
B: Cocoa powder	-5.566	-1.019	0.366	63.4
C: Maltodextrin	13.464	2.465	0.069	93.1
D: Magnesium stearate	-9.832	-1.800	0.146	85.4
E: PVP-K30	3.434	0.629	0.564	43.6
F: Silicon dioxide	3.336	0.611	0.574	42.6
G: Compression force	9.410	1.723	0.160	84.0

3.2 Optimization and Selection of the Optimal Formulation

Significant factors obtained from the Plackett–Burman experiment were varied to develop ten formulations (A–J). The hardness and water activity (a_w) of each formulation are presented in Table 4.

Table 4. Hardness and Water Activity of Coconut Sugar Tablets Samples.

Formula	Hardness (N)	a_w
A	173.58 ± 5.63^{f}	0.53 ± 0.02^{d}
B	130.23 ± 1.42^{d}	0.53 ± 0.01^{d}
C	132.79 ± 2.96^{d}	0.53 ± 0.01^{d}
D	188.32 ± 2.01^{g}	0.53 ± 0.01^{d}
E	118.21 ± 2.58^{c}	0.46 ± 0.01^{bc}
F	132.17 ± 1.25^{d}	0.53 ± 0.00^{d}
G	131.16 ± 8.63^{d}	0.55 ± 0.00^{e}
H	110.17 ± 6.47^{b}	0.46 ± 0.01^{c}
I	149.39 ± 4.05^{e}	0.40 ± 0.01^{a}
J	100.92 ± 2.53^{a}	0.44 ± 0.01^{b}

Means within the same column with different superscript letters are significantly different ($p < 0.05$).

Hardness was significantly different among all formulations ($p < 0.05$). The highest hardness was observed for formulation D, while formulation J showed the lowest hardness. Formulations containing higher levels of maltodextrin and using higher levels of compression force demonstrated high value of hardness. Water activity values ranged from 0.40 to 0.55. Samples of formula I showed the lowest a_w, whereas samples of formula G showed the highest. Lower a_w values mean better moisture stability and reduced possibility of microbial growth. Among all formulations, although formulation J did not show the highest hardness or lowest a_w, it demonstrated balanced physicochemical characteristics with moderate hardness and low water activity, making it suitable for further sensory evaluation and formulation development.

3.3 Sensory Evaluation of the Optimal Formulation

The sensory acceptance of formula J are presented in Figure 1. All evaluated attributes showed mean scores above 6.7, which means moderate to high consumer acceptance. The overall liking score reached 7.43, suggesting that the product was accepted and suitable for further development.

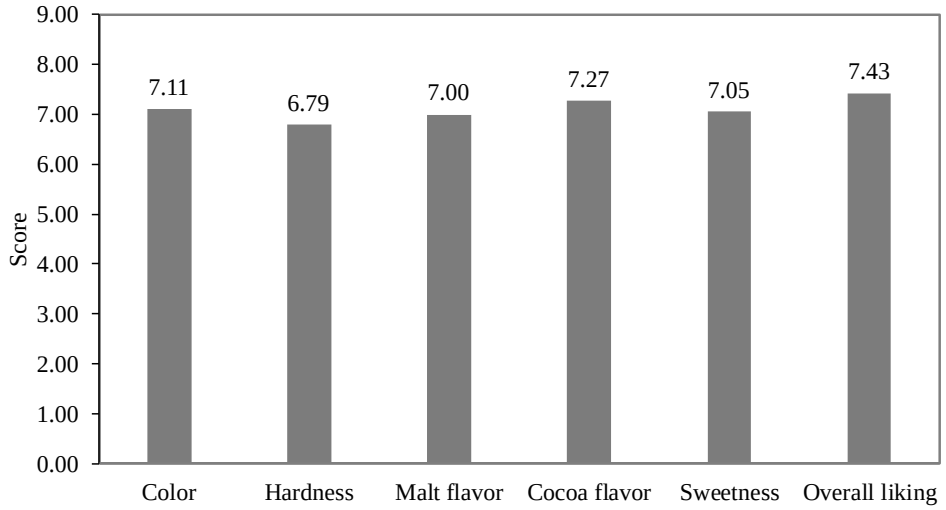

Fig. 1. Sensory evaluation for the coconut sugar tablets formula J.

Just-About-Right (JAR) analysis was performed, and the total penalty results are summarized in Table 5. Most attributes showed a high proportion of responses within the just-about-right category, which means those attributes showed appropriate intensity levels. The sensory evaluation suggested that Formula J has high balance in flavor and texture profile, supporting its selection as the optimal formulation.

Table 5. Total penalty analysis of coconut sugar tablets Formula J.

Attributes	**Scale**	**Low**	**OK**	**High**
Color	%	25	73.21	1.79
	Total Penalty	0.27	0	0.01
Hardness	%	19.64	64.29	16.07
	Total Penalty	0.22	0	0.19
Malt Flavor	%	28.57	69.64	1.79
	Total Penalty	0.33	0	0.03
Cocoa Flavor	%	25	71.43	3.57
	Total Penalty	0.09	0	-0.02
Sweetness	%	12.5	62.5	25
	Total Penalty	0.09	0	0.2

3.4 Shelf-Life Stability of the Optimal Formulation

Changes in hardness and water activity (a_w) during 28 days of storage are presented in Table 6. A significant increase in hardness and water activity was observed during storage ($p < 0.05$). The increase in hardness may be explained by the transition of the phase of amorphous sugar, which maltodextrin exhibited the amorphous nature [11]. Such hardening behavior could be observed in tablets during storage [11,13]. Although the a_w values increase during storage, the low a_w values suggest minimal risk of microbial growth [14].

Table 6. Changes in Hardness and Water Activity (a_w) During 28 Day Storage.

Day	Hardness (N)	a_w
0	112.17 ± 4.63^a	0.44 ± 0.00^a
7	141.78 ± 2.20^b	0.45 ± 0.01^a
14	154.28 ± 14.41^b	0.46 ± 0.00^a
21	158.40 ± 11.01^b	0.45 ± 0.01^a
28	156.26 ± 5.32^b	0.49 ± 0.01^b

Means within the same column with different superscript letters are significantly different ($p < 0.05$)

The color parameters are shown in Table 7 and they exhibited significant changes during storage ($p < 0.05$).

Table 7. Changes in Color During 28-Day Storage.

Day	L*	a*	b*
0	55.78 ± 1.23^b	7.43 ± 0.12^a	11.12 ± 0.17^a
7	53.55 ± 1.65^a	7.78 ± 0.15^b	11.60 ± 0.35^b
14	53.38 ± 1.51^a	8.07 ± 0.14^c	12.00 ± 0.17^c
21	53.74 ± 1.25^a	7.99 ± 0.13^c	12.03 ± 0.27^c
28	52.45 ± 0.69^a	8.15 ± 0.17^c	12.13 ± 0.22^c

Means within the same column with different superscript letters are significantly different ($p < 0.05$)

3.5 Economic Feasibility of the Optimal Formulation

The production cost of tablets formula J was evaluated to assess preliminary economic feasibility, and the cost elements are presented in Table 8

Table 8. Total Production Cost per Unit of Coconut Sugar Tablets Mixed with Cocoa.

Items	Cost per pack (THB)
Raw material cost	2.03
Packaging cost	1.70
Electricity cost	0.01
Machine depreciation cost	0.01
Utility cost	0.20
Production loss	0.20
Labor cost	1.04
Total production cost	5.19

Note: 1 Pack contains 15 tablets; Currency exchange rate: 1 THB = 0.032 USD (Feb 24, 2026)

Raw materials accounted for the largest proportion which was approximately 39% of total cost, followed by packaging cost and labor cost. The rest of the cost items contributed only 8% of the total production cost. The inclusion of a 10% production loss could reflect the cost occurring from realistic loss during production. The total production cost of 5.19 THB per sachet suggests that coconut sugar tablets can be economically viable. While this estimation does not include industrial-scale overhead or marketing costs, the results showed potential for commercial development and further study.

4 Conclusion

The Plackett–Burman design identified maltodextrin, magnesium stearate, and compression force as significant factors influencing tablet hardness. Formula J was the optimized formulation that exhibited hardness of 100.92 N and water activity of 0.44, with an overall liking score above 7. During 28 days of storage, both hardness and water activity of sample Formula J significantly increased. The estimated production cost was 5.19 THB per sachet (15 tablets), indicating economic feasibility. These results demonstrate the technical and commercial potential of coconut sugar tablets.

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