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MIXTURE DESIGN OPTIMISATION OF RED PALM OIL IN CANDY: EFFECTS ON HARDNESS AND FRIABILITY

TECK-KIM TANG[1]*; NORAZURA AILA MOHD HASSIM[1]; SOON-SEN LEOW[1]; SIVARUBY KANAGARATNAM[1]; RADHIKA LOGANATHAN[1]; HAZRATI WAZIR[1]; NUR HAQIM ISMAIL[1] and MEI-HUEY SAW[1]

ABSTRACT

Although red palm oil (RPO) is rich in carotenes (500-800 ppm) and vitamin E (800 ppm), its unique flavour may not be appealing to some consumers. Incorporating RPO in candy not only toning down the flavour but also serves as a convenient delivery system and increases its market acceptability. In this study, direct compression was chosen for preparing candy, as it generates minimal heat, thereby preserving most of the carotenes and vitamin E. The primary objective of this study was to optimise the formulation of RPO candy to achieve desirable responses: Hardness and friability. The process began with the screening of raw materials. Screening results indicated that erythritol with the highest sweetness-to-calorie ratio was a good candidate with a mesh size of 80-100, exhibited fair flow properties and good homogeneity. Gum arabic was selected among the three tested binders due to its highest binding ability. The mixture design was employed to examine the interaction of the three components: Erythritol, RPO powder (RPOP) and gum arabic on the responses. Through the optimisation process, the formulation consisting of 50% erythritol, 10% RPOP and 33.5% gum arabic was successful in producing intact RPO candy.

Keywords: candy, carotenes, red palm oil, vitamin E.

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INTRODUCTION

Red palm oil (RPO) is a type of refined palm oil rich in carotenes (500-800 ppm) and vitamin E (800 ppm). The carotenes in RPO function not only as pro-vitamin A, which is essential for eye health, but also act as a strong antioxidant with several health effects (Bohn, 2019; Parveez *et al.*, 2023; Tan *et al.*, 2021). In addition, the vitamin E in RPO is predominantly composed of tocotrienols, which exhibit higher antioxidant properties compared to the commonly recognised form of vitamin E – *i.e.*, tocopherols (Szewczyk *et al.*, 2021).

Studies conducted on RPO have revealed several promising health benefits. A meta-analysis conducted by Dong *et al.* (2017) demonstrated that RPO effectively addresses vitamin A deficiency in both adults and children. Furthermore, RPO may help reduce cholesterol and triglycerides supported by evidence from both human and animal studies. Its antiatherogenic properties contribute to improved cardiovascular health (Loganathan *et al.*, 2017). Due to its antioxidant-rich composition, RPO could improve oxidative status by reducing oxidative stress in patients with cardiovascular disease, cancer and other chronic diseases. Subsequently, lowering the risk of atherosclerosis and supporting overall wellbeing (Oguntibeju *et al.*, 2009).

In animal models, RPO shows potential in preventing neurodegenerative diseases like Alzheimer's disease. It improved cognitive function, increased levels of dopamine and antioxidant

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[1] Malaysian Palm Oil Board,
6, Persiaran Institusi, Bandar Baru Bangi,
43000 Kajang, Selangor, Malaysia.

* *Corresponding author e-mail: teck.kim@mpob.gov.my*

biomarkers and enhanced the spatial memory of treated rats. These effects are attributed to RPO's rich antioxidant profile, which helps mitigate neuron, mitochondrial, protein and DNA damage caused by aging-related oxidative stress (Zubaidi *et al*., 2021).

Despite RPO numerous health benefits, its distinct flavour may be unappealing to some individuals. Moreover, the commercially available RPO is typically in liquid form and is heat sensitive. Therefore, incorporating RPO into the food matrix could increase its acceptability and ease of consumption while preserving its nutrient profile. For instance, candy provides a ready-to-eat option that requires no additional preparation, making it a practical and desirable alternative for delivering RPO.

Candy is generally well-accepted due to its sweet taste, appealing flavour, ease of consumption, no additional preparation required during consumption and most importantly ability to mask RPO's distinct flavour. However, the use of sugar (usually sucrose) in conventional candy making has drawbacks. For example, the candy must be heated to melt and the mixing process with other ingredients is conducted at high temperatures. In view that carotenes are heat sensitive, they start to degrade at temperatures of 65°C (Demiray & Tulek, 2017). Thus, using the conventional candy-making process can lead to a significant loss of carotenes as well as other heat-sensitive vitamins during the process.

Besides that, high sugar content in candy can pose health issues such as tooth decay and type 2 diabetes if consumed excessively (Jayadevan *et al*., 2019; Qin *et al*., 2020). While sugar substitutes are widely used to replace sugar to avoid these problems, some of them, particularly artificial sweeteners such as aspartame possess side effects, including being harmful to individuals with phenylketonuria and possibly carcinogenic (Czarnecka *et al*., 2021). The existing evidence is inconclusive regarding the potential heightened risk of certain cancers with extended and frequent use of artificial sweeteners (Mishra *et al*., 2015). Nevertheless, this uncertainty contributes to consumer apprehension about the use of artificial sweeteners.

Although being natural does not necessarily mean that a product is safe, it is important to consider consumer preferences in product development. Natural sweeteners, such as sugar alcohols, are gaining prominence in recent years due to their safety guarantees, low calorie content and absence of oral issues (Mazi & Stanhope, 2023). They have gained interest as good candidates as sugar replacers with fewer side effects and possess the added benefit of providing bulkiness (better texture or mouthfeel) to the product.

Another important ingredient in candy making is the binder. Gum arabic is a good candidate due to its good binding effects, film-forming capability and can improve texture while preventing sugar crystallisation, making it beneficial for soft candies and gummy products (Afoakwah *et al*., 2023). Microcrystalline cellulose is also used as a binder. It enhances texture and stability in candy formulations by acting as a filler, disintegrant, lubricant and glidant (Bordoloi *et al*., 2021; Zhao *et al*., 2022). Additionally, staple food ingredients like rice flour, especially glutinous rice, have a higher oil-binding ability when heat-treated (Tabara *et al*., 2015).

Binders play a crucial role in candy making especially in processes like direct compression which involves minimal heat. For candy-making process, direct compression is one of the best methods for preparing candies that contain heat-sensitive compounds. Under short compression, the heat generated is minimal, allowing for the preservation of carotenes and vitamins in RPO. However, incorporating RPO into candy via direct compression may impose several challenges. Firstly, the addition of oil can reduce the flowability of the premix powder, causing clumping. A flowable powder is crucial to ensure smooth candy production during the feeding process of direct compression. Additionally, the presence of oil can interrupt the binder function of ingredients, causing a reduction in candy hardness and an increase in friability. Therefore, the main objective of this study is to determine the optimal composition for producing RPO candy, specifically addressing challenges related to flowability, hardness and friability of the product.

MATERIALS AND METHODS

Materials

RPO powder (RPOP, 70% w/w oil content) was procured from Lipidchem Sdn. Bhd., Johor, Malaysia and stored at -20°C prior to use. Erythritol, gum arabic, microcrystalline cellulose and other food ingredients used in the candy-making process were of food grade. The RPO used in this study contained 874.4 ppm carotenes and 503.1 ppm vitamin E.

Experimental Design

A screening was performed to select sugar alcohol types and the mesh size of the sugar alcohol with the highest sweetness to calorie ratio, binder types and RPOP range. Following the screening process, the selected ingredients were incorporated into the mixture design to study their interactions in terms of powdered mix flowability, hardness and friability of the produced candy.

Sugar Alcohol Selection and Evaluation

The sweetness level and calories of various sugar alcohols were evaluated through a literature search. The ratio of sweetness per calorie was calculated, and the sugar alcohol with the lowest calorie was chosen.

Mesh Size Selection of Selected Sugar Alcohol Based on Granular Separation and Flowability

Two sets of chosen sugar alcohols with different mesh sizes (40-60 and 80-100 mesh sizes) were tested for granular separation and flowability after being thoroughly mixed with other candy making ingredients. For homogeneity, the mixtures were tapped 700 times using a tap density tester (Electrolab, India). The colour distribution within the mixture was used as an indicator to determine the granular separation of the sample. Non-granular separation showed uniform yellow colour distribution whereas granular separation displayed non-uniform yellow colour distribution. The mixtures' flowability was then tested using an angle of repose. The test method involved carefully pouring 100 g of powdered mix into a funnel with a 10 mm nozzle to build a cone, with the height of the funnel to the base being 100 mm (Mat Dian *et al.*, 2019). The diameter and the height of the built cone were measured, and the angle of repose was calculated using the following Equation (1):

$$\text{Angle of repose} = \tan^{-1}\left(\frac{2 \text{ x height}}{\text{diameter}}\right) \tag{1}$$

The mesh size of sugar alcohol that was able to form a homogenous candy mixture and able to flow without aid (as determined by angle of repose) was chosen.

Binder Selection and RPOP Range

Four different binders, namely gum arabic, microcrystalline cellulose (MCC), glutinous rice flour (GRF) and cooked GRF, were evaluated for their binding abilities based on the intactness of candy produced. The screening process began with the mixing of ingredients. The amount of sugar alcohol, glidant and lubricant was kept constant, while the amount of binder and RPOP were varied. The process started with 10% RPOP and 33% binder to give a total composition of 43% while other ingredients were kept constant, then progressed to 15% RPOP with 28% binder, and continued in 5% intervals up to a maximum of 30% RPOP. The mixtures were then used to produce candy using an automatic tableting machine, Model EP200 (Elizabeth Parle, India). During this process, the integrity of the produced candies was observed. A candy was deemed intact if it remained unbroken upon release from the mould. Binders capable of producing intact candy with higher amounts of RPOP were chosen and this value was used to set the upper limit of RPOP in the mixture design.

Optimisation of RPO Candy

Design of experiment. Mixture design is commonly used when the responses depend on the proportions of the different ingredients rather than the absolute amount. Unlike factorial and response surface methodology, where the ingredients are treated independently, this method is suitable in formulation studies as the total amount of the overall composition remains constant despite changes in the formulation. Therefore, in this study, a Mixture Design-Optimal (Custom) Design was generated by Design-Expert® v13 software (Stat-Ease Inc., USA) and used to study the formulation of the candy ingredients. The selection of ingredients/components and the lower and upper constraints of each component were based on the screening results and literature reviews. Three major components comprising chosen sugar alcohol, RPOP and binder, and the responses of flowability of powdered mix, hardness and friability of the candy, were studied. The ranges for erythritol (A), RPOP (B) and gum arabic (C) in the candy formulation were set from 50.0%-73.5%, 10.0%-20.0%, 10.0%-33.5%, respectively and their combination was 93.5% of the formulation. Other additives constituted the remaining 6.5% were kept constant. A total of 16 runs (formulations) were generated by the software.

Preparation of powdered mix and candy. All ingredients were sieved and thoroughly mixed to create the powdered mix. The flowability of the powdered mix was assessed by angle of repose. Subsequently, the powdered mix was used to produce candy using an automatic tableting machine, Model EP200. The hardness and friability of the resulting candy were analysed.

Data Analysis, Model Fitting and Evaluation of Mixture Design

The software was used to analyse experimental data and create the models to define the relationship between components and responses. All responses were fitted to linear, quadratic, special cubic and cubic models. Statistical analyses were performed using analysis of variance (ANOVA). The model selection was based on the *p*-value of the model (must be lower than 0.05), coefficient of determination (R^2), adjusted R^2, predicted R^2, predicted residual sum of squares (PRESS) and lack of fix (*p*-value must be higher than or equal to 0.05).

Subsequently, the data were checked for normality and homogeneity using Box-Cox plots to determine if transformation was needed. Cook's distance was used to identify any outliers.

Optimisation of Candy Formulation

Based on the well fitted model obtained, optimisation was conducted to achieve the acceptable flowability and maximum value of hardness, while minimising friability of the candy with maximum RPOP content.

Flowability of powdered mix. The flowability of the ingredients was determined using the angle of repose as described previously.

Hardness of candy. Hardness of the candies was measured using a Texture Analyser, model TA.XTplusC (Stable Micro System, United Kingdom) according to Nakhon *et al*. (2023) with slight modification. A 30 kg load cell weight and a cylinder probe p35 were used. Five samples were compressed with a trigger distance of 1.6 mm and a force of 100 g. The maximum force recorded was defined as the hardness of the candies.

Friability of candy. Friability of the candy was determined using a friabilitor, model PI-FTV-01 (Pharmag Instruments, India). The test was conducted at a rotation speed of 25 rpm for 100 cycles. Initially, 10 tablets (candies) were weighed and placed in the friabilitor. After completing 100 cycles, the tablets (candies) were weighed again to determine the final weight. The weight loss was calculated by subtracting the final weight from the initial weight. The weight loss percentage, friability was determined as follows (Osei-Yeboah & Sun, 2015) Equations (2):

$$\text{Friability} = \left[\frac{(\text{Weight}_{\text{initial}} - \text{Weight}_{\text{final}})}{\text{Weight}_{\text{initial}}}\right] \times 100 \qquad (2)$$

Data Analysis

All experiments were performed in triplicate unless otherwise stated. Results are expressed as means ± standard deviations.

RESULTS AND DISCUSSION

Selection of Sugar Alcohol and Its Mesh Size

There are several types of sugar alcohols available in the market, such as erythritol, xylitol, sorbitol, maltitol and mannitol. Although many of these are claimed as zero calories, they do contain some calories. The results of the literature review and the calculated sweetness per calorie ratios are presented in *Table 1*. Most of the sugar alcohols exhibit lower sweetness compared to sucrose. However, erythritol has a high sweetness per calorie ratio of 2.5-3.5. This suggests that erythritol has lower calories while providing acceptable sweetness, making it a suitable ingredient for lower-calorie products while providing sufficient sweetness, particularly useful in products such as confectionery, beverages and baked goods (Li *et al*., 2023). Considering that obesity is a significant health issue in many countries, creating low-calorie products could be an effective approach to address this problem (Nogueira-de-Almeida & Filho, 2021). Besides, consumption of erythritol does not raise the blood sugar level and may help in preventing diabetes. It is also a good alternative for diabetic patients, allowing for controlled consumption without impacting blood sugar levels. Furthermore, candy made with erythritol does not pose the oral health problem, since it is not metabolised by oral bacteria that cause tooth decay. Therefore, in this study, erythritol with the highest sweetness per calorie ratio was selected for the development of the RPO candy.

Particle size significantly influences the flowability of ingredients. Generally, the granulated form (smaller mesh size) of the same ingredients exhibits better flowability than powdered forms (larger mesh size), as granulated ingredients have lesser interactions between particles (Mullarney *et al*., 2003). Although a small mesh size (big particles) offers better flow properties, it may cause granular separation when mixed with other fine particles. This phenomenon occurs when the larger particles tend to concentrate at the top and smaller particles settle at the bottom during shaking or vibration (Porion *et al*., 2004).

TABLE 1. SUGAR ALCOHOLS' SWEETNESS AND CALORIE CONTENT

Sugar alcohol	Relative sweetness to sucrose	Calorie (kcal/g)	Ratio (sweetness/ calorie)
Erythritol	0.5-0.7	0.2	2.50-3.50
Xylitol	1.0	3.0	0.33
Sorbitol	0.5-0.7	2.6	0.19-0.27
Maltitol	0.9	3.0	0.30
Mannitol	0.5-0.7	1.6	0.31-0.44
Sucrose (as reference)	1.0	4.0	0.25

Source: Health Canada (2005).

In this study, the flowability and granular separation effect of two common mesh sizes of erythritol (40-60 and 80-100 mesh sizes) were assessed after mixing with other candy-making ingredients to form the powdered mix. The powdered mix with 40-60 mesh erythritol exhibited higher flowability (good range); however, granular separation was observed after 700 taps. This indicates that the powdered mix using this mesh size of erythritol can cause a non-homogeneous sample during candy production. In contrast, the flowability of the powdered mix containing 80-100 mesh erythritol fell within the fair range, but no granular separation was observed after 700 taps. This suggests that the mix could flow freely during the feeding process of candy production while maintaining homogeneity with other ingredients. Flowable raw materials are essential in direct compression, as the materials must be able to flow and properly fill the mould. Raw materials that do not flow freely can form arches or ratholes in the hopper leading to production stoppage. Nevertheless, flowability can be improved using various tools such as vibratory feeders and stirring devices (Hörmann-Kincses *et al*., 2022). Therefore, erythritol with an 80-100 mesh size that ensures homogeneity and consistency was chosen for the production of RPO candy.

Screening of Binder and RPOP Range

In the candy production, binders play an important role in holding ingredients together. Binders are crucial as they determine the texture and structural integrity of the candy, such as its softness, or hardness, which ultimately affects the mouthfeel of the final product. The ability of various binders to form an intact candy with different amounts of RPOP is shown in *Table 2*. Powdered mixes using gum arabic and MCC as binders successfully formed intact candy with up to 20% of RPOP. However, when GRF and cooked GRF were used, the powdered mixes failed to form intact candy even at the lowest amount of RPOP (10%), indicating poor binding properties. Gum arabic not only demonstrated superior binding properties compared to other binders, but it also did not possess the dry mouthfeel effect associated with MCC. Therefore, gum arabic was chosen for the subsequent mixture design study, with the maximum range of RPOP set at 20%, beyond which intact candies could not be formed.

The following parameters, determined through screening, were incorporated into the mixture design: Erythritol (sweetener), 80-100 mesh erythritol, gum Arabic (binder) and RPOP (maximum 20%).

Evaluation of Mixture Design

Modelling fitting of the responses. The flowability of the powdered mix, hardness and friability of the produced candy, were determined and are presented in *Table 3*. None of the models fitted well with the flowability of the powdered mix, as *p*-values of the models were higher than 0.05, indicating non-significance in the models (data not shown). The observed variation in flowability, represented by the angle of repose, ranged between 36.94 and 40.58 (*Table 3*), indicating a narrow range. This suggested that the flowability of the powdered mix was not significantly influenced by the three components within the designed range. Generally, the flowability of the powder is greatly influenced by the oil content and the particle size of the ingredients.

Given that the powdered mix was made from erythritol with the same mesh size (80-100) and a narrow range of RPOP, the lack of statistical significance in the models was anticipated. Nevertheless, the angle of repose of the powdered mixes remained within the free-flow range (36-40) and none of the samples within 16 runs formed arches or ratholes in the hopper during the candy making process (Mat Dian *et al*., 2019). Even though no model could be built for flowability, it still fulfilled our objective. Widening the range of RPOP to more than 20% or below 10% to allow a model to be built, could lead to the production of broken candy for RPOP above 20%, while using less than 10% RPOP would compromise the purpose of making RPO candy.

Statistical analysis suggested that the best model for hardness was the quadratic model with a *p*-value of 0.0011 (significant), while for friability the best model was linear with a *p*-value of less than 0.0001 (*Table 4*). Model validation was assessed

TABLE 2. BINDER EFFECTIVENESS WITH DIFFERENT RPOP PERCENTAGES

Binder	RPOP % (w/w)				
	10	15	20	25	30
Gum arabic	O	O	O	X	X
Microcrystalline cellulose (MCC)	O	O	O	X	X
Glutinous rice flour (GRF)	X	X	X	X	X
Cooked GRF	X	X	X	X	X

Note: O - intact, X - not intact.

TABLE 3. COMPOSITION OF RPO CANDY (16 RUNS) AND THE RESPONSES

Run	Component			Responses		
	A (%)	B (%)	C (%)	Angle of repose (N/A)	Hardness of candy (N)	Friability (%)
13	62.4	20.0	11.1	39.73 ± 0.35	6.22 ± 0.50	28.64 ± 2.95
3	57.5	20.0	16.0	38.28 ± 0.62	8.45 ± 0.80	19.65 ± 6.48
11	67.6	15.9	10.0	38.67 ± 0.56	8.74 ± 0.51	19.30 ± 5.92
16	53.0	19.2	21.3	38.54 ± 0.25	8.83 ± 0.73	11.45 ± 3.02
14	63.6	14.5	15.4	39.50 ± 0.45	9.77 ± 0.51	12.27 ± 2.03
7	67.6	15.9	10.0	38.68 ± 0.32	9.85 ± 0.39	10.13 ± 3.70
12	50.0	16.4	27.1	38.83 ± 0.24	10.42 ± 0.74	4.64 ± 1.40
8	63.6	14.5	15.4	39.57 ± 0.29	11.75 ± 0.66	11.88 ± 2.97
2	50.0	16.4	27.1	37.70 ± 0.50	12.29 ± 0.69	8.66 ± 2.77
15	60.8	11.8	20.9	39.76 ± 0.25	16.27 ± 0.68	7.87 ± 5.08
4	60.8	11.8	20.9	36.94 ± 0.55	18.43 ± 1.35	6.16 ± 1.15
9	73.5	10.0	10.0	40.58 ± 0.38	18.44 ± 1.33	4.30 ± 0.56
6	60.8	11.8	20.9	38.52 ± 0.31	20.95 ± 1.47	4.81 ± 1.62
1	68.4	10.0	15.1	37.32 ± 0.29	22.70 ± 1.10	5.59 ± 3.85
5	56.0	10.0	27.5	37.65 ± 0.59	29.43 ± 1.16	3.46 ± 0.29
10	50.0	10.0	33.5	39.11 ± 0.37	31.30 ± 1.47	3.37 ± 1.23

Note: Mean value ± standard deviation; N - Newton; N/A - not applicable; A - erythritol; B - RPOP; C - gum arabic.

using indicators such as lack of fit, R² and other relevant metrics, as detailed below: The lack-of-fit was insignificant for both of the models, indicating a good fit to the data, with *p*-values of 0.6748 and 0.7107 for hardness and friability respectively. The hardness model also demonstrated a high R^2 of 0.9714, adjusted R^2 of 0.9571 and predicted R^2 of 0.9229, indicating a good fit and strong predictive power. The model's adequate precision of 24.56 (greater than 4) suggests a good signal-to-noise ratio (Kumar, 2022). For friability, the R^2, adjusted R^2 and predicted R^2 values were 0.8289, 0.8025 and 0.7207, respectively, indicating a good fit to the data with slightly lower predictive power. The adequate precision of the friability model was 16.88, which was also higher than 4. Cook's distance showed no outliers in the data for either response. The Box-Cox plot suggested that no data transformation was needed for hardness, while a log transformation of the data was needed for friability. Coded Equations (3) and (4) of the models are shown as follows:

$$\text{Hardness} = 19.28A + 47.30B + 31.66C - 95.96AB - 1.61AC - 123.07BC \quad (3)$$

$$\text{Log}_{10}\ \text{friability} = 0.831A + 2.12B + 0.44C \quad (4)$$

where A is Erythritol, B is RPOP and C is gum arabic.

Table 5 presents the coefficients along with the corresponding variance inflation factors (VIF) of the equation. The coefficients in the equation quantify the change in response for a one-unit change in the component, assuming all remaining components are held constant. A positive value indicates a positive effect, while a negative value indicates a negative effect on the response. VIF measures the multi-collinearity of the coefficients. If the value is 1, there is no correlation between the components. A VIF greater than 1 indicates multicollinearity. The greater the VIF, the more severe the correlation of factors.

Hardness of candy. The coefficients in *Table 5* indicate that gum arabic has a greater positive effect on the hardness of candy, with a coefficient of 31.66, compared to erythritol's coefficient of 19.28. The low VIF for both gum arabic (2.91) and erythritol (3.47) shows that their coefficients are less correlated with other ingredients, or higher accuracy towards the prediction of the hardness of the candy. Since both components positively affect the hardness of candy, it was anticipated that their interaction should produce a synergistic effect. However, the negative coefficient of erythritol and gum arabic combinations (AC), indicated that both ingredients counteract each other, resulting in a reduction in candy hardness. Fortunately, the antagonistic effect is just minor, with a coefficient of -1.61. Overall, the results suggest that an increase in these two components can help to improve the hardness of the candy but gum arabic has a more prominent effect due to its high coefficient value (31.66) and low VIF value (2.91). In order to improve the hardness of the candy one must increase the amount of gum arabic rather than erythritol.

TABLE 4. FIT SUMMARY OF THE MODELS

Suggested model	Source	Sequential *p*-value	Lack of fit *p*-value	R^2	Adjusted R^2	Predicted R^2	Adequate precision
Hardness	Quadratic	0.0011	0.6748	0.9714	0.9571	0.9229	24.56
Friability	Linear	<0.0001	0.7107	0.8289	0.8025	0.7207	16.88

Note: R^2 - coefficient of determination.

TABLE 5. COEFFICIENTS IN TERMS OF CODED FACTORS

Component	Coefficient			
	Hardness	VIF	Log_{10} friability	VIF
A	19.28	3.47	0.8296	1.47
B	47.30	62.83	2.1200	1.72
C	31.66	2.91	0.4448	1.35
AB	-95.96	33.63	-	-
AC	-1.61	2.58	-	-
BC	-123.08	24.47	-	-

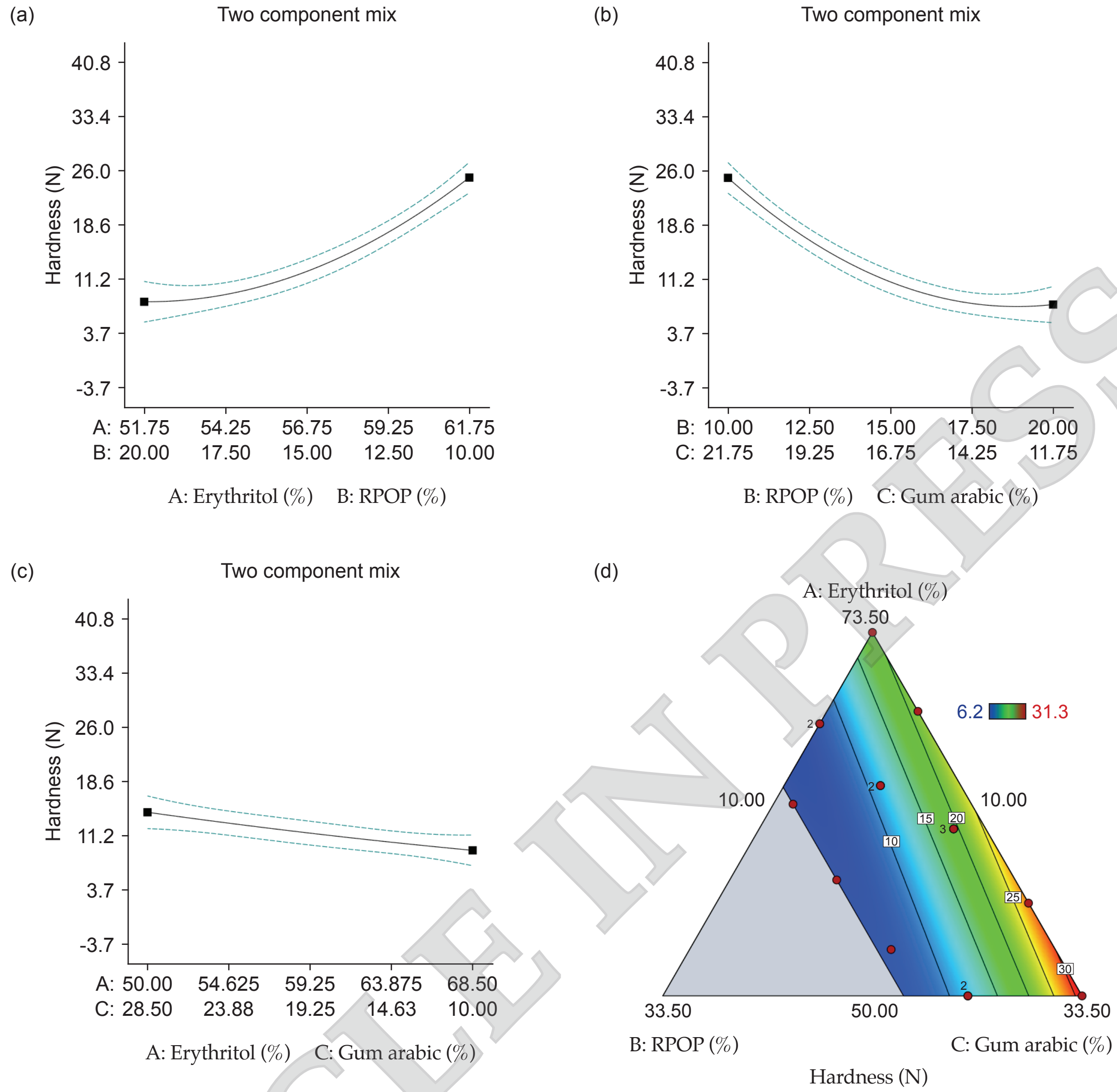
Note: VIF - variance inflation factor; A - erythritol; B - RPOP; C - gum arabic; AB - erythritol + RPOP; AC - erythritol + gum arabic; BC - RPOP + gum arabic.

Meanwhile, the RPOP which had the highest coefficient (47.30), reflects the greatest positive effect on the hardness of candy. However, the high VIF value (62.83) indicated that its coefficient was highly correlated with other components in the formulation. This is evident from RPOP's interaction with erythritol (AB), which had a negative coefficient value of -95.66, and interaction with gum arabic (BC), which had a negative value of -123.08. The result indicated that increasing the amount of RPOP in the formulation will have a substantial negative effect on the hardness of the candy. Similar results have been observed in hard candies, where an increase in liquid components (such as water or oil content) led to a reduction in hardness (Souiy *et al*., 2023). Overall, in order to maximise the RPOP, the Gum arabic amount should be increased to counterbalance the negative impact and the amount of erythritol must be reduced.

The interaction plot of two component mixes (AB, BC and AC) and a contour plot of three components on the hardness of candy are illustrated in *Figure 1*. The two component mixes in *Figure 1a-1b* revealed the non-linear interaction of RPOP with erythritol and gum arabic toward the hardness of the candy. When the percentage of RPOP reduced linearly (and other components increased linearly), the hardness of the candy increased exponentially. This shows a strong inverse relationship between RPOP content and candy hardness. In other words, the hardness of the candy was significantly influenced by the RPOP content, as a linear increase in RPOP can trigger a substantial exponential reduction in hardness (*Figure 1b*). To resemble a soft chewable tablet, the hardness of the candy should be above 1.5 kp (around 15 N) and should not exceed 12.0 kp (117 N) (Robinson *et al*., 2006; U.S. Food and Drug Administration [FDA], 2018). This implies that RPOP has to be kept low in the formulation to maintain the hardness of the candy within the soft chewable range. It can be deduced from *Figure 1b* that the maximum RPOP is approximately 12.5%.

Apart from this, the two-component mix plot of AC (*Figure 1c*) revealed that the linear interaction of erythritol and gum arabic blending on the hardness of candy, with gum arabic having a dominating effect on improving hardness (indicated by the increase of hardness when its amount increases). The contour plot (*Figure 1d*) summarises the effects of three components on the hardness of the candy. The colour transitions from dark blue through green to red, indicating an increase in hardness from low to high values. The plot also illustrated that the maximum hardness of the candy (~31 N) can be achieved with the lowest amount of RPOP and erythritol, with the maximum amount of gum arabic. Maximising RPOP in a candy production using direct compression while maintaining its hardness was a challenge nevertheless through adjustment of gum arabic content and sugar amount, the desired sweetness and hardness can be achieved.

Friability of candy. Friability is another criterion in tablet making. It describes the tendency of candy to break, chip and crumble under mechanical stress, such as handling, packaging and transportation. It can also be applied in candy making to determine how susceptible a candy is to mechanical stress (Zhao *et al*., 2022). High friability suggests that a candy is likely to break easily. Referring to Equation (4), RPOP (B) had a higher coefficient of 2.12, indicating a significant positive effect on friability of the candy,

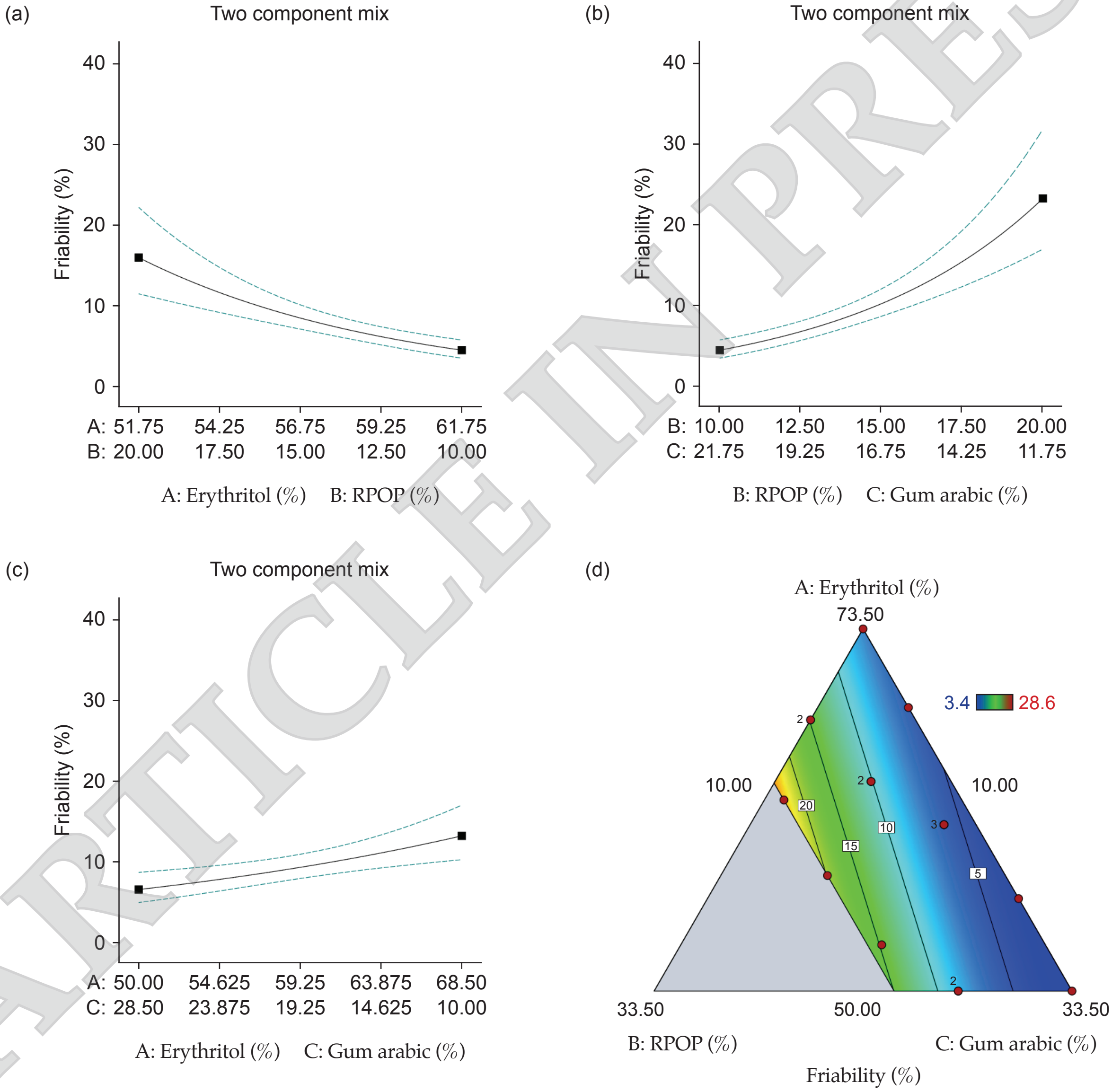


Note: The X-axis across the bottom of the two-component plot represents two variables. For instance, plot (a) the component associated with the X1 axis (A: Erythritol) increases in value from left to right in the top row, while the component associated with the X2 axis (B: RPOP) decreases in value from left to right in the bottom row. Dashed lines represent the 95.00% confidence interval. In the contour plots, colour represents the hardness of the candy, with values transitioning from low (blue) to high (red). The three values, A, B and C, are placed on the sides of the triangle, representing the maximum of each component for instance on the right side the 33.50 means 33.50% of gum arabic. The value at the middle of the triangle 50, 10, 10 represents the minimum value of opposite angle components, for example 50 indicates the minimum value of the erythritol in the design is 50.00%.

Figure 1. Two component mix plots (a, b and c) and contour plots (d) for the hardness of candy.

which is undesirable. In contrast, erythritol had a lower coefficient (0.8296), showing a moderate contribution to the friability of the candy. Gum arabic with the lowest coefficient value (0.4448), demonstrated that it can help reduce friability. With VIF values closer to 1 (as shown in *Table 5*), all the coefficients in the friability model can be considered to have a low correlation. This indicates that multicollinearity is not a concern in this model. Overall, the result suggests that an increase of RPOP in the candy could make it easier to break, while increase of gum arabic and erythritol improves this. Therefore, in order to maximise RPOP content in candy, it is unavoidable erythritol amount needs to be reduced, as gum arabic has a more prominent effect in reducing the friability.

The interaction plots of two-component mixes (AB, BC, AC) and a contour plot of three components on the friability of candy are illustrated in *Figure 2*. The two-component mix plots revealed that RPOP had a linear interaction with erythritol and gum arabic on the friability of the candy when its percentages was close to 10. An increase in RPOP in the formulation (while other components were reduced) caused an increase in friability. This suggests that the initial increase in RPOP is consistent and could predict friability, as evidenced by the closer 95% confidence interval (CI) bands (represented by the dashed line) in *Figure 2a-2b*. In contrast, as the RPOP percentages approach its maximum (20%) the friability tends to increase exponentially and becomes harder to predict, as illustrated by the wider 95% CI bands. This can be observed in the screening results, whereby the RPOP content increased by just 5% from 20%-25%, the candies broke down into pieces during production even without mechanical stress, indicating that the friability was 100% since the candies were not intact. Meanwhile, for the two-component plot of erythritol and gum arabic (*Figure 2c*), their effects towards the friability were linear with an increase in gum arabic reducing friability. The contour plot (*Figure 2d*) illustrates that gum arabic was the key component to maintain the low friability of candy, with erythritol having a similar but slightly lower effect. Low friability is important as it helps maintain the integrity of the candy.



Note: The X-axis across the bottom of the two-component plot represents two variables. For instance, plot (a) the component associated with the X1 axis (A: Erythritol) increases in value from left to right in the top row, while the component associated with the X2 axis (B: RPOP) decreases in value from left to right in the bottom row. Dashed lines represent the 95.00% confidence interval. In the contour plots, colour represents the friability of the candy, with values transitioning from low (blue) to high (red). The three values, A, B and C, placed on the sides of the triangle, represent the maximum of each component for instance on the right side the 33.50 means 33.50% of gum arabic. The value at the middle of the triangle 50, 10, 10 represents the minimum value of opposite angle components, For example 50 indicates the minimum value of the erythritol in the design is 50.00%.

Figure 2. Two-component mix plot (a, b and c) and contour plot (d) for the friability of the candy.

In pharmaceuticals, polyvinylpyrrolidone and similar types of binders are used to improve or reduce friability (Kurakula & Rao, 2020). Although these binders are effective in direct compression formulations, they have seldom been used in food products due to concerns regarding their safety and regulatory status. In this study, we demonstrate that achieving lower friability is feasible by adjusting the content in the formulation.

Optimisation of Red Palm Oil Powder

Higher RPOP content in candy is desirable and preferable since it offers optimal health benefits. Unfortunately, it also compromises the candy's resistance to mechanical stress and reduces its hardness. Therefore, optimisation should consider maximising the RPOP and the hardness of the candy while minimising friability. In the optimisation procedure, the goal of RPOP and hardness was set to maximum; while friability was set to minimum. However, the suggested formulation had a very low desirability score of 0.448. Therefore, the goal was adjusted to set the RPOP in range given the significant impact of RPOP on the hardness and friability of the candy. The new optimum formulation of the candy as suggested by the mixture design comprised 50.00% erythritol, 10.00% RPOP and 33.50% gum arabic, with an acceptable desirability of 0.834. The experimental values for the candy's hardness (29.61 ± 2.09 N) and friability (3.87 ± 0.84%) fell within the 95.00% prediction intervals.

CONCLUSION

Erythritol, with a high sweetness-to-calorie ratio of 2.5-3.5, emerged as an ideal sweetener for RPO candy production. Its mesh size (80-100) played an important role in the homogeneity of the powdered mix. Together with the most effective binder, gum arabic helped improve candy hardness and reduce friability, which were negatively affected by the oily ingredient RPOP. The optimisation result showed that the desirable amounts of erythritol, RPOP and gum arabic in RPO candy production were 50.00%, 10.00% and 33.50%, respectively. The resulting candy had moderate hardness (around 30 N) and low friability (3.87%) fell within 95.00% of the predicted interval, indicating that the optimised formulations met the desired quality standards. This formulation can serve as a healthier confectionery product and a convenient means of delivering RPO to consumers. This product aligns with the current market trend toward healthier options for those seeking to reduce sugar intake as well as enjoy the health benefits of RPO without compromising on taste. The success will motivate RPO manufacturers to look into another food segment such as snacks and ready-to-eat products. Lastly, future studies such as sensory studies and large-scale products should be conducted to further understand consumer preferences and challenges regarding scalability.

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