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Development of citrus peel by-product as a slice jam by using two-level factorial design

Wan Fatimah Wan Mohd Nowalid [a,b], Hazrulrizawati Abd Hamid [a,*], Shehu Hadiza Giwa [a,c]

[a] Faculty of Industrial Sciences and Technology, Universiti Malaysia Pahang Al-Sultan Abdullah, Lebuh Persiaran Tun Khalil Yaakob, 26300, Gambang, Kuantan, Pahang, Malaysia
[b] Jabatan Pendidikan Politeknik dan Kolej Komuniti JPPKK, Aras 4-7, Galeria PJH, Jalan P4W, Persiaran Perdana, 62100 Putrajaya, Malaysia
[c] Kaduna State University, Tafawa Balewa Way P.M.B. 2339, Kaduna, Nigeria

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ABSTRACT

Natural slice jam from the citrus peel is a product that enhances the economic value of the waste of citrus fruit peel. The goal of the study was to improve a recipe for a natural jam made entirely from citrus peel and shaped into a square to make it a more convenient and ready-to-eat product. A two-level factorial design was used to investigate the effects of four independent variables; X1: concentration lemon peel (*Citrus limonum*), X2: concentration orange peel (*Citrus sinensis*), X3: storage temperature, and X4: sugar. Sample processing was performed at range between 10 and 20 g of lemon and orange peel concentration and sugar (6–10 g) at a constant gelatine weight of 1.6 g. The samples were stored at 2 °C and 25 °C, and textural properties (hardness and adhesiveness) were evaluated. Results indicated that concentrations of lemon peel (10 g), orange peel (15 g), sugar (8 g), and storage temperature (13.5 °C) significantly influenced jam texture. Interaction effects, including AD, BC, and BD, were notable. Optimal conditions favoured higher orange peel concentration. Validation experiments confirmed a maximum 10 g lemon peel concentration with an error below 10%. Despite room temperature storage causing textural quality deterioration due to syneresis, this study contributes valuable insights for food industry applications of natural products, greener and more cost-effective. The factorial design approach effectively optimized citrus peel slice jam formulation, demonstrating the significance of applied sciences in addressing practical challenges.

1. Introduction

Global food demand is rising mainly due to the growing world population, and hunger indicators, in conjunction with the problems associated with nutrition today (Torres-León et al., 2018). A great alternative to secondary food products is the development of food using food byproducts or waste from various agro-industries. Transforming these by-products into functional foods not only addresses waste reduction but also serves as a potent strategy to combat hunger (Socas-Rodríguez et al., 2021). amplify.

Oranges, grapefruits, lemons, limes, tangerines, and mandarins are just a few of the citrus fruits commonly grown worldwide. Due to escalating consumer demand, manufacturing of citrus products grows yearly. Citrus waste, made up of non-edible peel and pulp, is produced in significant amounts during industrial processing and accounts for more than 50% of the weight of the fruit (Kim et al., 2022). Citrus peels are produced in enormous quantities worldwide and pose a threat to the environment in many regions (Khan et al., 2021). Typically, these peels are discarded, contributing to environmental concerns. The food processing business produces over 120 million tons of trash from the citrus industry each year, which is among the highest when compared to other fruits by about 30 to 50% (Wedamulla et al., 2022). In many countries, both industrialized and developing, the peels constitute an environmental menace. However, plenty of countries are currently searching for the possible utilization of the peels. The growth and expansion of the citrus industry has been hampered in different regions of the world due to the challenge of converting these wastes into economically viable products. Several countries have given significant focus on the transformation of waste into energy (Abdel-Raheem et al., 2022; Abdelhafeez et al., 2022; Kaid et al., 2022; Shamsan et al., 2023). The use of environmentally friendly techniques for the recovery and recycling of commercially valuable materials from citrus waste causes this capital-

* Corresponding author.
E-mail address: hazrulrizawati@umpsa.edu.my (H.A. Hamid).

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intensive operation to become unachievable for many poor countries. Therefore, it is necessary to explore the potential of converting this waste into functional food products.

The excellent nutritional composition of fruit and vegetable by-products makes them suitable for incorporation into various food categories, including baked goods and jams, owing to their outstanding nutritional profile. Jams are inexpensive to produce, simple to prepare, transport, and stored. Addition of citrus fruit peel in various food products, especially for jam, has favorable effects. The addition of sweet lemon peel to jam increased firmness and chewability, enhancing quality (Matsuo et al., 2022; Teixeira et al., 2020). Therefore, the primary objective of the research is to optimize the production of citrus peel slice jam using lemon and orange peel waste, with the main goal of enhancing the economic value of citrus fruit peel waste and reducing waste in the citrus industry. To achieve this, the researcher employs a 2^4 fractional factorial design to systematically investigate the effects of four independent variables, including the concentration of lemon peel, the concentration of orange peel, storage temperature, and sugar, on the quality and textural properties of the jam. These objectives are aligned with the principles outlined in the paper's abstract, emphasizing the optimization, quality enhancement, and sustainability of citrus peel slice jam production.

2. Material and methods

2.1. Raw materials

Two types of citrus peel were employed: lemon peel (*Citrus limonum*) and orange peel (*Citrus sinensis*). These two citrus peels were collected from Kempadang Restaurant in Kuantan, Pahang for the jam preparation. The peels were thoroughly washed with water and placed in an airtight container. The peels were kept in the refrigerator at 8 °C until the preparation of the jam. The white sugar and gelatine were sourced from Variasi Biz Trading.

2.2. Formulations of citrus peel slice jam

According to the standard guideline by World Health Organization (2020) in conventional techniques to produce fruit jams, the fruit content used must be at least 40% and the total sugar content must be not less than 68%. Citrus peel slice jam formulation was adapted from conventional jam formulation and modified with the addition of gelatin and reducing the amount of sugar used. A total of eight formulations of different concentrations of lemon peel (Factor A: 10.0–20.0 g), orange peel (Factor B: 10.0–20.0 g), sugar (Factor D: 6.0–10.0 g), and a constant amount of gelatine (1.6 g) are presented in Table 1. Lemon and orange peel slice jam samples were packed in plastic containers and underwent a testing period of 2 weeks with periodic evaluations. To simulate different storage conditions, half of the samples were stored under refrigeration at 2 °C, while the remaining half was stored at 25 °C. This storage arrangement allowed us to monitor the jam's characteristics and textural properties under varied temperature conditions throughout the 2-week testing period. The responses, including hardness and adhesiveness, were measured to evaluate the quality of the jam formulations.

2.3. Preparations of citrus peel slice jam

The procedure commenced with the individual measurement of citrus peel, sugar, and gelatine. Subsequently, the citrus peel was transformed into a puree by blending it with water, ensuring the attainment of the desired texture. The desired texture for the citrus peel puree was aimed to be a smooth and homogeneous consistency, ensuring a well-integrated blend of the citrus peel, sugar, and gelatine. This puree texture was crucial for achieving a uniform distribution of ingredients and, ultimately, the desired characteristics in the final product, citrus peel slice jam. A mixture of sugar and citrus peel puree was cooked in saucepans. The gelatine powder was added to this cooking mixture after the sugar had been adequately dissolved. The cooking process was conducted at a medium temperature of 105 °C for less than 5 min until the cooking of the jam achieved the desired setting. The mixture of lemon and orange peel was filled in the mold and stored in a chiller at 2 °C.

2.4. Texture parameter

2.4.1. Investigating the textural parameters of citrus peel slice jam

In Texture Profile Analysis (TPA), the textural characteristics such as hardness and adhesiveness of citrus peel Slice Jam were analysed by using Brookfield Engineering Labs. Inc. texture analyser device (TextureProCTV1.8 Build 31 model, USA) with a loading cell capacity of 50 kg. The 16 samples for eight formulations were placed on the fixture base table of the texture analyser and 25.4 mm cylindrical probe TA11/100 was used to test the hardness and adhesiveness by positioning the probe 10 mm above the test sample. The pre-test speed for the probe attached to the sample was 1 mm/s. The data of textural parameters were generated after the probe touched the sample and detects a trigger load 509.86-gram force. The test was repeated three times for each formulation.

2.5. Experimental design and statistical analysis

The Design Expert software (Version 13, Stat-Ease Inc., Minneapolis,

Table 1
2^4 fractional factorial design center points and other points in random order.

		Factor 1	Factor 2	Factor 3	Factor 4	Response 1	Response 2
Std	Run	A: Lemon	B: Orange	C: Storage Temperature	D: Sugar	Hardness Cycle 1	Adhesiveness
		g	g	°C	g	N	mJ
8	1	20.0	20.0	25.0	6.0	295.38	6.2
12	2	20.0	20.0	2.0	10.0	128.27	9.4
14	3	20.0	10.0	25.0	10.0	326.12	9.2
4	4	20.0	20.0	2.0	6.0	372.31	5.1
9	5	10.0	10.0	2.0	10.0	93.51	7.6
16	6	20.0	20.0	25.0	10.0	188.93	3.6
6	7	20.0	10.0	25.0	6.0	350.24	7.2
11	8	10.0	20.0	2.0	10.0	104	5.9
7	9	10.0	20.0	25.0	6.0	382.75	14.3
1	10	10.0	10.0	2.0	6.0	378.39	7
10	11	20.0	10.0	2.0	10.0	348.97	5.6
3	12	10.0	20.0	2.0	6.0	369.81	5.5
13	13	10.0	10.0	25.0	10.0	250.12	23.1
2	14	20.0	10.0	2.0	6.0	89.2	6.2
5	15	10.0	10.0	25.0	6.0	336.96	9.8
15	16	10.0	20.0	25.0	10.0	351.13	10.4

USA) for screening through a two-level factorial design to identify experimental variables and interactions significantly influencing citrus peel slice jam production. Employing a 2^4 fractional factorial design, the researcher systematically investigated the effects of four independent variables: concentration of lemon peel, concentration of orange peel, storage temperature, and sugar, on the quality and textural properties of the jam. In further, the experimental data were analyzed to fit the following first order multinomial equation (Eq. (1)):

$$Y = \beta_o + \sum_{i=1}^{n} \beta_i X_i \quad (1)$$

Regarding to the Eq. (1), Y represents the value of the responses, β_o is the constant coefficient, n is the number of variables, β_i represents the coefficient of the linear parameters, and *Xi* represents the coefficient of the interaction parameters. Four independent variables were X1: The concentration of lemon peel (A) (10–20 g), X2: The concentration of orange peel (B) (10–20 g), X3: Storage temperature (C) (2–25 °C) and X4: Sugar (D) (6–10 g). Responses investigated for duplicates at high (+) and low (−1) levels were hardness and adhesiveness, as detailed in Table 1. These factors were selected based on the main used to evaluate the suitability of the model and to achieve objective in producing an innovative and nutritious slice jam from citrus peel waste. In addition, the selected factors became a novel and essential ingredient by transforming the waste into beneficial food production.

A 2^4 fractional factorial design with 16 runs was carried out for all the parameters, as indicated in Table 2. The order of the running experiments was restrictedly randomized to eliminate possible bias (Sharif et al., 2021). Variables with a significant impact on texture analysis were found based on a confidence level above 95% (p-value < 0.05), as indicated by the two-level factorial design data. In addition, significant components and interactions were determined from the half-normal plot analysis. Effects and interactions were assessed to create a first-order model for texture response. The significance of the linear effect of the variables was evaluated and supported by an analysis of variance (ANOVA) following a linear regression analysis. In addition, the coefficient of determination R^2 (R-square) and the Adjusted R^2 coefficient were used to evaluate the suitability of the model.

3. Results and discussions

Two-level factorial design is used as a screening method to determine which of the four variables most significantly affects the results of citrus peel slice jams formulation. The design comprises 16 experiments. Independent variables that have a higher impact on the dependant variable response results of citrus peel slice jam formulation were detected through filtering design.

3.1. Factorial design analysis of variance (ANOVA)

The analysis of variance (ANOVA) for citrus peel slice jam formulation was prepared to determine the significance of the model. F-value was used to observe the significance of each variable, while the p-values were used to examine the significance of each coefficient (Samad & Zainol, 2017).

The model F-value of 599.35 indicates the significance of the model, with a corresponding p-value of 0.0320, which is less than the 0.0500 threshold. This implies that there is only a 3.20% chance that an F-value of this magnitude could occur due to noise. In this case A, B, C, D, AB, AD, BC, CD, ABC, ABD, ACD, BCD, ABCD are significant model terms. The model displays a good data fit with coefficient of determination (R^2). The R^2 (0.9999) from the ANOVA table is used to indicate how close the data to the regression line. The satisfactory R^2 value obtained from the hardness analysis (0.9999) and R^2 value > 0.9, which indicates that the model fits the experimental and predicted values well (Ya'acob et al., 2022). The relationship of hardness with the four factors represents by the codified linear regressions Eq. (2).

$$\begin{aligned}\text{Hardness, } Y_1 = {} & 599.35 - 76.92A + 87.24B + 980.61C + 1690.13D \\ & - 213.05AB + 64.65AC - 844.90AD - 33.01BC \\ & + 720.42BD - 224.81CD - 438.54ABC + 1199.37ABD \\ & + 920.34ACD + 575.87BCD + 408.29ABCD \end{aligned} \quad (2)$$

Table 2 summarize the ANOVA results for the hardness (Y_1) of citrus peel slice jam. The interactions identified in the model are related to the formulation and texture of citrus peel slice jam. Each interaction represents a combination of independent variables and their combined effect on the response variable, which is the hardness of the jam. The significant interaction between lemon peel concentration and sugar (AD) indicates their effects to the hardness of the jam. This interaction can be explained physically when the amount of lemon peel concentration increases, the acidity of the jam may also increase due to the presence of citric acid in lemon peel. The increase in acidity may affect the gel formation process, leading to changes in the hardness with varying levels of sugar. The interaction between orange peel concentration and storage temperature (BC) suggests that the hardness of the jam is influenced by both the amount of orange peel concentration and the storage temperature. At higher storage temperatures, the pectin in

Table 2
ANOVA (Analysis of variance) of Factorial design for jam hardness (Y_1).

Source	Sum of Squares	Df	Mean Square	F-value	p-value	
Model	1.907E + 05	14	13622.66	599.35	0.0320	significant
A-Lemon	1748.29	1	1748.29	76.92	0.0023	
B-Orange	3379.13	1	3379.13	87.24	0.0224	
C-Storage Temperature	22288.25	1	22288.25	980.61	0.0203	
D-Sugar	38415.02	1	38415.02	1690.13	0.0155	
AB	4842.42	1	4842.42	213.05	0.0435	
AC	1469.38	1	1469.38	64.65	0.0488	
AD	19203.72	1	19203.72	844.90	0.0219	
BC	750.35	1	750.35	33.01	0.0032	
BD	16374.40	1	16374.40	720.42	0.0237	
CD	5109.75	1	5109.75	224.81	0.0424	
ABC	9967.53	1	9967.53	438.54	0.0304	
ABD	27260.49	1	27260.49	1199.37	0.0184	
ACD	20918.56	1	20918.56	920.34	0.0210	
BCD	13089.08	1	13089.08	575.87	0.0265	
ABCD	9279.95	1	9279.95	408.29	0.0315	
Residual	22.73	1	22.73			
Cor Total	1.907E + 05	15				
R^2	0.9999					
Adjusted R^2	0.9982					

the orange peel may undergo changes, affecting the gel formation process and consequently effect the hardness of the jam. The identified interactions have meaningful physical implications for the textural properties of citrus peel slice jam. Understanding these interactions is crucial for explaining the model and optimizing the formulation to achieve the desired texture and quality of the jam.

Regarding to second response Y_2 (adhesiveness), ANOVA analysis of citrus peel slice jam (Table 3), the Model F-value of 22.75 indicates the model is significant with a p-value less than 0.0500 (p-value, 0.0429). There is only a 4.29 % chance that a Model F-Value this large could occur due to noise. In this case A, B, C, D, AB, AC, AD, BC, BD, CD, ABC, ABD, ACD, BCD and ABCD are significant model terms. The model displays a good data fit with coefficient of determination (R^2). The R^2 (0.9933) from the ANOVA table is used to indicate how close the data to the regression line. The relationship of adhesiveness with the three factors represents by the codified linear regressions Eq. (3). Y_1 referred as the response of hardness (N) and Y_2 adhesiveness (mJ), respectively.

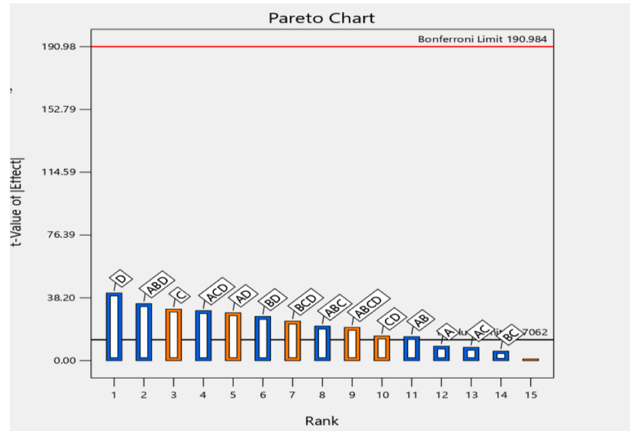
Factors of A (lemon), B (orange), C (storage temperature) and D (sugar) referred to the main effects.

$$\begin{aligned}\text{Adhesiveness},\ Y_2 = {} & 8.51 - 1.94A - 0.9563B + 1.97C + 0.8438D \\ & + 0.4688AB - 1.98AC - 0.4563AD - 0.8938BC \\ & - 1.07BD + 1.11ABD - 0.7938ACD - 1.66BCD \\ & + 0.4688ABCD\end{aligned} \quad (3)$$

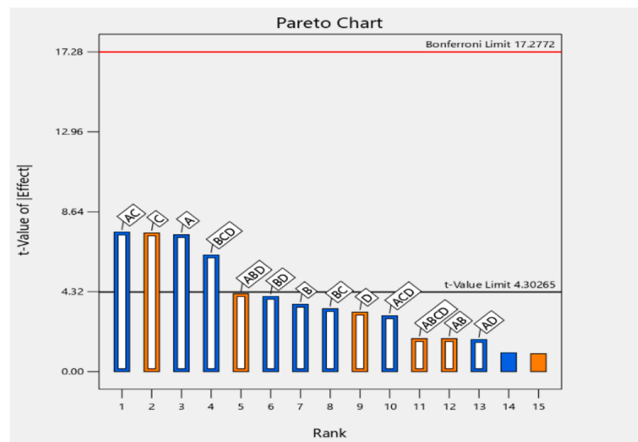
3.2. Main factors effect

The main effects of the factors for the hardness and adhesiveness of citrus peel slice jam displayed by Pareto charts shown in Fig. 1(a) and (b) respectively. The chart is very useful to analyse the most significant factors. Based on the Pareto chart in Fig. 1, the orange colour indicates a positive effect, when the factors present at higher levels, the hardness or adhesiveness of the jam will increase. This may be attributed by the factors of gel formation or improved texture stability. Conversely, factors represented by the blue color signify a negative effect on the properties being measured. When the factors present at higher levels, the hardness or adhesiveness of the jam will decrease. This decrease may be due to adverse effects on the gel structure or texture stability, leading to softer or less adhesive jam (Kadiri et al., 2019). The height of the bars presents the impact of the factors. The t-values of the bars are the values of the square root of the F-values from ANOVA. Two limit lines, namely Bonferroni limit line and t-value limit line, present the t-value of the effects (Mesiarová-Zemánková et al., 2018).

Fig. 1(a) displays the value of Bonferroni limit line and t-value limit line on the Pareto chart of hardness are 190.984 and 12.7062, respectively. The Pareto chart clearly shows that the factors of C, D, AB, ABC, ABD, ACD, AD, BD, BCD, CD and ABCD exceed the t-value limit of 12.7062 and have significant effects on the hardness of citrus peel slice jam formulation. Coefficient is probable to be significant when the t-value of effect is between the Bonferroni line and the t-value limit line (Samad & Zainol, 2017).



(a) Hardness



(b) Adhesiveness

Fig. 1. Pareto chart for factorial analysis of hardness and adhesiveness in citrus peel slice jam formulation.

The value of the Bonferroni limit line (17.2772) and t-value limit line

Table 3
ANOVA (Analysis of Variance) of Factorial Design for Jam Adhesiveness (Y_2).

Source	Sum of Squares	Df	Mean Square	F-value	p-value	
Model	326.26	13	25.10	22.75	0.0429	significant
A-Lemon	60.45	1	60.45	54.80	0.0178	
B-Orange	14.63	1	14.63	13.26	0.0254	
C-Storage Temperature	62.02	1	62.02	56.22	0.0173	
D-Sugar	11.39	1	11.39	10.33	0.0324	
AB	3.52	1	3.52	3.19	0.0162	
AC	62.81	1	62.81	56.93	0.0171	
AD	3.33	1	3.33	3.02	0.0244	
BC	12.78	1	12.78	11.59	0.0465	
BD	18.28	1	18.28	16.57	0.0454	
ABD	19.58	1	19.58	17.75	0.0320	
ACD	10.08	1	10.08	9.14	0.0301	
BCD	43.89	1	43.89	39.79	0.0242	
ABCD	3.52	1	3.52	3.19	0.0162	
Residual	2.21	2	1.1			
Cor Total	328.47	15				
R^2	0.9933					
Adjusted R^2	0.9496					

(4.3027) on the Pareto chart of adhesiveness on citrus peel slice jam. From the Pareto chart, factors A, ABD, AC, BCD, and C exceed the t-value limit of 4.3027 (Fig. 1(b)). These factors had significant effects on the adhesiveness values of citrus peel slice jams.

3.3. Interaction effects between factors on hardness and adhesiveness of citrus peel slice jam

Hardness is the force required to achieve a certain amount of deformation (Nourmohammadi et al., 2021). It is a standard parameter in determining jam texture. Based on Fig. 2, the colours are intended to represent the high (+1) and low (−1) levels of parameters, as indicated by the key. Specifically, the red lines correspond to the high level (+1), while the black lines represent the low level (−1).

Fig. 2(a) shows the plot of the significant interaction effect between lemon and sugar (AD) on the results of hardness. Notice that the effect of lemon peel concentration on the hardness of the citrus slice jam depends on the level of sugar concentration, represented by the two lines on the graph. From the figure, the highest hardness 382.75 N was attained at 26.6% lemon. Meanwhile, the lowest hardness 89.2 N reached 53.2% in the lemon peel concentration. Thus, the results showed that the hardness of the citrus peel slice jam decreased with the increased amount of lemon peel concentration. As per early expectation by the researcher, with the increased amount of lemon and orange peel, the acidity of the concentration will be increased, therefore, affecting the hardness of the citrus peel slice jam. It proves the early research by Natnicha et al., (2019) that the acidity value affects the gel formation of the slice jam. Hence, the gel increases in hardness as the acidity decreases. Acidity was crucial, and it influenced the texture of jams. Other than that, sugar also may contribute to the hardness response. The results demonstrated when the amount of sugar increased, the hardness of the citrus peel slice jam decreased. The decrease in hardness could be recognized as the weakening of the gelling agent and the release of a large amount of water makes the slice jam softer (Nourmohammadi et al., 2021).

Fig. 2(b) clearly shows a significant interaction between orange peel concentration and storage temperature (BC) on the hardness of the citrus peel slice jam. The line contributed to the negative effect whereby the figure shows that the hardness of the citrus peel slice jam would decrease with the increased amount of orange peel concentration (53.2%) at the high temperature (25 °C). The highest value of hardness is 382.75 N, while the lowest value is 89.2 N. The slice jams stored at ambient conditions exhibited more significant changes in texture than jams stored at chill temperature. The researcher suggested that jam prepared from citrus peel cannot be stored for long periods at room temperature. Jam stability was better at 2 °C than 25 °C. Thus, the interaction of the orange peel concentration-storage temperature factor significantly affects the hardness texture of citrus peel slice jam.

Based on Fig. 2(c), the plot of the significant interaction effect between orange and sugar (BD) on the results of adhesiveness. Adhesiveness, also known as stickiness, denotes the work required to overcome

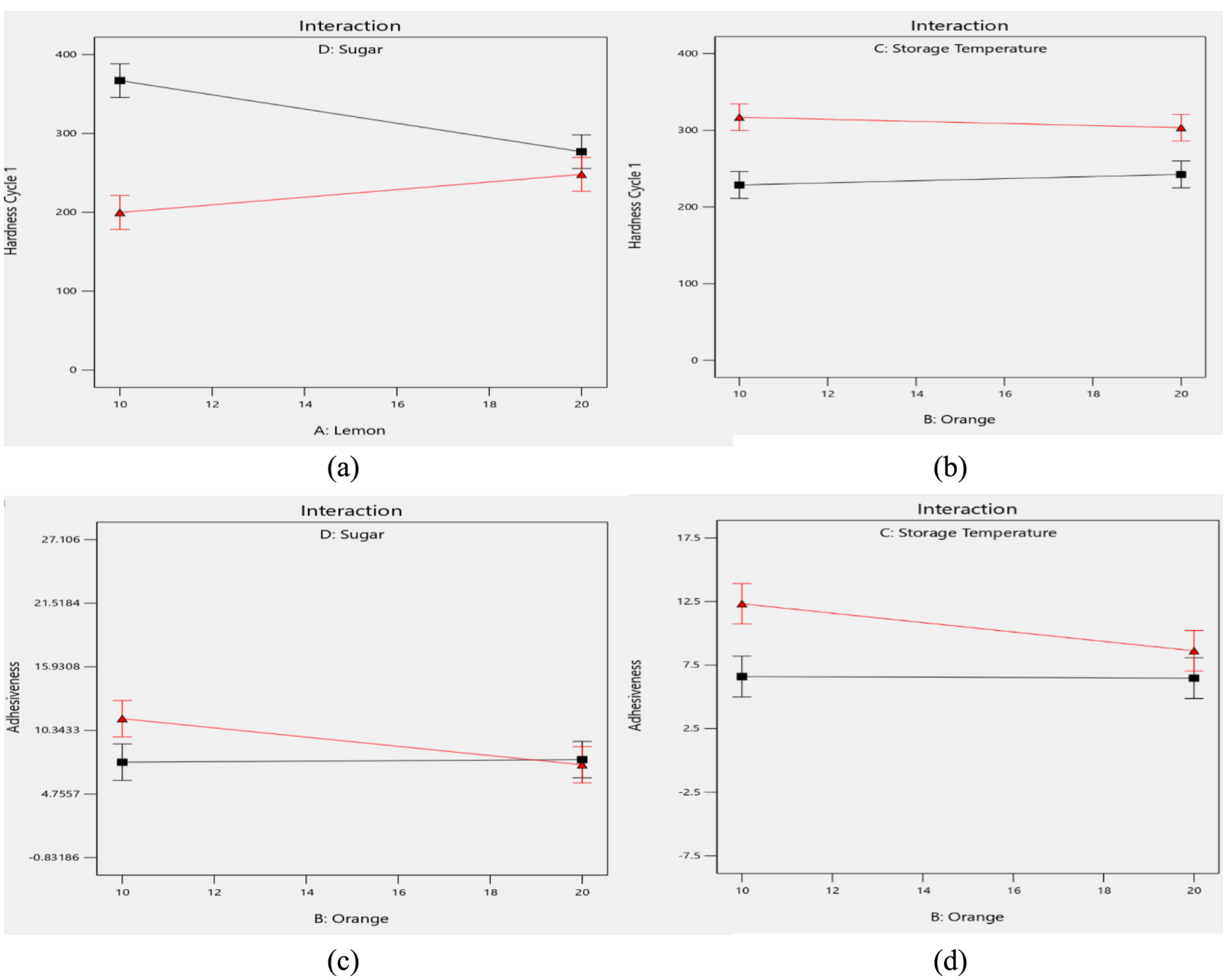


Fig. 2. Plot of significant interaction effect between (a) lemon and sugar (AD) and (b) orange and storage temperature (BC) on the results of hardness and (c) orange and sugar (BD) and orange and storage temperature (BC) on the results of adhesiveness. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Table 4
Suggested best conditions for citrus peel slice jam formulation.

Factors	Best conditions
Lemon	10 g
Orange	15 g
Sugar	8 g
Hardness	283.334 N
Adhesiveness	10.45 mJ

the attractive forces between the food's surface and the material's surface with which the food contacts the tongue, teeth, and palate (Yusof et al., 2019). Based on the result obtained from the two-level factorial design, the highest adhesiveness is 14.3 N, and the lowest is 3.6 N. The results demonstrated that when the amount of sugar increased with the increased amount of orange peel concentration, the adhesiveness of the citrus peel slice jam decreased. Thus, the results showed that the adhesiveness responded to the acidic point-like hardness. The adhesiveness of citrus peel slice jam decreased with the increased amount of lemon and orange peel concentration.

Sugar plays a vital role in the slice jam shapes and functions as a natural food preservative (Ab. Rahim et al., 2022). Sugar was observed to affect the texture and plays an important role in maintaining the gluey texture of the citrus peel slice jam and increasing the gelatine solution's glueyness (Saad et al., 2021).

Fig. 2(d) shows a significant interaction between orange peel concentration and storage temperature (BC) on the adhesiveness texture of citrus peel jam. It indicated that the citrus slice jam's adhesiveness response depends on the storage temperature level and amount of orange peel concentration. The two lines on the graph represent it. Thus, the results showed that the adhesiveness of the citrus peel slice jam slightly changed with the increased amount of orange peel concentration at a low temperature.

3.3.1. *Syneresis analysis in citrus peel slice jam*

While the interaction effects between factors have offered valuable insights into the hardness and adhesiveness of citrus peel slice jam, it is crucial to explore another critical aspect which is syneresis. Syneresis, the release of water from the gel-like structure, can significantly influence the overall texture and stability of the jam.

The gel formation and texture stability of the citrus peel slice jam, attributed to factors like pectin content, play a crucial role in shaping the product's quality. Pectin, inherent in citrus peel, contributes to gel formation, providing the desired shape and firmness. The water-holding capacity (WHC) of fruit dietary fiber, particularly pectin, it becomes apparent that the jam benefits from a mechanism that helps prevent syneresis by binding the released water.

However, findings also reveal that storage conditions, especially warmer and fluctuating environments, can exacerbate the syneresis effect. The decrease in hardness and adhesiveness observed during storage at room temperature for two weeks is attributed to syneresis. The released water, no longer physically bound to the jam, leads to alterations in the overall consistency and structure.

This analysis underscores the importance of not only optimizing the formulation for desirable textural properties but also considering strategies to mitigate the syneresis effect during storage. Future research avenues may explore ways to enhance the jam's shelf life and maintain textural quality under various storage conditions.

3.4. *Validation studies*

In this study, to determine the optimal conditions for the citrus peel slice jam formulation, all four independent variables (factors: lemon peel concentration, orange peel concentration, storage temperature and sugar) and dependent variables (responses: hardness and adhesiveness) were considered in range. The higher value of the experiment is 25 g of lemon and orange peel concentration. The error of lemon peel concentration is below 10% making this experiment validated to study. This error normally is caused by random and systematic errors which can be observational, environmental, or instrumental. The validation experiment was performed to identify the error between the predicted and experimental results based on the suggested best condition to achieve the greatest textural properties for citrus peel slice jam formulation. Therefore, Table 4 shows that the best condition for the development of citrus peel slice jam formulation is by using more orange peel rather than lemon peel: orange peel (15 g), lemon peel (10 g), and sugar (8 g).

4. Conclusion

The present study aimed to produce citrus peel slice jam using lemon and orange peel to achieve the desired textural properties. To achieve this goal, the two-level factorial design in Design Expert software was used to optimize the lemon peel concentration, orange peel concentration, storage temperature, and sugar levels. The analysis identified these independent variables significantly affecting citrus peel slice jam formulation. In addition, the interaction of lemon peel concentration and sugar (AD), orange peel concentration and storage temperature (BC), and orange peel concentration and sugar (BD) were also significant in hardness and adhesiveness value. As shown in the Pareto chart, the orange peel concentration was the most significant factor for citrus peel slice jam formulation. At the end of the study, 2LFD suggested the best condition formulation is the amount of orange peel used is more than lemon peel. On the other hand, through the validation experiment, a maximum of 10 g of lemon peel concentration achieved an error of less than 10%. The findings revealed that during stored citrus slice peel at room temperature for two weeks, the hardness and adhesiveness texture of the slice jam were decreased. Syneresis was the main cause of textural quality deterioration, whereby the storage place was too warm and fluctuated. This work aligns with the broader literature emphasizing the high importance of applied sciences, particularly in the context of agricultural and food-related research. The addition of these references underscores the relevance of our research within the broader scientific landscape and highlights the practical implications of our findings in the field of agriculture sciences. In conclusion, this research has successfully utilized a factorial design approach to optimize the formulation of citrus peel slice jam and has identified critical factors influencing its textural properties. The findings offer valuable insights for the food industry, demonstrating the significance of applied sciences in addressing practical challenges. Further studies may explore strategies to mitigate the syneresis effect and extend the shelf life of such products.

CRediT authorship contribution statement

Wan Fatimah Wan Mohd Nowalid: Writing – review & editing, Writing – original draft, Formal analysis, Conceptualization. **Hazrulrizawati Abd Hamid:** Writing – review & editing, Supervision, Project administration.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

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