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STUDY ON OPTIMIZATION OF PECTIN EXTRACTION FROM UNRIPE BANANA PEEL (*Musa* sp.)

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ABSTRACT

Pectin is a valuable polysaccharide widely used in the pharmaceutical and food industries. Pectin is usually obtained from a variety of plant sources. The quality and sell price of pectin depends on many different extraction factors including temperature, extraction time, solvent ratio, concentration, banana ripeness, grain size, and extraction method. This study was performed to optimize factors affecting pectin yield from unripe banana peels by response surface methodology (RSM) according to the Box-Behnken model. The results reveal that at the extraction conditions: solvent: material ratio of 29.85% (v/w), temperature of 90.67 °C, and alcohol: solvent ratio of 1.2% (v/v)), pectin extraction efficiency reached the highest value with 49.67%. At this condition, the tested values agree with the values predicted by the optimal models. Extracted pectin product contains specific functional groups similar to those of commercial pectin; pectin content reached 65.01%; degree of esterification (DE) index reached 37.37% and methoxyl index (MI) reached 9.45 ± 0.45%.

Keywords: Pectin, banana peel, optimization, response surface methodology.

1. INTRODUCTION

The banana tree (*Musa* spp.) is extensively cultivated across tropical and subtropical regions, representing approximately 19% of Vietnam's total fruit production area, yielding around 1.4 million tons annually [1]. While ripe bananas are widely consumed for their nutritional value, high fiber, and mineral content, research is increasingly focusing on green bananas due to their high fiber and resistant starch (RS) content. Green banana flour contains about 64–75% starch, with resistant starch constituting 17.5-48% [2]. This ingredient acts physiologically as a dietary fiber and functions as a prebiotic, promoting intestinal health. Globally, green banana flour is recognized as a superfood and is considered a potential substitute for traditional flour [3].

Banana peels, which make up about 20-40% of the fruit's weight [4-6] pose a risk of environmental pollution if not managed effectively. However, utilizing these peels for value-added products could enhance the economic potential of green bananas [7, 8]. In addition to their application as a bio-fertilizer, green banana peels have been investigated for fermentation into bio-alcohol, and their potential use as adsorbents and in pectin production [5]. Pectin extraction from banana peels has attracted particular research interest [9-11]. Pectin, a structural polysaccharide in cell walls, supports both the mechanical strength and functional integrity of plant cells [12]. It is widely utilized as a gelling agent and stabilizer in food and pharmaceutical applications. Other by-products in Vietnam, such as coffee peel [13], dragon

fruit peel [14], *Tithonia diversifolia* leaves [15], and watermelon peel [16] have also been studied for pectin extraction.

The extraction method and experimental conditions significantly impact the recovery yield and physicochemical properties of pectin, including the degree of esterification (DE), solubility, colloidal behavior, pH, and molecular weight. Conventional extraction with temperature-assisted organic acids, such as citric acid, has demonstrated environmental advantages over inorganic acids while yielding similar pectin quality and recovery rates. This method is also highly suited for industrial-scale pectin production [17]. Key parameters influencing pectin yield and quality include extraction temperature, material-to-solvent ratio, pH, particle size, and extraction duration. Experimental optimization techniques allow simultaneous assessment of these factors, reducing the total number of experiments and clarifying the interactions between factors for optimal conditions. Consequently, recent studies have widely adopted this approach for optimizing pectin extraction from banana peels.

For instance, Design-Expert software was applied to optimize the effects of temperature, extraction time, and citric acid concentration on pectin yield from banana peels [4]. Other studies commonly employ response surface methodology (RSM) with central composite design (CCD) to optimize hot-acid extraction processes by focusing on key parameters such as pH, temperature, duration, and material-to-solvent ratio [8, 9, 18]. Additionally, the precipitation of pectin immediately following extraction is crucial for obtaining pure pectin. Ethanol is frequently used in this step, given its suitability for large-scale polysaccharide production [19]. Factors such as precipitation pH, ethanol volume, and inorganic salt concentration affect the interaction between alcohol and polymer during precipitation [20]. Thus, research combining factor optimization during extraction with optimal ethanol volume in precipitation could improve pectin recovery.

The literature has not reported any comprehensive studies on the simultaneous optimization of extraction and precipitation conditions for pectin recovery. Addressing this gap, the present study aims to optimize critical factors in pectin extraction using alcohol precipitation to recover pectin from unripe banana peels (*Musa* sp.), a commonly cultivated variety in Vietnam. The extracted pectin will then be evaluated for key physicochemical properties to assess its suitability as a film-forming material for fruit preservation.

2. MATERIALS AND METHODS

2.1. Materials

Unripe bananas (*Musa* sp., genotype AAA, locally known as Tieu bananas) were sourced from farmers in Cai Trom hamlet, Tan Quoi Trung commune, Vung Liem district, Vinh Long province, Viet Nam (10°10'7.212"N, 106°7'212"E). Damaged portions of the banana peels were removed, and the peels were rinsed with water three times, cut into 10 mm × 10 mm sections, and blanched in hot water at 85 °C for 10 minutes [21]. Following blanching, the peels were soaked in 0.5% $NaHSO_3$ solution for 1 hour and then dried at 60 °C for 24 hours until reaching a constant weight with a moisture content of 3.6%.

The dried peels were subsequently ground, passed through a 0.3 mm sieve, and stored in glass containers at room temperature. Key reagents used in this study included citric acid (China), sodium bisulfite (China), commercial pectin (HiMedia, India), and alcohol (China).

2.2. Methods

2.2.1. Investigate the specific effects of factors on the pectin extraction process

Five key factors were investigated in the pectin extraction process: citric acid concentration, ingredient-to-solvent ratio (w/v), stirring duration, extraction temperature, and alcohol-to-extract ratio (v/v). The extraction procedure followed the main steps outlined in Figure 1.

First, banana peel powder was combined with citric acid at varying concentrations (5%, 10%, 15%) to create different ingredient-to-solvent ratios (1:10, 1:20, 1:30, 1:40). Each mixture was stirred at 300 rpm using a magnetic stirrer at temperatures of 80 °C, 90 °C, and 100 °C, respectively, for various durations (60, 90, and 120 minutes). After stirring, the mixture was filtered through a coarse filter cloth and centrifuged at 5000 rpm for 15 minutes. The resulting supernatant was then mixed with 96% cold ethanol at different alcohol-to-extract ratios (1:0.5, 1:1, 1:1.5, 1:2) to precipitate pectin over 1 hour.

The precipitate was separated by centrifuging at 3500 rpm for 15 minutes, washed twice with distilled water, and centrifuged again at 3500 rpm for 15 minutes to isolate the pectin. Finally, the raw pectin was dried at 50 °C to constant weight to achieve the desired moisture content. The primary evaluation criterion for this process was raw pectin recovery (%).

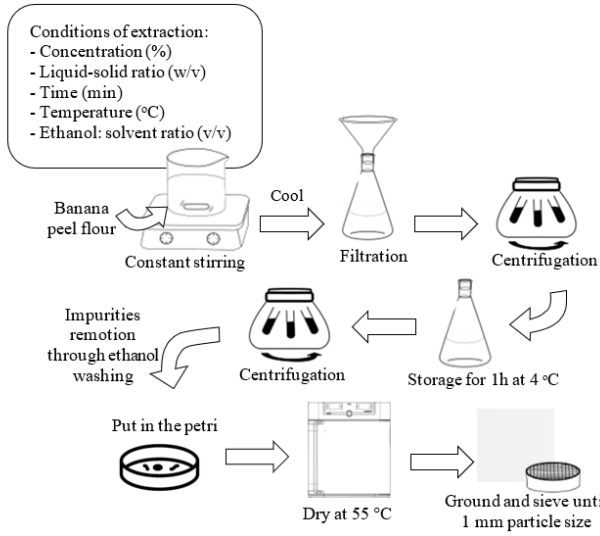

Figure 1. Diagram for extraction and recovery of pectin

2.2.2. Plackett-Burman experimental design

The Plackett-Burman design is a robust method for screening and identifying the most influential factors in an experimental process. In this study, five factors were examined: citric acid concentration, raw material-to-solvent ratio, stirring duration, extraction temperature, and alcohol concentration. The primary objective function was the raw pectin recovery yield. Parameters for the experimental setup are presented in Table 1, and the complete experimental design is outlined in Table 2 [4, 18].

Table 1. Experimental set-up for Plackett-Burman design

Symbol	Independent variable	Unit	Code	
			Low (-1)	*High (+1)*
X_1	Concentration	%	5	10
X_2	Liquid-solid ratio	w/v	1/20	1/30
X_3	Time	min	60	90
X_4	Temperature	C	80	90
X_5	Ethanol:solvent ratio	v/v	1/0.5	1/1

Table 2. Plackett-Burman Experiment plan and pectin yield

Runs	X_1	X_2	X_3	X_4	X_5	Observed	Calculated
	Concen-tration	*Liquid-to-solid ratio*	*Time*	*Temperature*	*Ethanol-to-solvent ratio*	Response, %	
1	1	-1	-1	1	-1	33.00	32.69
2	1	1	-1	-1	1	35.89	35.43
3	1	1	1	-1	-1	32.56	33.10
4	-1	1	1	1	-1	39.44	38.99
5	1	-1	1	1	1	40.67	41.08
6	-1	1	-1	1	1	40.78	41.32
7	-1	-1	1	-1	1	35.22	34.91
8	-1	-1	-1	-1	-1	26.11	26.52
9	0	0	0	0	0	35.44	35.50
10	0	0	0	0	0	35.67	35.50
11	0	0	0	0	0	35.78	35.50

2.2.3. Determine the optimal range by steepest ascent method (Box – Wilson design)

Three factors that have the most influence on the pectin recovery efficiency, denoted X_1, X_2, and X_3 respectively, are applied to the Box-Wilson design to determine the steepest ascent for the response (pectin recovery yield, %). The Box-Wilson experimental plan is shown in Table 3 [4]. The step of one factor with the greatest influence is chosen as a standard to calculate the steps of other factors using the formula:

$$\delta_j = \delta_1 \frac{b_j \Delta_j}{b_1 \Delta_1} \quad (1)$$

Where: δi is the step of the i^{th} factor, Δi is the variation range of the i^{th} factor.

Table 3. Experimental set-up for Box–Wilson design

Item	*X_1 (v/w)* Liquid-to-solid ratio	*X_2 (^oC)* Temperature	*X_3 (v/v)* Ethanol-to-solvent ratio
Base (0)	25	85	0.75
Δ_j	5	5	0.25
b_j	1.57	2.875	2.82
δ_j	1.092	← 2 →	0.098
(δ_j)	1.1		0.1

Table 4. Experimental plan and response values of Box-Wilson design

Steps	Movement	Factors			Response (%)
		X_1	X_2	X_3	
1	Base (0)	25	85	0.75	34.67 ± 1.45^{a}
2	Base + Δ	26.1	87	0.85	38.33 ± 1.53^{b}
3	Base + 2Δ	27.2	89	0.95	42.44 ± 1.39^{c}
4	Base + 3Δ	28.3	91	1.05	46.56 ± 2.36^{ef}
5	Base + 4Δ	29.4	93	1.15	48.89 ± 1.35^{f}
6	Base + 5Δ	30.5	95	1.25	47.44 ± 1.39^{ef}
7	Base + 6Δ	31.6	97	1.35	45.89 ± 1.17^{de}
8	Base + 7Δ	32.7	99	1.45	43.78 ± 1.39^{cd}

Note: Data in the same columns with different superscripts were significantly different ($p < 0.05$)

2.2.4. Optimization by response surface methodology

Based on the screening and steepest ascent results, the important factors and their appropriate ranges are clearly defined. At this step, further optimization was carried out by response surface methodology with Box-Behnken design [22] to identify the ideal conditions for pectin extraction. Three key factors-liquid-to-solid ratio (X_1), temperature (X_2), and alcohol-to-solvent ratio (X_3)-were assessed at three levels (low, medium, and high), as shown in Table 5. The response variable was the raw pectin recovery yield (%).

The experimental design consisted of 15 trials, including three replicates at the center point and 12 additional trials along the factor axes, as presented in Table 6. In this setup, the stirring time was fixed at 90 minutes, and the citric acid concentration was set at 10%, as their effects were found to be insignificant. The model representing the relationship between these factors and pectin recovery can be expressed by a quadratic equation.

$$Y = b_0 + \sum_{i=1}^{3} b_i X_i + \sum_{i=1}^{3} b_{ii} X_i^2 + \sum_{i=1}^{2} \sum_{j=i+1}^{3} b_{ij} X_i X_j + \varepsilon \quad (2)$$

Where b_0 is a constant, b_i is the linear coefficient of X_i, b_{ii} is the quadratic coefficient of X^2_{ii}, and bij is the interaction coefficient of X_iX_j.

Table 5. Experimental set-up for Box-Behnken design

Symbol	Independent variable	Code		
		Low (-1)	Middle (0)	*High (+1)*
X_1	Liquid-to-solid ratio	27.2	29.4	31.6
X_2	Temperature	89	93	97
X_3	Ethanol-to-solvent ratio	0.95	1.15	1.35

Table 6. The experimental plan for Box-Behnken design and pectin recovery values

Runs	X_2	X_4	X_5	Observed	Calculated
	Liquid-to-solid ratio	*Temperature*	*Ethanol-to-solvent ratio*	*Response (%)*	
1	-1	-1	0	42.67	43.11
2	1	-1	0	44.78	44.25
3	-1	1	0	35.89	36.41
4	1	1	0	40.11	39.67
5	-1	0	-1	41.89	41.60
6	1	0	-1	36.22	36.90
7	-1	0	1	36.78	36.10
8	1	0	1	44.89	45.18
9	0	-1	-1	42.33	42.18
10	0	1	-1	40.11	39.87
11	0	-1	1	46.67	46.90
12	0	1	1	37.78	37.93
13	0	0	0	48.56	48.26
14	0	0	0	48.00	48.26
15	0	0	0	48.22	48.26

2.2.5. Evaluation of some physicochemical properties of the obtained pectin

The pectin products were systematically evaluated based on several key criteria, including moisture content, equivalent weight (EW), degree of esterification (DE), methoxyl content index (MI), overall pectin content, and chemical structure. Each parameter provides insight into the quality and suitability of the extracted pectin for various applications.

2.3. Analytical methods

Raw pectin recovery efficiency was determined according to formula 3 [23]. Moisture was analyzed by gravimetric method after drying until the mass stabilizes at 105 °C. Surface functional groups of pectin were determined by Fourier transform infrared spectroscopy (FT-IR). Samples were measured at the Laboratory of Polymer & Composite Materials, VNUHCM – Ho Chi Minh City University of Technology. DE index of pectin was calculated based on the results of FTIR spectral and formulas 4 and 5 [23]. DE and methoxyl index (MI) were stated based on the suggestion of Bocheck et al. [23]. The pectin content was determined by the calcium pectate method [24].

$$\text{Raw pectin recovery Yield}(\%) = \frac{\text{raw pectin weight(g)}}{\text{banana peel powder weight(g)}} \times 100 \quad (3)$$

$$\text{DE} = 124.7\text{R} + 2.2013 \quad (4)$$

$$\text{R} = \frac{A_{1745}}{A_{1745}+A_{1630}} \quad (5)$$

Where, A_{1745} and A_{1630} are the areas of the bands at 1745 cm^{-1} and 1630 cm^{-1}, respectively.

2.4. Methods of data analysis and processing

The experiment was replicated three times. Statistical parameters were determined, and graphs were plotted using Microsoft Office Excel 2016 software and Statgraphics software version 9.0 (Untitled StatFolio). Analysis of variance (ANOVA) with 95% confidence was calculated to conclude the difference between the means with the LSD test. The optimization process is performed using software Mode 5.0 (Umetrics AB).

3. RESULTS AND DISCUSSION

3.1. Partial effects of factors on the yield of pectin

As shown in Figure 2, increasing the citric acid concentration from 5% to 10% improved pectin recovery efficiency, rising from 40.3% to 45.78%. This increase is likely due to the higher acid concentration facilitating the breakdown of bonds within the polysaccharide chains of the cell wall, allowing for easier release of pectin. However, excessively high citric acid concentrations cause a significant drop in solution pH, leading to extensive cleavage of the polygalacturonic acid chains. This results in partial degradation of pectin and, consequently, a decrease in extraction efficiency [24]. This declining yield trend with increasing citric acid concentration aligns with previous studies on pectin extraction from *Mesona chinensis* Benth [25], as well as from mango and banana peels [24]. Therefore, a 10% citric acid solution was selected as the optimal extraction solvent for subsequent experiments.

The material-to-solvent ratio significantly influenced pectin yield. At a ratio of 1:10 (w/v), no pectin was obtained, likely because the limited solvent volume caused the powder to swell without dissolving, preventing pectin extraction. When the ratio was increased to 1:20 and 1:30, pectin recovery efficiencies of 24.83% and 28.33% were achieved, respectively. However, further increases to ratios of 1:30 and 1:40 led to diminished yields, as illustrated in Figure 2.

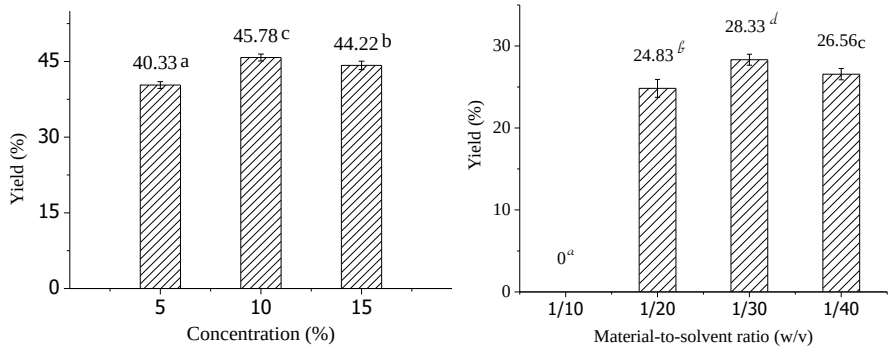

Figure 2. Effect of citric acid concentration and material-to-solvent ratio on pectin yield
Note: The values with different superscript letters in a column are significantly different ($p<0.05$)

This outcome can be explained by two factors: (i) the acidic solvent facilitates both the penetration into raw materials and the conversion of protopectin, thereby solubilizing pectin into the extract. As the solvent volume increases, more pectin is extracted initially; (ii) however, excessive solvent ratios reduce efficiency due to the marked decrease in pH, which can partially decompose pectin. Consequently, to balance high pectin extraction efficiency with solvent conservation, a material-to-solvent ratio of 1:30 (w/v) was selected as optimal.

Figure 3 demonstrates that the maximum pectin recovery yield (47.56%) was achieved with a stirring time of 90 minutes, representing increases of 1.05 and 1.03 times over yields at 60 and 120 minutes, respectively. These results indicate that an increase in stirring time up to 90 minutes enhances pectin recovery. However, beyond this duration, yields decline.

This decrease in yield at prolonged stirring times can be attributed to the thermal instability of pectin, as decomposition rates accelerate with both higher temperatures and extended heating durations. Consequently, prolonged exposure to high temperatures results in a substantial reduction in pectin yield. A similar observation was reported by Quynh et al. in a study on pectin extraction from grass jelly [25]. Therefore, the optimal extraction time for maximizing pectin yield was determined to be 90 minutes.

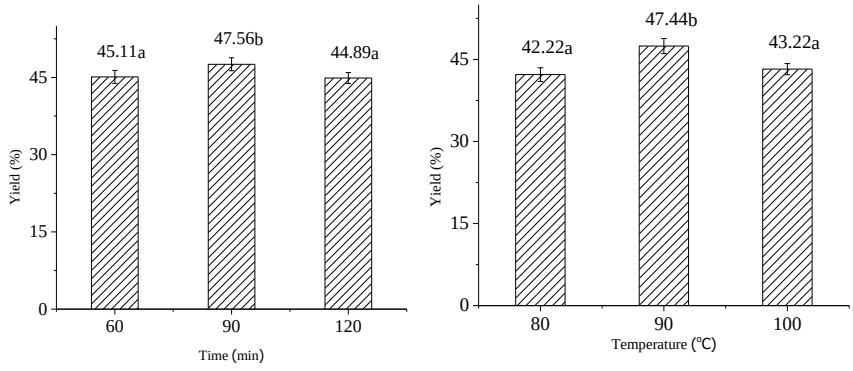

Figure 3. Effect of time and temperature on pectin yield
Note: The values with different superscript letters in a column are significantly different ($p<0.05$)

The influence of temperature on extraction efficiency followed a similar trend to time, as shown in Figure 3. The highest extraction efficiency was achieved at 90 °C, with yields decreasing as the temperature increased beyond this point. This decline is likely due to pectin denaturation at elevated temperatures, particularly at 100 °C, impairs extraction efficiency. Additionally, as the temperature rises, the pectin solution darkens, likely due to the Maillard reaction and caramelization, which are accelerated in acidic environments.

During the pectin precipitation process, the solvent ratio also significantly impacted extraction efficiency. A solvent ratio of 1:1 (v/v) produced the highest raw pectin yield, while further increases in the solvent ratio led to decreased yields (Figure 4). Faravash et al. reported similar findings in their study on pectin extraction from peach pomace [26]. Consequently, a 1:1 solvent ratio was selected for subsequent experiments due to its high precipitation efficiency.

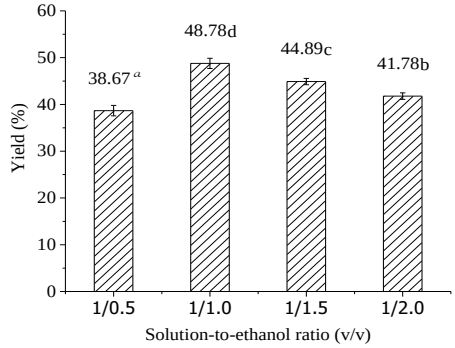

Figure 4. The effect of the ratio of ethanol to solvent on pectin yield

Note: The values with different superscript letters in a column are significantly different ($p<0.05$)

3.2. Screening of factors affecting pectin extraction by Plackett–Burman design

After determining the partial impact of each factor affecting the yield of pectin, the Plackett–Burman design was used to eliminate the factors that did not greatly affect the extraction process. Table 2 shows the experimental conditions and results. The data was analyzed and processed using Mode 5.0 software. The regression equation is calculated and shown in equation 6. The calculated coefficient of determination R^2 is 0.945, which shows that 94.5% of the experimental data are compatible with the data inferred from the model. R^2 value > 0.75 shows that the model is compatible with the experiment.

$$Y= 35.5 + 0.069X_1 + 1.708X_2 + 1.514X_3 + 3.014X_4 + 2.68X_5 \quad (6)$$

Where, Y is the response, X_i is the independent factors.

As shown in Figure 5, pectin yield increased significantly with higher extraction temperatures, greater solvent-to-raw-material ratios, higher ethanol-to-solvent ratios, and extended stirring times. Conversely, the concentration of the solvent exhibited minimal impact on extraction efficiency. This finding aligns with the work of Tanaid and Lauzon, who observed improved pectin yield from green banana peels with incremental increases in extraction temperature, solvent-to-material ratio, and extraction duration. An increase in extraction temperature, coupled with optimal extraction time, enhances the solubility of pectin, thereby improving the overall extraction rate [9].

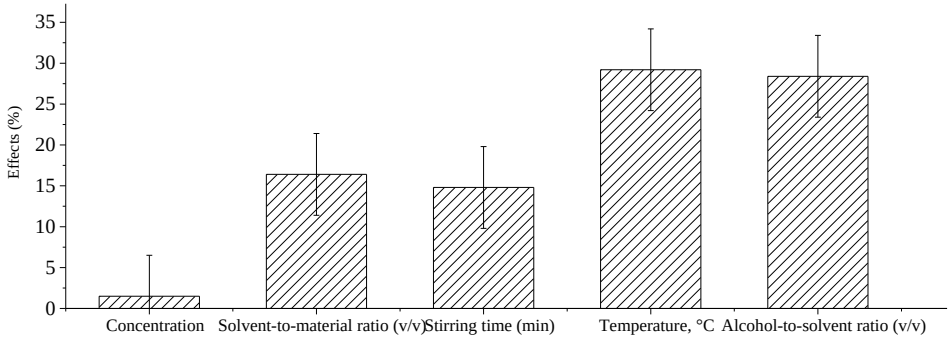

Figure 5. Influence of factors on the yield of pectin recovery

For the next phase, three key factors: solvent-to-material ratio, extraction temperature, and alcohol-to-solvent ratio were selected for further examination. Due to their significant impact on extraction yield, the concentration of the extraction solvent and stirring time were fixed at their optimal high levels (10% solvent concentration and 90 minutes stirring time) in subsequent experiments. This approach ensures that the conditions likely to yield the highest pectin recovery are consistently maintained while optimizing the remaining variables.

3.3. Determine the optimal interval of the factors by the steepest ascent method

Figure 6 indicates that experiment 5 achieved the highest pectin recovery efficiency, reaching 48.89% ($p < 0.05$). The optimal conditions in this experiment were: X_1 (solvent-to-material ratio) at 29.4 w/v, X_2 (extraction temperature) at 93 °C, and X_3 (alcohol-to-solvent ratio) at 1.15 v/v. Experiments 3 to 7 consistently demonstrated high extraction efficiencies, ranging from 42.45% to 45.89%, suggesting an optimal parameter range for pectin recovery. Based on these findings, this range was selected for conducting the response surface analysis, with the conditions from experiment 5 (the highest pectin yield) set as the central level for further testing.

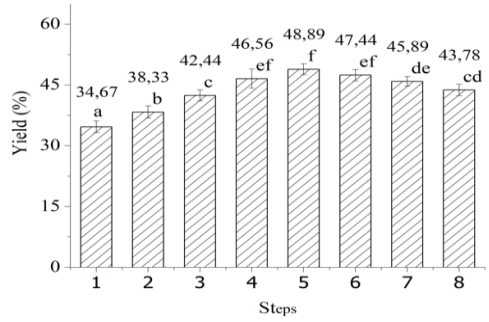

Figure 6. The trend of response changes along the path of the steepest ascent

Note: The values with different superscript letters in a column are significantly different ($p<0.05$)

3.4. Optimization of pectin extraction using Box - Behnken design

ANOVA analysis shows that the coefficient of determination R^2 of the regression model is 0.94. This shows that the selection regression model is reliable. In addition, the Lack of Fit assessment also gave a p-value of 0.157 (>0.05). This proves that the model is consistent with the experiment.

Based on the regression equation (7) shows that temperature, solvent-to-material ratio, and alcohol-to-solvent ratio all affect the pectin extraction process. And this result once again confirms that temperature is the most influential factor in pectin extraction. This result is consistent with the study on extracting pectin from banana peel [4].

$$Y = 48.26 + 1.10X_1 - 2.82X_2 + 0.69X_3 - 4.59X_1^2 - 2.81X_2^2 - 3.72X_3^2 + 3.45X_1X_3 - 1.67X_2X_3 \quad (7)$$

The optimizer function in Mode 5.0 software was employed to identify the optimal extraction conditions. The results indicated that the optimal parameters for pectin extraction were a solvent-to-material ratio of 29.85 w/v, an extraction temperature of 90.67 °C, and an ethanol-to-solvent ratio of 1.2 v/v. These values align closely with optimal conditions reported in the literature. For instance, Tanaid and Lauzon reported optimal conditions of a 28 w/v solvent-to-material ratio, 88-minute extraction time, and 95 °C temperature [9]. Happi et al. found an optimal extraction temperature of 90 °C at pH 2.0 with a 60-minute duration [17], while Oliveira et al. recommended a slightly lower extraction temperature of 87 °C under similar pH and time conditions [18]. Conversely, Pagarra et al. identified an optimal extraction temperature as high as 100 °C at pH 2.5 [8].

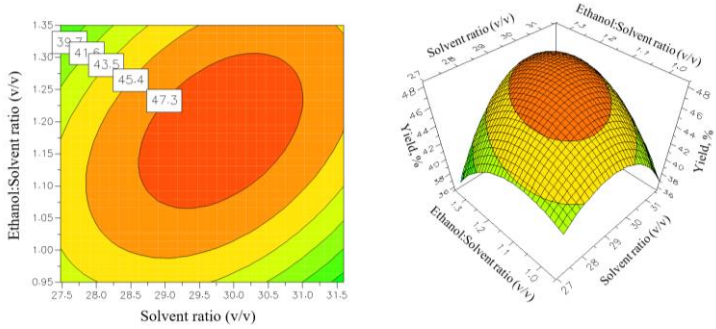

Figure 7. Contour graph and 3-D graph showing the effect of parameters on pectin yield

Comparative experiments conducted under the optimized conditions yielded a pectin recovery rate of 49.67%, closely aligning with the model's predicted result of 49.29%. This recovery rate exceeds those reported in similar studies, demonstrating the effectiveness of multi-factor optimization in enhancing pectin yield. However, the improvement was relatively modest, likely because the selected values for single-factor experiments were already near the optimal range. This outcome further validates the suitability of the chosen parameter range, confirming its accuracy in determining conditions that maximize pectin yield.

3.5. Evaluation of some physicochemical properties of raw pectin

The raw pectin preparation from banana peels gets dark brown in color (Figure 8). The DE index is 37.37 ± 1.12%, lower than that of commercial pectin powder (60.15 ± 0.77%). The MI index represents the degree of methylation, which is the mass percent of the methoxyl group (-OCH_3) to the total molecular mass. Raw pectin has a MI value of 9.45 ± 0.45%, higher than commercial pectin (7.2 ± 0.45%).

From the results of the DE index, the extracted pectin belongs to the type of LMP (in the pectin molecule, there are less than 50% of the acid groups esterified (DE ≤ 50% & MI > 7%). Meanwhile, commercial pectin belongs to the type of HMP (High Methoxyl Pectin, DE > 50% & MI > 7%). Pectin type HMP will gel in acidic environment and high sugar concentration (sugar concentration > 55% (w/w), pH 2 - 3.5). However, LMP-type pectin has the ability to form gel without the addition of sugar, only the presence of the cation Ca^{2+} as a bridge in the galacturonic acid chain.

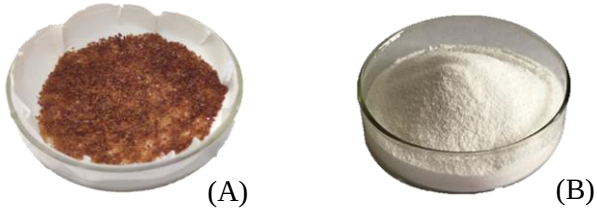

Figure 8. Pectin extracted from green banana peel (A) and commercial pectin (B)

The functional groups in pectin from banana peels were evaluated by infrared spectroscopy. The results in Figure 8 show that both commercial pectin and banana peel pectin samples absorb light at many similar wavelengths and the adsorption intensity has little different. Thus, it can be confirmed that the sample extracted from banana peel powder is pectin. However, Figure 9 also states some peaks of banana peel pectin that are not homologous to commercial pectin. It indicates that the extracted pectin contains other sugar derivatives besides polygalacturonic acid

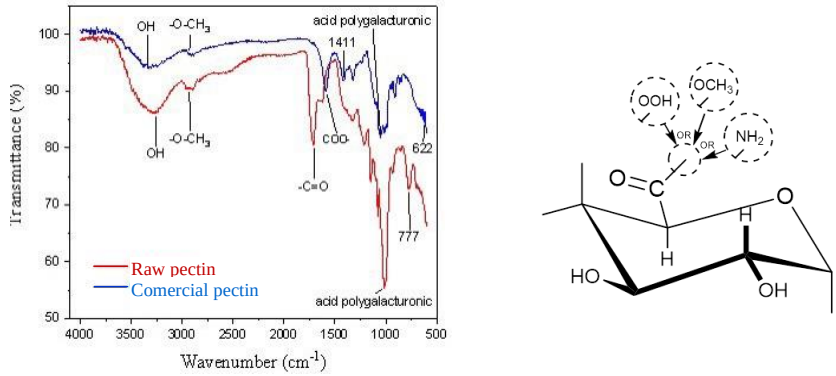

Figure 9. Comparison of FTIR spectra of raw pectin and commercial pectin

4. CONCLUSION

The unripe peel of the banana (*Musa* sp.) represents a promising raw material for pectin extraction. Pectin derived from this source contains 65.01% pectin, with a degree of esterification (DE) index of 37.37, and a methoxyl index (MI) of 9.45 ± 0.45%. The pectin exhibits characteristic functional groups that are comparable to those found in commercial pectin. Among the factors examined, the solvent-to-material ratio, extraction temperature, and ethanol-to-solvent ratio had the most pronounced effects on pectin recovery efficiency. The optimal extraction conditions were identified as a solvent-to-material ratio of 29.85% (w/v), an extraction temperature of 90.67 °C, and an ethanol-to-solvent ratio of 1.2% (v/v), yielding a maximum pectin recovery efficiency of 49.67%.

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TÓM TẮT

NGHIÊN CỨU TỐI ƯU HOÁ QUÁ TRÌNH THU NHẬN PECTIN TỪ VỎ CHUỐI XANH (*Musa* sp.)

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Pectin là một polysacharide có giá trị được sử dụng rộng rãi trong ngành công nghiệp dược phẩm và thực phẩm. Pectin thường được thu nhận từ nhiều nguồn thực vật khác nhau. Chất lượng và giá thành của pectin phụ thuộc vào nhiều yếu tố chiết xuất khác nhau bao gồm nhiệt độ, thời gian chiết xuất, tỷ lệ, nồng độ dung môi, độ chín của chuối, kích thước hạt và phương pháp chiết xuất. Nghiên cứu này tối ưu hóa một số yếu tố ảnh hưởng đến hiệu suất thu hồi pectin từ vỏ chuối xanh bằng phương pháp đáp ứng bề mặt theo mô hình Box-Behnken. Kết quả cho thấy, ở điều kiện chiết xuất gồm: tỉ lệ dung môi : nguyên liệu 29,85% (v/w), nhiệt độ 90,67 °C, và cồn sử dụng kết tủa trong dịch chiết ở tỉ lệ 1,2% (v/v) cho hiệu suất chiết pectin đạt giá trị cao nhất với 49,67%. Ở điều kiện này, các số liệu thực nghiệm phù hợp với các giá trị được dự đoán bởi các mô hình tối ưu. Sản phẩm pectin chiết xuất từ vỏ chuối chứa các nhóm chức năng đặc trưng tương tự như pectin thương mại, hàm lượng pectin đạt 65,01%, chỉ số DE đạt 37,37% và chỉ số MI đạt 9,45 ± 0,45%.

Keywords: Pectin, vỏ chuối, tối ưu hoá, phương pháp đáp ứng bề mặt (RSM).