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EFFECT OF VACUUM FRYING TEMPERATURE ON THE PHYSICOCHEMICAL AND SENSORY PROPERTIES OF CHAYOTE CHIPS

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Abstract

Chayote (Sechium edule) is a high-moisture vegetable with considerable potential for development into value-added snack products through vacuum frying technology. This study aimed to evaluate the effect of vacuum frying temperature on the physicochemical, nutritional, and sensory properties of chayote chips in order to determine the optimal processing condition. Fresh chayote was first characterized for its initial chemical composition and subsequently vacuum-fried at five temperature levels. This study uses a Completely Randomized Design (CRD) with five treatments and three replications. The treatments consist of frying temperatures of 70°C (A), 75°C (B), 80°C (C), 85°C (D), and 90°C (E). The resulting chips were analyzed for yield, texture, color, frying time, oil absorption, proximate composition, vitamin C content, potassium concentration, and sensory attributes. The data were analyzed using analysis of variance (ANOVA), followed by Duncan's New Multiple Range Test (DNMRT). Increasing frying temperature significantly reduced yield, moisture content, hardness, and frying time, while increasing oil absorption and relative mineral concentration. Nutritional analysis revealed progressive degradation of heat-sensitive components, particularly protein and vitamin C, at higher temperatures. Sensory evaluation revealed that frying temperature significantly influenced aroma, taste, and texture attributes, with the highest aroma score (4.10), taste score (4.13), and texture score (4.37 for crispiness) observed at 85 °C. Overall, vacuum frying temperature played a critical role in determining product quality, highlighting a trade-off between processing efficiency, nutritional retention, and sensory acceptance. Frying at 85 °C under vacuum conditions was identified as the optimal temperature for producing chayote chips with desirable physical characteristics, acceptable nutritional quality, and superior consumer acceptance..

Keywords: Chayote, Vacuum Frying, Temperature Optimization, Physicochemical Properties, Sensory Quality.

1. Introduction

Chayote (*Sechium edule*), a vegetable belonging to the Cucurbitaceae family, possesses notable nutritional and functional attributes, including vitamin C, dietary fiber, and essential minerals such as potassium, which make it an attractive raw material for diversifying food products (Ramírez-Rodas et al., 2022). However, its very high moisture content (approximately 90–93%) renders chayote highly susceptible to softening, discoloration, and microbial spoilage, resulting in a relatively short shelf life. Therefore, appropriate processing strategies are required to enhance its stability and economic value.

Processing chayote into dried snack products such as chips offers promising commercial potential. Nevertheless, conventional deep-fat frying of high-moisture materials often leads to quality deterioration, including excessive oil uptake, undesirable browning due to Maillard reactions, and thermal degradation of nutrients at elevated temperatures (Patra, 2022). Consequently, alternative frying technologies that allow operation at lower temperatures while maintaining product quality are essential for the development of chayote-based snack products.

Vacuum frying has emerged as a promising alternative because frying under reduced pressure lowers the boiling point of water, enabling processing at relatively low temperatures (typically 70–100 °C). This condition contributes to improved retention of natural pigments, aroma compounds, and thermolabile nutrients such as vitamin C, while reducing acrylamide formation and oxidative degradation compared to atmospheric frying (Juvvi et al., 2024; Pal, 2024). Recent studies have also demonstrated that optimizing processing parameters (temperature, pressure, and time), as well as applying pretreatments such as osmotic dehydration or ultrasound, can enhance texture and reduce oil absorption in vacuum-fried products (Ren et al., 2022; Park et al., 2024).

Although vacuum frying has been extensively studied for fruits and vegetables such as bananas, sweet potatoes, mangoes, and mushrooms, investigations focusing specifically on chayote remain limited. This lack of information necessitates further exploration of optimal frying temperatures and processing conditions for chayote, as its tissue structure and carbohydrate–fiber composition may influence drying kinetics, pore formation, oil uptake, and nutrient retention differently from other raw materials (Ramírez-Rodas et al., 2022).

Therefore, this study aimed to (1) evaluate the effect of vacuum frying temperature on the physicochemical and sensory characteristics of chayote chips and (2) determine the optimal frying temperature that provides the best balance between crispiness, nutritional retention, color quality, and consumer acceptance.

2. Materials and Methods

2.1 Method

This study uses a Completely Randomized Design (CRD) with five treatments and three replications. The treatments consist of frying temperatures of 70°C (A), 75°C (B), 80°C (C), 85°C (D), and 90°C (E).

2.2 Materials

Fresh chayote (*Sechium edule*) was obtained from a traditional market in Padang City, Indonesia. Analytical-grade chemicals were used for proximate analysis, in accordance with AOAC standards. Reagents for vitamin C analysis, potassium determination by atomic absorption spectrophotometry (AAS), and food-grade $CaCl_2$ were also used. All chemicals were of analytical grade.

2.3 Equipment

The leading equipment included a water-jet vacuum fryer with a capacity of 1.5 kg per batch (PT Globalindo, Malang, Indonesia), a spinner, a drying oven, a Soxhlet extraction unit, a texture analyzer (Brookfield CT3), a HunterLab colorimeter, an atomic absorption spectrophotometer, an analytical balance, a water bath, and standard laboratory glassware. All instruments were calibrated prior to use according to the manufacturer's procedures.

2.4 Sample Preparation

Chayote fruits were peeled, washed, and sliced to a uniform thickness of 5 mm using a manual slicer to ensure consistency in size. The slices were immersed in a 1000 ppm $CaCl_2$ solution for 10 min as a tissue-strengthening pretreatment, following recommendations for vacuum-fried vegetable products (Ren et al., 2022).

2.5 Vacuum frying process

Vacuum frying was conducted at five temperature levels: 70, 75, 80, 85, and 90 °C, with three replications per treatment. The pressure was maintained at ≤ -70 cmHg under vacuum conditions, following established vacuum frying protocols (Pal, 2024; Juvvi et al., 2024). Frying was terminated when bubbling ceased, after which the products were de-oiled using a spinner for 3 min.

2.6 Physical analysis

Physical properties analyzed included yield, texture, color, frying time, and oil absorption. Yield was calculated as the percentage ratio of the final product weight to the initial raw material weight prior to processing, in accordance with the AOAC (2019) procedures. Texture was evaluated by measuring hardness using a texture analyzer with a penetration test, in accordance with ASTM D882-18 for crispy food materials.

Color measurements were conducted using a HunterLab colorimeter to determine lightness (L*) and hue angle based on the CIE Lab* color system (CIE, 2015). Hue angle was calculated according to Wrolstad (2017). Frying time was recorded as the duration from sample immersion until bubbling ceased, following vacuum frying protocols reported by Pal (2024). Oil absorption was determined by measuring the weight differences before and after frying, following the methods described by Park et al. (2024) and Ren et al. (2022).

2.7 Chemical analysis

Chemical analyses included proximate composition, carbohydrate content, vitamin C, and potassium. Moisture, ash, fat, and protein contents were determined according to AOAC (2019) methods. Moisture content was analyzed using the oven-drying method at 105 °C to constant weight (AOAC 925.10). Ash content was determined by dry ashing at 550 °C (AOAC 923.03). Fat content was analyzed using Soxhlet extraction with n-hexane (AOAC 920.39). Protein content was determined using the Kjeldahl method (AOAC 979.09).

Carbohydrate content was calculated by difference. Vitamin C was determined using iodometric titration (AOAC 967.21). The potassium content was analyzed using atomic absorption spectrophotometry, in accordance with ISO 11047:1998.

2.8 Sensory evaluation

Sensory evaluation was conducted using 30 semi-trained panelists. A five-point scoring test was applied to assess color, aroma, taste, and texture attributes. Panelist training adhered to ISO 8586:2012 guidelines, and sensory scoring followed the procedures outlined in ISO 4121:2003. Samples were presented in a randomized complete block design to minimize bias.

2.9 Statistical analysis

The data will be analyzed using analysis of variance (ANOVA), followed by Duncan's New Multiple Range Test (DNMRT), as described by Montgomery (2019), at a 5% significance level to identify significant differences between the treatments. Statistical analysis was performed using SPSS version 25.

3. Results and Discussion

3.1 Chemical characteristics of fresh chayote

Raw material characterization is crucial for understanding the nutritional baseline and quality attributes that impact processing efficiency and final product quality, particularly in heat-based processes such as vacuum frying (Li et al., 2022; Ayustaningwarno et al., 2018). In this study, fresh chayote was analyzed for moisture, ash, fat, and potassium contents.

The moisture content of chayote was 93.58%, confirming that chayote is a high-moisture vegetable. Similar moisture levels have been reported for fresh chayote and related vegetables (>85%), significantly influencing their functional properties and stability during processing (Salam et al., 2023; Chooi Ong, 2007). The ash content was 0.38%, indicating a relatively low total mineral content, consistent with previous compositional studies of chayote pulp (Hussain, 2025). Fat content was low (0.29%), confirming that chayote is a low-fat food material, as commonly reported for fresh vegetables (Salam et al., 2023).

Potassium content was recorded at 3.30 ppm, reflecting its contribution as an essential mineral involved in electrolyte balance (Hussain, 2025; Sakung et al., 2020).

3.2 Physical properties of chayote chips

Table 1 shows the physical analysis of chayote chips. The results demonstrated that yield decreased with increasing frying temperature, from 8.66% at 70 °C to 7.97% at 90 °C. This reduction is associated with accelerated moisture evaporation and a corresponding reduction in frying time at higher temperatures. Similar trends have been reported, where increased frying temperatures enhance heat and mass transfer, leading to greater water loss and lower yields (Ayustaningwarno et al., 2018; Li et al., 2022).

Hardness decreased significantly as frying temperature increased, from 92.03 N/cm² at 70 °C to 25.24 N/cm² at 90 °C, indicating the formation of a more porous and fragile structure due to rapid dehydration and cell wall disruption. This phenomenon has been widely reported in vacuum frying studies, where higher temperatures promote pore formation and reduced product density (Patra et al., 2022; Park et al., 2024).

Color analysis showed a reduction in lightness (L*) at the highest temperature (90 °C), indicating more pronounced browning reactions despite vacuum conditions. Although vacuum frying reduces non-enzymatic browning compared to atmospheric frying, Maillard reactions may still occur at elevated temperatures (Wang et al., 2020). However, hue angle values remained relatively stable (76–80°), suggesting that color changes were still within an acceptable range, consistent with previous reports on vacuum-fried vegetables (Pereira et al., 2023).

Frying time decreased markedly from 101 min at 70 °C to 47 min at 90 °C, reflecting enhanced heat transfer and water evaporation at higher temperatures (Li et al., 2022; Rahman et al., 2023). Oil absorption increased with temperature, ranging from 17.83% at 70 °C to 24.89% at 90 °C, likely due to increased pore size and capillary oil uptake during cooling (Liu et al., 2021; Park et al., 2024).

The characteristics of chayote chips are significantly influenced by physical-chemical mechanisms, including oil diffusion, pore changes, and protein denaturation. Oil diffusion is a key mechanism that affects the oil content in fried products. During frying, oil infiltrates the product’s pores, replacing water present in the food. This process is strongly influenced by the frying temperature, with higher temperatures accelerating the penetration of oil into the product’s structure. As the frying temperature increases, oil absorption increases, resulting in a higher fat content in the fried product. noted that at elevated temperatures, oil diffusion is enhanced, contributing to changes in texture and overall product quality (Rani et al., 2023).

Pore changes also play a vital role during frying. As the water content within the product evaporates due to high temperatures, a process known as structural expansion occurs. This leads to the enlargement of pores, which impacts the texture, such as crispness or chewiness, of the final product. Higher frying temperatures accelerate water evaporation, which in turn causes changes in the pore size and number (Dangal, 2024). Protein denaturation is another important factor in the frying process. At elevated temperatures, proteins undergo denaturation, which alters their structure and consequently affects both texture and the overall quality of the product. This alteration enhances the crispiness and flavor of the product, as the denaturation process modifies the physical and chemical properties of proteins (Chen et al., 2024).

Overall, these results indicate a clear trade-off between process efficiency and product quality. Lower temperatures yielded a higher product yield and lower oil absorption, but required longer frying times. In contrast, higher temperatures enhanced efficiency, albeit at the expense of negatively affecting oil content and color.

Table 1. Physical analysis of chayote chips

Treatment (temperature)	Yield (%) ±SD	Hardness (N/cm²)±SD	L*	a*	b*	Hue (°) ±SD	Frying time (minutes)±SD	Oil absorption (%)±SD
A (70 °C)	8.66±0.48	92.03±1.65[a]	50.63	−1.70	18.98	79.69±3.39	101 ± 11,37[a]	17.83 ± 1.44
B (75 °C)	8.65±0.43	35.84±2.03[b]	55.21	−1.33	22.43	76.26±3.11	81 ± 4,36[b]	20.93 ± 1.61
C (80 °C)	8.20±0.71	33.94±1.29[bc]	54.29	−1.64	22.39	76.45±2.75	64 ± 7,94[c]	21.15 ± 4.89
D (85 °C)	8.13±0.41	28.33±9.24[c]	50.84	0.22	22.78	76.14±2.21	57 ± 9,71[c]	21.78 ± 0.65
E (90 °C)	7.97±0.47	25.24±5.00[c]	45.42	0.76	21.41	77.19±0.83	47 ± 11,14[c]	24.89 ± 0.75

Note: numbers in the same column followed by different lowercase letters are significantly different according to DNMRT at the 5% significance level.

3.3 Chemical properties of chayote chips

Table 2 shows the chemical analysis of chayote chips The vacuum frying temperature significantly influenced the chemical composition of the chayote chips. Moisture content decreased progressively from 10.90% at 70 °C to 7.04% at 90 °C, indicating more efficient dehydration at higher temperatures (Juvvi et al., 2024). The ash content increased from 2.73% to 3.34%, reflecting a relative increase in mineral concentration as the water content decreased (Hussain, 2025).

Fat content increased with temperature (18.12–25.18%), consistent with the increased oil absorption resulting from structural changes in the product matrix (Al Faruq et al., 2022). Protein content decreased markedly at higher temperatures, likely due to heat-induced denaturation and involvement in Maillard reactions. The carbohydrate content was highest at intermediate temperatures (75–85 °C) and declined at 90 °C, possibly due to the thermal degradation of polysaccharides.

Vitamin C content decreased steadily with increasing temperature, from 0.25 mg/100 g at 70 °C to 0.16 mg/100 g at 90 °C, confirming its high sensitivity to heat and oxidation (Al Faruq et al., 2022). Potassium content showed a relative increase with temperature, attributed to moisture loss rather than actual mineral gain (Hussain, 2025).

Table 2. Chemical analysis of chayote chips

Treatment (temperature)	Moisture (%)±SD	Ash (%)±SD	Fat (%)±SD	Protein (%)±SD	Carbohydrate (%)±SD	Vitamin C (mg/100g)±SD	Potassium (ppm)±SD
A (70 °C)	10.90±0.67[a]	2.73±0.71	18.12±0.75	15.36±0.15[a]	52.89±1.64[b]	0.25±0.01[a]	1.92±0.08[d]
B (75 °C)	9.15±0.42[b]	2.91±0.58	21.22±0.65	7.49±0.87[c]	59.23±1.78[a]	0.22±0.01[b]	2.28±0.07[c]
C (80 °C)	8.19±0.67[bc]	3.04±0.46	21.44±4.89	6.91±0.98[c]	60.09±4.18[a]	0.20±0.01[c]	2.52±0.04[b]
D (85 °C)	7.68±0.13[c]	3.25±0.38	22.07±1.61	9.75±0.94[b]	57.25±0.87[ab]	0.19±0.01[c]	2.65±0.14[ab]
E (90 °C)	7.04±1.05[c]	3.34±0.42	25.18±1.44	10.60±0.08[b]	53.82±2.79[b]	0.16±0.01[d]	2.79±0.10[a]

Note: numbers in the same column followed by different lowercase letters are significantly different according to DNMRT at the 5% significance level.

3.4 Sensory Analysis

Sensory evaluation revealed that frying temperature significantly influenced aroma, taste, and texture attributes. Color scores remained relatively stable (3.57–3.83), indicating that vacuum frying effectively preserved visual quality across treatments (Park et al., 2024).

The highest aroma (4.10) and taste (4.13) scores were obtained at 85 °C, suggesting optimal formation of desirable volatile compounds without excessive thermal degradation. Texture scores increased with temperature, with the highest crispiness score observed at 85

°C (4.37). These findings indicate that moderate frying temperatures promote favorable sensory characteristics by balancing dehydration rate and structural development (Patra et al., 2022; Wang et al., 2023).

Overall, frying at 85 °C provided the best balance among sensory attributes, aligning with the physical and chemical results and highlighting its suitability as the optimal processing temperature.

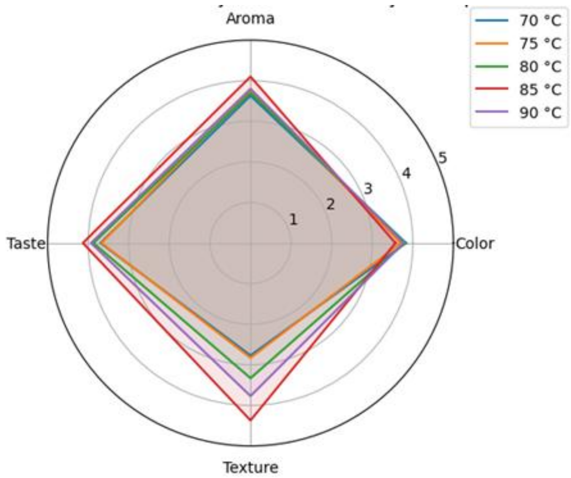

Figure 1. Sensory analysis of chayote chips

4. Conclusion

Vacuum frying temperature has a significant impact on the physical, chemical, and sensory quality of chayote chips. Increasing temperature accelerates moisture removal, reduces frying time and hardness, but decreases yield, color brightness, protein content, and vitamin C, while increasing oil absorption and relative mineral concentration. These results reflect the complex interactions between heat and mass transfer during vacuum frying.

Among the evaluated treatments, frying at 85 °C yielded the most optimal balance between processing efficiency, nutritional quality, and sensory acceptance, particularly in aroma, taste, and texture. Therefore, vacuum frying at moderate temperatures is recommended for producing high-quality chayote chips with controlled oil content and enhanced sensory appeal, supporting their development as healthier vegetable-based snack products.

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