DEVELOPMENT OF VALUE-ADDED PRODUCTS FROM LOW-GRADE POMELO: A STRATEGY FOR WASTE REDUCTION AND INCOME GENERATION IN SAMUT SONGKHRAM, THAILAND

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Abstract

This research addresses the critical issue of post-harvest losses and market surplus of low-grade pomelo (Citrus maxima) in Samut Songkhram Province, a key agricultural region in Thailand. The study employed a product development framework to transform underutilized pomelo into high-value consumer goods, thereby creating economic opportunities for local farmers. Three distinct product lines were developed: 1) Candied Pomelo Fortified with Natural Herbal Extracts (Butterfly Pea, Beetroot, Pandan), 2) Ready-to-Eat Pomelo Salad (Yum Som-O), and 3) Pomelo Peel Marmalade. Through iterative formulation and rigorous sensory evaluation using a 9-point hedonic scale (n=30 untrained panelists), optimal recipes were identified. The candied pomelo with butterfly pea extract achieved the highest sensory scores (Overall Liking: 8.20). The ready-to-eat pomelo salad (Formula 1) demonstrated a refrigerated shelf-life of 7 days, with peak quality at 3 days. For the marmalade, a 10% pomelo peel incorporation rate was found to be optimal, receiving significantly higher acceptance ($p \leq 0.05$) than other levels. The project culminated in a technology transfer workshop for the Bang Sakae farmer group. The findings demonstrate a successful model for agricultural waste valorization, promoting a circular economy, enhancing food security, and supporting sustainable community development through the creation of market-driven, innovative products.

Keywords: Pomelo Valorization, Sensory Evaluation, Product Development, Food Waste Reduction, Circular Economy, Agricultural Innovation, Thailand

Introduction

The pomelo (Citrus maxima (Burm.) Merr.), a flagship fruit of Thailand, faces significant post-harvest challenges. In prime growing regions like Samut Songkhram Province, a substantial portion of the harvest is classified as "low-grade" or "off-grade" due to superficial blemishes, size variations, or market gluts, leading to drastic price reductions and economic losses for farmers (Kazuma, K. et al., 2004). The COVID-19 pandemic further disrupted supply chains, exacerbating this issue and highlighting the vulnerability of dependent agricultural communities (Mukherjee, P.K. et al., 2008).

Concurrently, global trends are shifting towards sustainable food systems, emphasizing waste reduction, circular economy principles, and the development of value-added products from agricultural by-products (Pimporn, P. & Nithiya, R., 2009). Pomelo peel, a rich source of fiber, essential oils, and bioactive compounds, is often discarded, representing a lost opportunity for value creation (USDA Nutrient Database, n.d.).

This study bridges this gap by applying a practical product development framework to convert low-grade pomelos and their by-products into premium, shelf-stable goods. In collaboration with the Bang Sakae farmer group in Samut Songkhram, this research aimed to: 1) Develop and sensorially optimize formulations for three distinct pomelo-based products, 2) Assess the shelf-life of the most perishable product, and 3) Facilitate technology transfer to

the local community. This initiative aligns with the Bio-Circular-Green (BCG) economic model promoted by Thailand, aiming to enhance farmer resilience, reduce food waste, and stimulate local entrepreneurship.

Research Objectives

1. To develop value-added products from low-grade pomelo through appropriate processing techniques that meet consumer needs.
2. To analyze the potential of such product development in reducing agricultural waste and generating additional income for farmers in Samut Songkhram Province.

Materials and Methods

1. Raw Material Preparation

Low-grade 'Khao Yai' pomelos were sourced directly from farmers in Bang Sakae, Samut Songkhram. The fruits were sorted, washed, and processed. For different products, specific parts were utilized: the albedo (pith) for candied pomelo, the flesh segments for the salad, and the flavedo (outer peel) and albedo for the marmalade.

2. Product Development and Experimental Design

- **Candied Pomelo:** A base recipe was optimized from two initial formulas. The superior base formula was then fortified with three concentrated natural extracts:
  - **Butterfly Pea (Clitoria ternatea):** Provided a vibrant blue hue and associated with antioxidant properties (Samut Songkhram Provincial Pomelo Planning Office, 2020).
  - **Beetroot (Beta vulgaris):** Imparted a deep red color and earthy sweetness.
  - **Pandan (Pandanus amaryllifolius):** Provided a classic green color and fragrant aroma.
- **Ready-to-Eat Pomelo Salad (Yum Som-O):** Three traditional-style formulas with variations in dressing composition and ingredient ratios were developed and tested.
- **Pomelo Peel Marmalade:** Three base formulas with differing sugar-to-fruit ratios and gelling agents were evaluated. The optimal base formula was subsequently tested with three levels of shredded pomelo peel incorporation: 5%, 10%, and 15% (by total weight).

3. Sensory Evaluation

All formulations underwent affective sensory testing. A panel of 30 untrained assessors evaluated the products for **appearance, color, aroma, taste, texture, and overall liking** using a standardized 9-point hedonic scale (1=dislike extremely, 9=like extremely). The testing environment was controlled with neutral lighting and water for palate cleansing. Data were analyzed using one-way Analysis of Variance (ANOVA) in SPSS Statistics, and mean separations were performed using the Least Significant Difference (LSD) test at a 95% confidence level ($p \leq 0.05$).

4. Shelf-life Study

The optimized ready-to-eat pomelo salad was packaged in transparent food-grade PP containers and stored at 4±1°C. The product was evaluated daily for 7 days for visual changes (color of herbs and dressing separation), texture (sogginess of pomelo segments), and off-odors.

5. Technology Transfer

The finalized formulations and processing techniques were transferred to representatives of the Bang Sakae farmer group through a structured hands-on training workshop, covering raw material selection, production steps, and basic quality control.

Results and Discussion

1. Optimization of Candied Pomelo with Natural Colorants

Sensory evaluation confirmed **Formula 1** as the superior base recipe, outperforming Formula 2 significantly ($p<0.05$) in all attributes, particularly taste (6.97 vs. 5.33) and overall liking (6.83 vs. 5.40). The subsequent fortification with herbal extracts demonstrated the powerful impact of natural colorants on consumer perception (Table 1).

Table 1: Sensory Scores of Herbal-Fortified Candied Pomelo

Sensory Attribute	Pandan	**Butterfly Pea**	Beetroot
Color	6.70 ± 1.05^{b}	$\mathbf{8.30 \pm 0.65^{a}}$	6.23 ± 1.45^{b}
Aroma	6.70 ± 1.53^{b}	$\mathbf{7.53 \pm 1.07^{a}}$	6.93 ± 1.14^{ab}
Taste	6.50 ± 1.73^{b}	$\mathbf{7.90 \pm 1.02^{a}}$	7.23 ± 1.40^{a}
Overall Liking	7.30 ± 0.83^{b}	$\mathbf{8.20 \pm 0.66^{a}}$	7.17 ± 0.91^{b}

Means in the same row with different superscripts are significantly different ($p \leq 0.05$).

The **butterfly pea variant** was overwhelmingly preferred. Its visually striking blue color and subtle floral notes significantly enhanced its perceived quality, aligning with studies that show color is a primary determinant of food acceptability (Niyomrat, R. et al., 2021). This successful application provides a natural and marketable alternative to synthetic food colorants.

2. Shelf-Stable Ready-to-Eat Pomelo Salad Formula 1 of the pomelo salad was consistently rated highest, achieving an overall liking score of 8.20. The shelf-life study established a practical shelf-life of **7 days** under refrigeration. However, the peak sensory quality, characterized by crisp pomelo segments and vibrant, fresh-tasting herbs, was best maintained for the first **3 days**. This finding is critical for defining "best before" dates and managing inventory for potential commercial distribution.

3. Valorization of Pomelo Peel through Marmalade

The base **Formula 2** for marmalade was selected for its balanced sweetness and gel consistency. The investigation into peel inclusion rate revealed a clear optimal point (Table 2). The 10% peel addition provided an ideal balance, contributing a desirable bitterness, chewy texture, and intense pomelo flavor without being overwhelming. The 15% addition was likely too fibrous and bitter for most panelists, while the 5% was insufficient to deliver a distinct peel character.

Table 2: Sensory Scores of Marmalade with Varying Pomelo Peel Content

Sensory Attribute	5% Peel	**10% Peel**	15% Peel
Color	7.03 ± 1.24[a]	**7.53 ± 1.13[a]**	6.03 ± 2.04[b]
Taste	5.43 ± 1.90[b]	**7.46 ± 1.16[a]**	6.13 ± 1.97[b]
Overall Liking	6.43 ± 1.59[b]	**7.60 ± 1.16[a]**	6.36 ± 1.62[b]

Means in the same row with different superscripts are significantly different (p≤0.05).

This result is significant as it successfully transforms a waste stream (peel) into a primary ingredient, enhancing the product's nutritional profile (dietary fiber, antioxidants) and economic value, a core principle of the circular economy (Pimporn, P. & Nithiya, R., 2009).

Conclusion and Implications

This research provides a comprehensive and actionable strategy for addressing the economic and waste challenges associated with low-grade pomelos. The key outcomes are:

1. Successful Product Innovation: The development of three sensorially-optimized, value-added products that cater to modern consumer trends (natural ingredients, convenience, uniqueness).

2. Waste Valorization: Effective utilization of the whole fruit, particularly the peel, moving towards a "zero-waste" pomelo processing system.

3. Practical Commercial Data: Determination of critical product parameters, such as optimal formulations and shelf-life, which are essential for scaling up production.

4. Community Empowerment: The successful technology transfer ensures that the benefits of this research are directly channeled to the local farming community, fostering entrepreneurship and income diversification.

The study demonstrates that challenges in agricultural surpluses can be innovatively reframed as opportunities for product diversification and value creation. The developed products hold strong potential for branding and commercialization, not only within Thailand but also in international markets seeking authentic, tropical, and sustainably-produced food items. Future work should focus on detailed nutritional analysis, scaling up production parameters, packaging optimization, and a thorough market feasibility study.

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