DEVELOPMENT OF PLANT-BASED DIP UTILIZING SOURSOP (*ANNONA MURICATA*) AND SPINACH (*SPINACIA OLERACEA*) WITH DIFFERENT TYPES OF VEGETABLE OILS: PHYSICOCHEMICAL PROPERTIES, SENSORY EVALUATION, AND NUTRITIONAL COMPOSITION

JOHN LERRY D. MARQUEZ[1], ANGELIKA S. MANUEL[2], RICA MAE M. VIERNES[3], KRISTINE MAE P. IPAN[4], MARY KATHERINE A. APOLONIO[5], RIZALYN M. KOLMAN[6], ROSALYN G. ROSAL[7]
http://0009-0002-0205-6318[1], http://0000-0007-0120-9024[1], http://0009-0006-0982-0461[1],
http://0000-0000-9874-1939[1,2], http://0009-0006-2080-2977.[1,2], http:// 0000-0002-7170-1328[2],
http://0009-0006-4310-1356[2]
jl.marquez1309@student.edu.ph[1], a.manuel1838@student.edu.ph[2], ricamaeviernes@student.tsu.ph[3],
kmpipan@tsu.edu.ph[4], mkaapolonio@tsu.edu.ph[5], rizalyn.kolman@vmuf.edu.ph[6],
rosalyn.rosal@vmuf.edu.ph[7]
Tarlac State University, College of Science, Food Technology Department[1-5]
Villa Lucinda Extension Campus, Bgry. Binauganan, Tarlac City 2300, Tarlac, Philippines
Virgen Milagrosa University Foundation Inc.[4-7]
Martin P. Posadas Avenue, San Carlos City 2420 Pangasinan, Philippines

DOI: https://doi.org/10.54476/ioer-imrj/826177

ABSTRACT

The escalating consumer demand for plant-based alternatives necessitates innovative product development that combines nutritional excellence with superior sensory characteristics. This study investigated the incorporation of different vegetable oils (palm, soybean, and canola) in plant-based dips formulated with soursop (Annona muricata) and spinach (Spinacia oleracea). A completely randomized design with four treatments was employed: control (oil-free), palm oil (T1), soybean oil (T2), and canola oil (T3). Physicochemical analyses included water activity, pH, instrumental color measurement, and rheological properties. Consumer acceptance was evaluated using a 9-point hedonic scale with 100 untrained panelists. Proximate composition was determined following AOAC methods. Results indicated no significant differences in water activity (0.963-0.972, $p > 0.05$) and pH (3.856-4.128, $p > 0.05$) among treatments. Color parameters a* and b* showed significant variations ($p < 0.001$), while lightness (L*) remained unchanged. Viscosity differed significantly ($p < 0.001$), ranging from 6845.59 to 8354.44 cP. All sensory attributes demonstrated significant improvements ($p < 0.001$) with oil incorporation, with canola oil treatment achieving the highest overall acceptability (7.16 ± 1.71). Proximate analysis revealed substantial compositional differences, with T3 exhibiting the highest fat content (28.05 ± 1.42%) and energy density (374 ± 8.2 kcal/100g). Statistical analysis showed highly significant treatment effects for fat content ($F_{3,8} = 289.45$, $p < 0.001$, $\eta^2 = 0.991$), moisture ($F_{3,8} = 156.78$, $p < 0.001$, $\eta^2 = 0.983$), and energy density ($F_{3,8} = 201.33$, $p < 0.001$, $\eta^2 = 0.987$). The incorporation of vegetable oils significantly enhanced physicochemical stability and consumer acceptance while maintaining food safety parameters, with canola oil demonstrating optimal performance characteristics for commercial plant-based product development.

Keywords: plant-based foods, tropical fruits, vegetable oils, food emulsions, consumer acceptance

INTRODUCTION

The future of food innovation lies in the strategic integration of underutilized tropical fruits with nutrient-dense vegetables, creating plant-based alternatives that surpass traditional products in both nutritional value and sensory appeal. The contemporary food landscape is experiencing an unprecedented transformation driven by consumer awareness of health, environmental sustainability, and ethical considerations surrounding food production systems (Estell et al., 2021; Małecki et al., 2021). This paradigmatic shift has catalyzed the development of sophisticated plant-based alternatives that not only replicate traditional animal-based products but also offer enhanced nutritional profiles and novel sensory experiences (McClements & Grossmann, 2021). The plant-based food sector, valued at approximately $29.4 billion globally, continues to expand at a compound annual growth rate of 11.9%, indicating robust consumer acceptance and market potential (McClements & Grossmann, 2021). Recent market analysis indicates that the plant-focused dips market alone is projected to reach $15 billion by 2025, exhibiting a robust compound annual growth rate (CAGR) of 12% from 2025 to 2033, driven by increasing adoption of flexitarian diets and demand for convenient, healthy snack options (Archive Market Research, 2024).

The vegan spreads and dips market has demonstrated exceptional growth, with the US market valued at $27.09 million in 2023 and expected to grow to $67.48 million by 2035 at a CAGR of 7.916% (Market Research Future, 2024). This growth is attributed to rising consumer demand for healthier, more sustainable, and ethically sourced food options, coupled with growing awareness of the environmental impact of animal agriculture (Archive Market Research, 2024).

In the Philippines, the growing health consciousness among consumers has created substantial opportunities for innovative plant-based product development. The country's rich biodiversity offers access to numerous underutilized tropical fruits and nutrient-dense vegetables that can serve as functional ingredients for novel food formulations. The Department of Science and Technology's Food and Nutrition Research Institute has emphasized the importance of developing value-added products from indigenous ingredients to promote both nutritional security and economic development. Recent studies on soursop product development in the Philippines have demonstrated the successful formulation of alternative fruit syrups with acceptable microbial and physicochemical properties (Innspub Research, 2024).

Soursop (*Annona muricata* L.), a tropical fruit indigenous to Central and South America but widely cultivated in Southeast Asia, including the Philippines, represents an underutilized resource with exceptional potential for functional food applications. The fruit exhibits remarkable nutritional density, containing substantial quantities of ascorbic acid (20.6 mg/100g), dietary fiber (3.3 g/100g), and bioactive compounds including acetogenins, which demonstrate potent antioxidant and antimicrobial properties. Research demonstrates that soursop possesses significantly higher antioxidant capacity compared to other tropical fruits, with ORAC values reaching 4,095 μmol TE/100g. The fruit's distinctive flavor profile, characterized as a complex amalgamation of tropical notes, positions it as an attractive ingredient for innovative product development.

Spinach (*Spinacia oleracea* L.) stands among the most nutrient-dense leafy vegetables, exhibiting exceptional concentrations of folate

(194 μg/100g), vitamin K (483 μg/100g), and carotenoids including lutein (12.2 mg/100g) and β-carotene (5.6 mg/100g). Contemporary research has established compelling evidence for spinach's cardiovascular protective effects, attributing these benefits to its high nitrate content (2.46 g/kg fresh weight) and antioxidant compounds. The synergistic combination of soursop and spinach presents opportunities for developing products with enhanced nutritional functionality and complex flavor profiles.

The incorporation of lipids in food matrices serves multiple critical functions beyond simple caloric contribution, fundamentally influencing textural properties, flavor release mechanisms, and overall consumer perception. Different vegetable oils exhibit distinct physicochemical characteristics that significantly impact emulsion stability, rheological behavior, and sensory attributes. Palm oil, characterized by its balanced saturated/unsaturated fatty acid composition (49.3% saturated), provides exceptional oxidative stability and contributes to desirable textural properties.

Despite extensive research on individual components, limited scientific literature addresses the systematic integration of tropical fruits with nutrient-dense vegetables in oil-stabilized emulsion systems. The complex interactions between fruit-derived pectin, vegetable proteins, and various lipid phases require comprehensive investigation to optimize product functionality and consumer acceptance. This study addresses this critical knowledge gap by providing comprehensive physicochemical, sensory, and nutritional characterization of innovative plant-based dips that combine the exotic appeal of soursop with the nutritional powerhouse of spinach, stabilized with carefully selected vegetable oils. The findings reveal surprising interactions between these components that challenge conventional formulation approaches and offer unprecedented opportunities for creating commercially viable, consumer-preferred plant-based alternatives that could revolutionize the healthy snacking market.

OBJECTIVES OF THE STUDY

This investigation aimed to develop innovative plant-based dips incorporating soursop and spinach with different vegetable oils, specifically (1) comprehensively evaluate physicochemical properties including water activity, pH, color parameters, and rheological characteristics, (2) assess consumer acceptance through systematic sensory evaluation, and (3) determine nutritional composition and adequacy of the developed formulations.

MATERIALS AND METHODS

Raw Materials

Fresh soursop fruits (*Annona muricata*) and spinach (*Spinacia oleracea*) were procured from certified vendors at Tarlac Public Market, Philippines, following established quality criteria for optimal ripeness and absence of physical defects. Refined vegetable oils, including palm oil (*Elaeis guineensis*), soybean oil (*Glycine max*), and canola oil (*Brassica napus*), were obtained from commercial suppliers and verified for compliance with international quality standards. Coconut cream (24% fat content), food-grade additives including xanthan gum (E415), sodium benzoate (E211), and citric acid (E330) were sourced from established food ingredient suppliers. All analytical-grade chemicals and reagents were procured from Merck KGaA (Darmstadt, Germany).

Product Formulation and Development

Formulation development is shown in Table 1, proceeded through systematic optimization trials following established protocols for emulsion-based products. The final compositions were determined based on preliminary sensory evaluation and physicochemical stability assessments. Oil incorporation levels were standardized at 88g per 500g total formulation (17.6% w/w) to ensure consistency across treatments while maintaining emulsion stability.

Table 1
Optimized Formulations of Plant-Based Dips with Different Vegetable Oils

Ingredients	Control (g)	T1 - Palm Oil (g)	T2 - Soybean Oil (g)	T3 - Canola Oil (g)
Soursop pulp	160	160	160	160
Blanched spinach	20	20	20	20
Coconut cream	130	130	130	130
Vegetable oil	0	88	88	88
Lemon juice	10	10	10	10
Dried parsley	1	1	1	1
Onion leeks (dried)	1	1	1	1
Garlic powder	2	2	2	2
White onion (minced)	5	5	5	5
Sodium chloride	2	2	2	2
Xanthan gum	1	1	1	1
Sodium benzoate	0.033	0.042	0.042	0.042
Citric acid	2.5	2.5	2.5	2.5

Processing Protocol

The processing methodology was adapted from established protocols for fruit-vegetable composite products with modifications to optimize emulsion formation and stability. Spinach underwent controlled blanching at 70°C for 2-3 minutes in citric acid solution (0.1% w/v) to minimize enzymatic browning and preserve color integrity. Soursop fruits were processed according to standardized protocols, including washing, peeling, deseeding, and thermal treatment at 100°C for 10 minutes to ensure microbiological safety while preserving nutritional components.

The emulsification process employed high-speed homogenization at 8,000 rpm for 5 minutes to achieve uniform particle size distribution and optimal emulsion stability. Thermal processing was conducted at 80-90°C for 8 minutes, followed by hot-filling at 65-70°C into sterilized glass containers. Rapid cooling to 4°C was implemented using a controlled cooling protocol to minimize thermal damage and maintain product quality.

Physicochemical Analyses

Water Activity Determination

Water activity (aw) measurements were conducted using a calibrated water activity meter (AquaLab 4TE, METER Group, USA) following AOAC Method 978.18. Samples (2g) were equilibrated at 25.0 ± 0.1°C for 30 minutes before measurement. Three replicate measurements were performed for each sample, with the coefficient of variation maintained below 2%.

pH Analysis

pH determination employed a calibrated digital pH meter (Hanna HI-2020, Romania) following AOAC Method 981.12. Calibration was performed using certified buffer solutions (pH 4.01, 7.00, and 10.01) before each measurement session. Sample preparation involved dilution with distilled water (1:1 w/v) and thorough homogenization for 2 minutes.

Instrumental Color Measurement

Color characterization utilized a calibrated tristimulus colorimeter (Konica Minolta CR-400, Japan) following CIE L*ab** color space protocols. Instrument calibration was performed using a standard white tile (L* = 97.83, a* = -0.45, b* = +1.98). Measurements were conducted under standardized illumination (D65/10°) with five replicate readings per sample.

Rheological Properties

Viscosity measurements were performed using a Brookfield viscometer (DV-II+ Pro, USA) equipped with spindle #6 at 100 rpm rotation speed and 25°C. Samples (500 mL) were conditioned at measurement temperature for 15 minutes before analysis. Apparent viscosity was expressed in centipoise (cP).

Sensory Evaluation

Consumer acceptance testing was conducted following established protocols for hedonic evaluation. The study employed a 9-point hedonic scale (1 = dislike extremely, 9 = like extremely) administered to 100 untrained panelists recruited from the university community. Panelist selection criteria included age 18-65 years, absence of food allergies, and informed consent provision.

Sensory sessions were conducted in individual testing booths under controlled conditions (22 ± 2°C, 65% relative humidity, white fluorescent lighting). Samples (10g) were served at 4°C in coded plastic cups with plain tortilla chips as carriers. Panelists evaluated appearance, color, aroma, texture, taste, and overall acceptability using standardized scorecards.

Proximate Composition Analysis

Proximate analysis was conducted following AOAC official methods at an accredited laboratory (INTERTEK Testing Services, Philippines). Moisture content determination employed oven-drying at 105°C (AOAC Method 925.09), ash content by muffle furnace incineration at 550°C (AOAC Method 923.03), crude protein by Kjeldahl nitrogen determination (AOAC Method 2001.11), and total lipids by acid hydrolysis followed by petroleum ether extraction (AOAC Method 922.06). Carbohydrate content was calculated by difference.

RESULTS AND DISCUSSION

1. Physicochemical Properties

The comprehensive physicochemical characterization revealed differential effects of oil incorporation on various product attributes, with significant implications for both food safety parameters and consumer acceptance potential. The statistical analysis demonstrated varying degrees of significance across the evaluated parameters, providing critical insights for product optimization and commercial viability, as reflected in Table 2.

The physicochemical, sensory, and nutritional properties of plant-based dips formulated with soursop and spinach varied significantly depending on the type of vegetable oil used. Water activity (aw) values ranged from 0.963 ± 0.004 to 0.972 ± 0.003, with no significant differences across treatments ($p > 0.05$). Despite being above the microbial safety threshold of 0.85, the low pH values (3.856–4.128) ensured safety as acidified foods ($p < 4.6$), offering protection against *Clostridium botulinum* growth, as emphasized by the FDA (2018).

Color analysis showed significant differences in redness (a*) and yellowness (b*) ($p < 0.001$). Soybean oil (T2) yielded the highest b* value (14.12 ± 0.65), likely attributed to its carotenoid content, aligning with results from Rodrigues et al. (2022) who found similar effects in oil-stabilized emulsions. The L* values, indicating brightness, remained statistically unchanged, consistent with Sharma et al. (2012), suggesting lipid addition did not interfere with light reflectance properties in a water-dominant matrix.

Table 2
Physicochemical Properties of Plant-Based Dips with Different Vegetable Oils

Parameter	Control	T1 (Palm Oil)	T2 (Soybean Oil)	T3 (Canola Oil)
Water Activity	0.963±0.004[a]	0.971±0.003[a]	0.970±0.004[a]	0.972±0.003[a]
pH	3.856±0.076[a]	4.089±0.133[a]	4.042±0.148[a]	4.128±0.098[a]
L* (Lightness)	81.55±1.16[a]	82.42±1.92[a]	84.48±1.54[a]	83.22±1.88[a]
a* (Redness)	0.95±0.16[a]	0.81±0.11[b]	1.16±0.09[c]	1.38±0.12[d]
b* (Yellowness)	12.16±0.99[a]	13.42±0.77[b]	14.12±0.65[c]	12.82±0.89[b]
Viscosity (cP)	8354±182[a]	6846±97[b]	6922±187[bc]	7029±94[c]

Note. Values represent mean ± standard deviation (n=9). Different superscript letters within rows indicate significant differences (p < 0.05).

In terms of viscosity, the control formulation (no oil) had the highest viscosity (8354 ± 182 cP), while oil-containing samples displayed significantly lower values ($p < 0.001$), consistent with findings from Dickinson (2018), who demonstrated that dispersed lipid phases interrupt aqueous network structures, decreasing apparent viscosity. All values fell within the commercial range for dips (5,000–10,000 cP), according to Brookfield Engineering standards (2005).

2. Consumer Acceptance and Sensory Characteristics

Comprehensive sensory evaluation revealed statistically significant differences among treatments for all evaluated attributes ($p < 0.001$), with oil incorporation consistently enhancing consumer acceptance across multiple sensory modalities, as exhibited in Table 3.

Table 3
Sensory Evaluation Scores for Plant-Based Dips Using a 9-Point Hedonic Scale

Attribute	Control	T1 (Palm Oil)	T2 (Soybean Oil)	T3 (Canola Oil)
Appearance	6.93±1.42[a]	6.31±1.86[b]	7.66±1.08[c]	7.48±1.22[c]
Color	6.97±1.38[a]	7.15±1.44[a]	7.63±1.15[b]	7.50±1.33[b]
Aroma	6.47±1.59[a]	6.98±1.52[b]	7.16±1.48[b]	6.89±1.67[b]
Texture	6.47±1.48[a]	6.95±1.39[b]	7.15±1.31[b]	6.92±1.55[b]
Taste	5.89±1.71[a]	6.73±1.49[b]	7.14±1.44[b]	6.78±1.52[b]
Overall Acceptability	6.31±1.64[a]	6.89±1.58[b]	7.11±1.47[b]	7.16±1.71[b]

Note. Values represent mean ± standard deviation (n=100). Different superscript letters within rows indicate significant differences (p < 0.05).

Consumer sensory scores improved significantly with oil incorporation. Canola oil (T3) showed the highest overall acceptability (7.16 ± 1.71), reflecting its smooth mouthfeel and balanced flavor, supported by Lin et al. (2013), who reported favorable organoleptic profiles for canola oil due to its high oleic acid content and oxidative stability. This reinforces lipid's multifunctional role in improving texture, flavor delivery, and consumer perception (Tarancón et al., 2013).

3. Nutritional Composition and Adequacy Assessment

Proximate analysis revealed in Table 4, had substantial compositional differences among treatments, reflecting the significant impact of oil incorporation on nutritional profiles. The comprehensive statistical analysis demonstrated highly significant treatment effects across multiple nutritional parameters.

Table 4
Proximate Composition of Plant-Based Dips (g/100g fresh weight)

Moisture	Control	T1 (Palm Oil)	T2 (Soybean Oil)	T3 (Canola Oil)
	71.61±2.18[a]	47.56±1.89[b]	52.34±2.12[c]	43.62±1.76[d]
Ash	1.53±0.09[a]	1.25±0.07[b]	1.24±0.08[b]	1.20±0.06[b]
Crude Protein	1.33±0.11[a]	1.36±0.09[a]	1.23±0.08[a]	1.19±0.07[a]
Total Fat	5.99±0.34[a]	24.04±1.23[b]	26.46±1.35[c]	28.05±1.42[d]
Carbohydrates	19.54±1.12[a]	25.79±1.45[b]	18.73±1.08[ac]	25.94±1.38[b]
Energy (kcal/100g)*	125±3.2[a]	341±7.8[b]	352±8.1[c]	374±8.2[d]

*Note. Values represent mean ± standard deviation (n=9). Different superscript letters within rows indicate significant differences (p < 0.05). *Calculated using Atwater factors: protein = 4 kcal/g, carbohydrates = 4 kcal/g, fat = 9 kcal/g.*

Nutritional profiling revealed that oil type significantly influenced macronutrient distribution. Total fat content demonstrated dramatic variation among treatments, with highly significant treatment effects ($F_{3,8}$ = 289.45, $p < 0.001$, η^2 = 0.991), ranging from 5.99 ± 0.34% (control) to 28.05 ± 1.42% (T3). The exceptionally large effect size (η^2 = 0.991) indicates that oil type accounts for over 99% of the variance in fat content, demonstrating the profound impact of oil incorporation on lipid composition. This substantial increase in lipid content fundamentally altered the nutritional profile and energy density of the products. T3 had the highest fat content (28.05 ± 1.42%) and energy density (374 ± 8.2 kcal/100g), matching data trends in lipid-rich emulsions as described by Przybylski et al. (2013).

Moisture content showed equally significant treatment effects ($F_{3,8}$ = 156.78, $p <$ 0.001, η^2 = 0.983), with the control having the highest moisture (71.61 ± 2.18%) and T3 the lowest (43.62 ± 1.76%). This inverse relationship between moisture and fat content is expected due to the displacement effect of oil incorporation in the matrix. Moisture content decreased significantly with oil addition (p < 0.001), indicating a displacement effect common in lipid-aqueous phase matrices (Fellows, 2016).

Energy density demonstrated highly significant differences ($F_{3,8}$ = 201.33, $p < 0.001$, η^2 = 0.987), with T3 containing approximately three times the energy of the control formulation (374 vs 125 kcal/100g). The large effect size confirms that oil type is the primary determinant of caloric density in these formulations.

Ash content showed significant variation ($F_{3,8}$ = 12.45, $p <$ 0.001, η^2 = 0.823), with the control having higher mineral content compared to oil-containing treatments, likely due to concentration effects. Protein content remained relatively stable across treatments ($F_{3,8}$ = 1.89, p = 0.167, η^2 = 0.415), indicating that oil incorporation does not significantly affect protein levels.

Carbohydrate content varied significantly ($F_{3,8}$ = 34.67, $p <$ 0.001, η^2 = 0.929), primarily reflecting differences in total solid content and moisture displacement rather than actual carbohydrate addition. The protein quality, while modest in quantity, derives from both plant sources, providing a spectrum of amino acids typical of plant-based formulations.

CONCLUSIONS

This investigation successfully demonstrated the feasibility of developing innovative plant-based dips that combine the nutritional benefits of soursop and spinach with the functional advantages of different vegetable oils. The systematic evaluation confirmed that oil incorporation significantly enhanced sensory acceptability across multiple attributes while maintaining appropriate physicochemical characteristics for commercial viability.

Statistical analyses revealed that vegetable oil type substantially influences product characteristics, with canola oil demonstrating optimal performance in terms of overall consumer acceptance and nutritional profile. The comprehensive statistical analysis of proximate composition revealed highly significant treatment effects for most nutritional parameters, with effect sizes exceeding 0.90 for fat content, moisture, and energy density, indicating that oil type is the primary determinant of nutritional composition.

From a commercial perspective, these findings provide valuable guidance for formulating plant-based alternatives that meet consumer expectations for sensory quality while delivering enhanced nutritional benefits. The successful integration of underutilized tropical fruits like soursop with nutrient-dense vegetables represents a promising avenue for developing functional foods that address contemporary consumer demands for healthy, sustainable food options.

RECOMMENDATIONS

Based on the comprehensive findings of this study, the following recommendations are proposed:

1. *Commercial Development*: Prioritize canola oil formulation (T3) for commercial production due to superior sensory acceptance and optimal nutritional profile.
2. *Process Optimization*: Implement standardized emulsification protocols at 8,000 rpm for 5 minutes to ensure consistent product quality and stability.
3. *Quality Assurance*: Establish critical control points for pH monitoring (target: 3.8-4.2) and water activity (target: <0.97) to ensure microbiological safety.
4. *Shelf-life Studies*: Conduct comprehensive shelf-life evaluation under various storage conditions to determine optimal packaging and storage recommendations.
5. *Nutritional Enhancement*: Investigate fortification opportunities with additional micronutrients to further enhance the functional food potential.
6. *Market Research:* Conduct consumer preference studies across different demographic segments to optimize market positioning and acceptance.
7. *Scaling Studies*: Develop pilot-scale production protocols to maintain quality consistency during commercial manufacturing.

REFERENCES

Alcorta, A., Porta, A., Tárrega, A., Alvarez, M. D., & Vaquero, M. P. (2021). Foods for plant-based diets: Challenges and innovations. Foods, 10(2), 293. https://doi.org/10.3390/foods10020293

AOAC International. (2019). Official methods of analysis of AOAC International (21st ed.). AOAC International.

Archive Market Research. (2024). Plant-focused dips report probes the market size, share, growth report and future analysis by 2033. Archive Market Research.https://www.archivemarketresearch.com/reports/plant-focused-dips-161287

Barbosa-Cánovas, G. V., Fontana Jr, A. J., Schmidt, S. J., & Labuza, T. P. (2007). Water activity in foods:

Fundamentals and applications. Blackwell Publishing Professional.

Blekkenhorst, L. C., Sim, M., Bondonno, C. P., Bondonno, N. P., Ward, N. C., Prince, R. L., Devine, A., Lewis, J. R., & Hodgson, J. M. (2018). Cardiovascular health benefits of specific vegetable types: A narrative review. Nutrients, 10(5), 595. https://doi.org/10.3390/nu10050595

Calabro, A., Maggiore, R., Fallico, B., Arena, E., & Ballistreri, G. (2024). Nutritional, biochemical, and functional properties of spinach leaf-enriched dough: A healthier alternative to conventional pasta. Foods, 13(22), 3608. https://doi.org/10.3390/foods13223608

Chen, J., & Stokes, J. R. (2012). Rheology and tribology: Two distinctive regimes of food texture sensation. Trends in Food Science & Technology, 25(1), 4-12. https://doi.org/10.1016/j.tifs.2011.11.006

Coria-Téllez, A. V., Montalvo-Gónzalez, E., Yahia, E. M., & Obledo-Vázquez, E. N. (2018). Annona muricata: A comprehensive review on its traditional medicinal uses, phytochemicals, pharmacological activities, mechanisms of action and toxicity. *Arabian Journal of Chemistry, 1*1(5), 662-691. https://doi.org/10.1016/j.arabjc.2015.11.009

Coria-Téllez, A. V., Hernández-Herrero, M. M., Roig-Sagués, A. X., López-Malo, A., & Hernández-Hierro, J. M. (2024). Comparative nutrient and chemometric analysis of leaf to fruits of soursop (Annona muricata) and bullock's heart (Annona reticulata): Implications for nutraceutical development. Food Chemistry, 456, 140058. https://doi.org/10.1016/j.foodchem.2024.140058

Dickinson, E. (2018). On the road to understanding and control of creaminess perception in food colloids. Food Hydrocolloids, 77, 372-385. https://doi.org/10.1016/j.foodhyd.2017.10.014

Espinosa-Andrews, H., Báez-González, J. G., Cruz-Sosa, F., & Vernon-Carter, E. J. (2007). Gum Arabic-chitosan complex coacervation. Biomacromolecules, 8(4), 1313-1318. https://doi.org/10.1021/bm0611634

Estell, M., Hughes, J., & Grafenauer, S. (2021). Plant protein and plant-based meat alternatives: Consumer and nutrition professional attitudes and perceptions. Sustainability, 13(3), 1478. https://doi.org/10.3390/su13031478

García-Zapateiro, L. A., Rojas-Montoya, D., & Quintana, S. E. (2024). Development and characterization of functional beverage based on soursop (Annona muricata L.), inulin, and whey powders. Future Foods, 10, 100329. https://doi.org/10.1016/j.fufo.2024.100329

Gavamukulya, Y., Abou-Elella, F., Wamunyokoli, F., & AEl-Shemy, H. (2014). Phytochemical screening, antioxidant activity and in vitro anticancer potential of ethanolic and water leaves extracts of Annona muricata (Graviola). *Asian Pacific Journal of Tropical Medicine,* 7, S355-S363. https://doi.org/10.1016/S1995-7645(14)60258-3

Gonçalves, E. M., Pinheiro, J., Abreu, M., Brandão, T. R., & Silva, C. L. (2007). Modelling the kinetics of peroxidase inactivation, colour and texture changes of pumpkin (Cucurbita maxima L.) during blanching. Journal of Food Engineering, 81(4), 693-701. https://doi.org/10.1016/j.jfoodeng.2007.01.011

Guichard, E. (2002). Interactions between flavor compounds and food ingredients and their influence on flavor perception. Food Reviews International, 18(1), 49-70. https://doi.org/10.1081/FRI-120003417

Helmy, E. M., El-Salam, A. M., Abd El-Salam, S. S., & Omar, M. M. (2020). Use of spinach powder as functional ingredient in the manufacture of UF-soft cheese. Heliyon, 6(1), e03278. https://doi.org/10.1016/j.heliyon.2020.e03278

Hoek, A. C., Luning, P. A., Weijzen, P., Engels, W., Kok, F. J., & de Graaf, C. (2011). Replacement of meat-by-meat substitutes. A survey on person-and product-related factors in consumer acceptance. Appetite, 56(3), 662-673. https://doi.org/10.1016/j.appet.2011.02.001

Innspub Research. (2024). Development and acceptability of soursop (Annona muricata) as alternative fruit syrup in food service industry. International Journal of Biosciences, 24(4), 123-132. https://innspub.net/development-and-acceptability-of-soursop-annona-muricata-as-alternative-fruit-syrup-in-food-service-industry/

Jiménez, V. M., Grusak, M. A., & Morales, I. (2018). Minerals and bioactive compounds in soursop (Annona muricata L.). In V. R. Preedy (Ed.), Nutritional composition of fruit cultivars (pp. 555-576). Academic Press.

Lin, L., Allemekinders, H., Dansby, A., Campbell, L., Durance-Tod, S., Berger, A., & Jones, P. J. (2013). Evidence of health benefits of canola oil. Nutrition Reviews, 71(6), 370-385. https://doi.org/10.1111/nure.12033

Liu, K., Zhao, Y., Chen, F., & Fang, Y. (2020). Soybean oil-based oleogels structuring with γ-oryzanol and β-sitosterol. Journal of the American Oil Chemists' Society, 97(1), 95-106. https://doi.org/10.1002/aocs.12306

Lucas-González, R., Viuda-Martos, M., Pérez-Álvarez, J. A., & Fernández-López, J. (2021). Assessment of chemical, physicochemical, and lipid stability properties of gelled emulsions elaborated with different oils chia (Salvia hispanica L.) or hemp (Cannabis sativa L.) and pseudocereals. Antioxidants, 10(6), 967. https://doi.org/10.3390/antiox10060967

Małecki, J., Tomasevic, I., Djekic, I., & Sołowiej, B. G. (2021). The effect of protein source on the physicochemical, nutritional properties and microstructure of high-protein bars intended for physically active people. LWT, 144, 111187. https://doi.org/10.1016/j.lwt.2021.111187

Mao, Y., & Miao, S. (2015). Rheological properties of acid milk gels. In J. Ahmed, P. Ptaszek, & S. Basu (Eds.), Advances in food rheology and its applications (pp. 181-199). Woodhead Publishing.

Market Research Future. (2024). US vegan spreads and dips market size, share and forecast 2035. Market Research Future. https://www.marketresearchfuture.com/reports/us-vegan-spreads-dips-market-13593

Mba, O. I., Dumont, M. J., & Ngadi, M. (2015). Palm oil: Processing, characterization and utilization in the food industry--A review. Food Bioscience, 10, 26-41. https://doi.org/10.1016/j.fbio.2015.01.003

McClements, D. J. (2015). Food emulsions: Principles, practices, and techniques (3rd ed.). CRC Press.

McClements, D. J., & Grossmann, L. (2021). The science of plant-based foods: Constructing next-generation meat, fish, milk, and egg analogs. Comprehensive Reviews in Food Science and Food Safety, 20(4), 4049-4100. https://doi.org/10.1111/1541-4337.12771

Montejo-Mendez, H. B., Lesher-Gordillo, J. M., Hormaza, J. I., Lobato-Garcia, C. E., Gomez-Rivera, A., Machkour-M'Rabet, S., Gonzalez-Gomez, J. C., Martinez-Yañez, R., & Cruz-Lopez, L. (2025). Genetic analysis and phytochemical profile of soursop (Annona muricata L.) cultivated in family orchards in southeastern Mexico. PLOS One, 20(5), e0321846. https://doi.org/10.1371/journal.pone.0321846

Noor Lida, H. M. D., Sundram, K., & Idris, N. A. (2002). Effect of chemical interesterification on triacylglycerol and solid fat contents of palm stearin, sunflower oil and palm kernel olein blends. European Journal of Lipid Science and Technology, 104(8), 505-514. https://doi.org/10.1002/1438-9312(200208)104:8<505::AID-EJLT505>3.0.CO;2-0

Pal, R. (2011). Rheology of simple and multiple emulsions. Current Opinion in Colloid & Interface

Science, 16(1), 41-60. https://doi.org/10.1016/j.cocis.2010.10.001

Pathare, P. B., Opara, U. L., & Al-Said, F. A. J. (2013). Colour measurement and analysis in fresh and processed foods: A review. Food and Bioprocess Technology, 6(1), 36-60. https://doi.org/10.1007/s11947-012-0867-9

Przybylski, R., Gruczynska, E., & Aladedunye, F. (2013). Performance of regular and modified canola and soybean oils in rotational frying. *Journal of the American Oil Chemists' Society*, 90(9), 1271-1280. https://doi.org/10.1007/s11746-013-2278-0

Qian, C., Decker, E. A., Xiao, H., & McClements, D. J. (2012). Physical and chemical stability of β-carotene-enriched nanoemulsions: Influence of pH, ionic strength, temperature, and emulsifier type. Food Chemistry, 132(3), 1221-1229. https://doi.org/10.1016/j.foodchem.2011.11.091

Roberts, J. L., & Moreau, R. (2016). Functional properties of spinach (Spinacia oleracea L.) phytochemicals and bioactives. Food & Function, 7(8), 3337-3353. https://doi.org/10.1039/C6FO00051G

Rodriguez-Saona, L. E., Giusti, M. M., & Wrolstad, R. E. (2001). Color and pigment analyses in fruit products. In R. E. Wrolstad (Ed.), Current protocols in food analytical chemistry (pp. F1-1). John Wiley & Sons.

Rodrigues, A. M., Silva, L. H., Santos, I. L., & Amante, E. R. (2022). Physical and chemical characterisation of conventional and nano/emulsions: Influence of vegetable oils from different origins. Foods, 11(6), 889. https://doi.org/10.3390/foods11060889

Santos, I. L., Rodrigues, A. M. da C., Amante, E. R., & Silva, L. H. M. da. (2023). Soursop (Annona muricata) properties and perspectives for integral valorization. Foods, 12(7), 1448. https://doi.org/10.3390/foods12071448

São José, J. F. B. D., Medeiros, H. S. D., Bernardes, P. C., & Andrade, N. J. D. (2014). Removal of Salmonella enterica Enteritidis and Escherichia coli from green peppers and melons by ultrasound and organic acids. *International Journal of Food Microbiology,* 190, 9-13. https://doi.org/10.1016/j.ijfoodmicro.2014.08.015

Sharma, P., Segat, A., Kelly, A. L., & Sheehan, J. J. (2012). Colorimetric evaluation of cheese and its correlation with visual appearance. *Journal of Food Engineering,* 111(1), 191-198. https://doi.org/10.1016/j.jfoodeng.2012.01.012

Siddique, R., Khan, A., Akram, K., Kwon, J. H., & Ali, A. (2021). Nutritional characterization and food value addition properties of dehydrated spinach powder. Food Science & Nutrition, 9(2), 1213-1225. https://doi.org/10.1002/fsn3.2094

Silva, L. H. M., Santos, I. L., Rodrigues, A. M., & Barbosa, P. P. M. (2024). Physicochemical and nutritional properties of vegetable oils from Brazil diversity and their applications in the food industry. Foods, 13(10), 1565. https://doi.org/10.3390/foods13101565

Simopoulos, A. P. (2016). An increase in the omega-6/omega-3 fatty acid ratio increases the risk for obesity. Nutrients, 8(3), 128. https://doi.org/10.3390/nu8030128

Singh, S. P., Zhou, X. R., Liu, Q., Stymne, S., & Green, A. G. (2018). Metabolic engineering of new fatty acids in plants. Current Opinion in Plant Biology, 19, 32-37. https://doi.org/10.1016/j.pbi.2014.02.007

Stone, H., Bleibaum, R. N., & Thomas, H. A. (2012). Sensory evaluation practices (4th ed.). Academic Press.

Tarancón, P., Fiszman, S. M., Salvador, A., & Tárrega, A. (2013). Formulating biscuits with healthier fats. Consumer profiling of textural and flavour sensations during consumption. Food Research International, 53(1), 134-140. https://doi.org/10.1016/j.foodres.2013.03.048

Taylor, A. J., & Linforth, R. S. (2010). Food flavour technology (2nd ed.). Wiley-Blackwell.

Wang, X., Li, Y., Yang, R., & Zhang, Q. (2023). Vegetable oils: Classification, quality analysis, nutritional value and lipidomics applications. Food Chemistry, 402, 134447. https://doi.org/10.1016/j.foodchem.2022.134447

Wise Guy Reports. (2025). Plant focused dips sales market size, share, industry trends, forecast 2035. Wise Guy Reports. Retrieved from https://www.wiseguyreports.com/reports/plant-focused-dips-sales-market

Young, V. R., & Pellett, P. L. (1994). Plant proteins in relation to human protein and amino acid nutrition. The American Journal of Clinical Nutrition, 59(5), 1203S-1212S. https://doi.org/10.1093/ajcn/59.5.1203S

AUTHORS' PROFILE

John Lerry D. Marquez was born November 13, 2001, in La Paz, Tarlac, John Lerry excelled academically from elementary through senior high school, graduating with honors and awards such as Most Industrious and Best in Work Immersion. He pursued a Bachelor of Science in Food Technology at Tarlac State University, consistently making the Dean's List. His strong academic record reflects perseverance and a passion for science and arts. John Lerry aims to become a skilled professional in food technology, using his education and achievements to uplift his family and contribute meaningfully to the field.

Angelika S. Manuel was born December 27, 2000, in La Paz, Tarlac, Angelika demonstrated academic excellence throughout her studies, progressing from early education in La Paz and Concepcion to college at Tarlac State University. Despite not initially getting her preferred course, she excelled in the Bachelor of Science in Food Technology, consistently earning Dean's List recognition. Her educational journey highlights resilience and dedication.

Rica Mae M. Viernes was born November 14, 2001, Rica Mae was valedictorian of her elementary school and a consistent honor student through junior and senior high school at Nambalan National High School, where she earned Best in Work Immersion honors. She is currently pursuing a Bachelor of Science in Food Technology at Tarlac State University, maintaining a strong academic record with multiple Dean's List placements. Rica Mae's education and achievements reflect her dedication to excellence and her goal to build a meaningful career that supports her family and community.

Kristine Mae P. Ipan was born April 25, 1993, Kristine Mae excelled academically from elementary through high school, consistently earning honors. She initially studied Applied Science in Nursing before shifting to Food Technology at Tarlac State University, where she graduated Cum Laude in 2016. She received academic excellence awards for three consecutive years and later joined Tarlac State University as an instructor. Kristine Mae is pursuing a Master's in Food Science and a PhD in Science Education, underscoring her commitment to lifelong learning and academic excellence in food technology education.

Mary Katherine A. Apolonio is a dedicated Assistant Professor II with over eight years of academic experience in Food Science and Technology. She is currently pursuing a PhD in Science Education, demonstrating her commitment to continuous learning. Specializing in quality assurance and food safety, her research focuses on food product development and industry innovation. She actively engages in extension services, consultancy, and professional organizations, promoting community involvement and knowledge transfer. Passionate about teaching, research, and service, Mary Katherine strives to advance the field of Food Technology through excellence and practical application, with a passion for advancing the field of Food Technology.

Dr. Rizalyn Mendoza-Kolman obtained her Master of Education and Ph.D. in Educational Development from Hiroshima University, Japan, and finished her Bachelor of Secondary Education, majoring in Social Science at the College of Education - Pangasinan State University Bayambang Campus. She served as a faculty member at De la Salle University-Manila (2005-2008), as director for research at Colegio De Dagupan, now Universidad De Dagupan (2010-2017), and as a part-time lecturer at panpacific university.

She has published scholarly articles, written in english and filipino, in various international academic journals that focus on her research and interests in curriculum development. Her current research focuses on local history and geographical education. She has presented papers at various international and national conferences like the annual meeting of american geographers, unesco conference, and international geographic union conference held in the USA Thailand, South Korea, Japan, and in the Philippines.

Dr. Rosalyn G. Rosal, PhD, is a licensed Registered Pharmacist with advanced degrees in Pharmacy (MS), Public Health (MPH), and a Doctor of Philosophy in Science Education. With over 30 years in higher education, she excels in teaching, research, and mentorship across multiple institutions. Her interdisciplinary expertise spans health research, drug development, and community-based studies, emphasizing scientific inquiry and ethics. Dr. Rosal leads impactful projects addressing public health and pharmaceutical innovation. Active in professional organizations, she fosters collaboration and capacity-building. Her strong educational background drives her dedication to scholarship, inspiring future health professionals and advancing community well-being.

COPYRIGHTS