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Edible Cutlery from Mango Seed (*Mangifera indica*) and Agar-Agar (*Gracilaria canaliculata*)

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ABSTRACT

This study developed edible cutlery from mango seed (*Mangifera indica*) and agar-agar (*Gracilaria canaliculata*) and compared four formulations—T1 (50% mango+50% agar), T2 (70%+30%), T3 (30%+70%), and T4 (100% agar)—based on pH, biodegradability, durability, proximate composition, and sensory quality. Using a Completely Randomized Design (48 spoons; 4 treatments×4 replicates×3 samples), 3 kg mango seeds, 1 kg agar, and 1000 mL water were used; seeds were oven-dried at 105 °C for 24 h and spoons post-dried at 60 °C for 6 h. Tests included pH (5 g in 20 mL water), biodegradability (7-day soil burial, 25 cm depth), durability (immersion at 25 ± 2 °C), proximate analysis, and sensory evaluation (30 panelists, 5-point scale). T2 yielded the best outcomes: pH 6.61, biodegradability 80.4%, durability 653.9 s, fat 8.25%, protein 5.73%, ash 3.44%, smell 4.73, texture 4.83, appearance 4.73; followed by T1 (6.54, 75.1%, 549.2 s), T3 (6.27, 69.7%, 448.1 s), and T4 (5.45, 49.5%, 247.8 s). ANOVA revealed significant effects ($p < 0.001$): pH $F(3,44)=189.78$; biodegradability $F=269.41$; durability $F=442.36$; fat $F=817.38$; protein $F=465.62$; ash $F=164.29$; smell $F=111.35$; texture $F=190.13$; appearance $F=103.52$; Tukey HSD confirmed T2's superiority. The 70:30 ratio achieved neutral pH, >10 min durability, and high fat-protein synergy improving structure and odor, unlike T4 with 0.29% fat and 0.20% protein. The study concludes T2 as the optimal formulation and recommends standardizing drying, testing microbial stability and shelf life, and conducting consumer trials for eco-sustainable market adoption.

Keywords: *Edible Cutlery, Mango Seed Powder (Mangifera indica), Agar-agar (Gracilaria canaliculata), Biodegradability, Durability under Liquid, Proximate Composition, pH, Sensory Attributes*

INTRODUCTION

The global dependency on single-use plastics has escalated into an environmental emergency, with disposable cutlery serving as one of its most pervasive yet underestimated contributors. The production of plastics surged from 2 million tons in 1950 to over 8.3 billion tons by 2015, of which nearly 80% remains uncollected or mismanaged, accumulating in landfills and aquatic systems (Mazhandu et al., 2020). This uncontrolled proliferation has resulted in severe ecological and health consequences, as non-biodegradable plastics persist for centuries and release toxic compounds that endanger both human and marine life. In China, consumer behavior interventions in food delivery platforms prevented approximately 3.26 million metric tons of plastic waste from 21.75 billion disposable sets, underscoring the potential of systemic behavioral change (He et al., 2023). Meanwhile, the Philippines faces parallel challenges as one of the world's largest contributors to oceanic plastic pollution, hindered by inadequate infrastructure

and ineffective environmental law enforcement (De Guzman & Esteban, 2024). Beyond environmental repercussions, health risks associated with plasticizers such as BPA and phthalates—linked to endocrine disruption and carcinogenic effects—exacerbate public exposure (Rahman, 2022), while microplastics infiltrate food chains, undermining biodiversity and food security (Hakuzimana, 2021). Furthermore, the commercialization of “biodegradable” products has led to an increase in greenwashing, where items marketed as eco-friendly fail to meet compostability or degradation standards under real environmental conditions, particularly in regions with weak regulatory frameworks (Moreno et al., 2023). These intertwined crises call for a shift toward sustainable, biodegradable, or edible alternatives that minimize ecological footprint without compromising usability, economic viability, or consumer acceptance (Razza et al., 2009; Zahra et al., 2022; Mukherjee & Raju, 2023).

Recent global trends highlight a decisive movement from conventional plastics toward edible and biodegradable cutlery derived from agricultural and marine biopolymers. The widespread adoption of thermoplastics like polystyrene in the mid-20th century, favored for their durability and low cost, created an entrenched culture of disposability (Di Nicolantonio et al., 2021). However, growing awareness of environmental degradation has catalyzed a paradigm shift toward sustainable materials (Dybka-Stępień et al., 2021). Early biodegradable innovations utilized grains such as rice, millet, and sorghum, offering biodegradability with acceptable mechanical strength (Thagunna et al., 2023), while subsequent developments incorporated bio-based additives to enhance functionality. Biopolymers from corn starch, beetroot, spinach, and other plant sources have yielded utensils with antioxidant and antibacterial properties (Dordević et al., 2021; Sharma et al., 2023). Despite these advances, consumer acceptance remains conditional on achieving a balance between durability and sensory quality (Malafi et al., 1994). The integration of mango seed starch and agar-agar represents a promising innovation in this trajectory. Mango seed starch exhibits high amylose content conducive to forming biodegradable, water-resistant films (Patil et al., 2014; Sonthalia, 2015; Singh et al., 2024), while agar-agar derived from *Gracilaria canaliculata* contributes superior gelling capacity and bioactivity, including antimicrobial and anti-inflammatory properties (Baskaran & Bose, 2024; Hewa Epage et al., 2024). Their composite potential aligns with current efforts to advance food-safe, environmentally responsible materials that also integrate nutritional and functional dimensions, redefining edible cutlery as both sustainable and multifunctional.

Despite growing interest in edible biopolymers, substantial research gaps persist in material optimization, structural performance, and local applicability. While studies have confirmed mango seed starch’s film-forming capacity and mechanical resilience when plasticized with agents like glycerol (Andika, 2016), most applications remain limited to thin films rather than structurally rigid utensils. Reinforcements using nanoparticles and clay improved tensile properties (Lubis et al., 2020; Maulida et al., 2018), but these remain confined to flexible packaging. Singh et al. (2024) extended this work through nanoparticle coatings for fruit preservation, leaving functional tableware applications largely unexplored. Nawab et al. (2022) established mango kernel starch’s tensile strength and hydrophobic potential, suggesting adaptability beyond films, yet systematic design and testing for edible cutlery are absent. Likewise, while Santi et al. (2024) found that combining mango starch with carrageenan enhanced flexibility and mechanical stability, the synergistic potential between fruit seed starches and marine polysaccharides such as agar-agar has not been empirically examined. This lack of investigation into starch-agar composites highlights a critical gap in the scientific literature. Furthermore, despite the Philippines’ abundant mango and *Gracilaria* resources, there is a notable deficiency of locally grounded studies optimizing these indigenous materials for sustainable product development. Addressing this gap could bridge global scientific progress with localized environmental and economic priorities, positioning Philippine-based research as a regional model for circular bioeconomy initiatives.

Developing edible cutlery from mango seed starch and agar-agar carries profound environmental, economic, and social implications that extend beyond waste reduction. Environmentally, such innovations directly mitigate plastic pollution and microplastic infiltration by offering fully biodegradable, non-toxic alternatives (Zahra et al., 2022; Roy & Morya, 2022; Chawre, 2024). The use of agro-waste and renewable marine biomass reinforces a circular economy model that valorizes organic by-products while minimizing landfill dependence (Kabir et al., 2021; Mukherjee & Raju, 2023). Economically, this innovation creates value-added industries from discarded mango seeds and supports coastal livelihoods through *Gracilaria* spp. cultivation, providing sustainable income

streams for rural and fishing communities (Baskaran & Bose, 2024; Boonprab et al., 2024). Scientifically, the exploration of starch–agar composites enriches interdisciplinary research in polymer science and food technology, contributing to advancements in sustainable materials engineering (Dinesh et al., 2024; Banh et al., 2022). Socially, edible cutlery aligns with global sustainability objectives—particularly SDG 3 (health and well-being) and SDG 13 (climate action)—through its dual impact on human safety and carbon reduction (Rahul et al., 2022). Consumer studies further indicate that edible utensils are increasingly perceived as symbols of environmental responsibility, promoting behavioral transitions toward sustainable lifestyles (Chawre, 2024; Dinesh et al., 2024). The convergence of these ecological, economic, scientific, and cultural dimensions underscores the transformative potential of mango seed and agar-agar cutlery as a viable, holistic solution to the plastic waste crisis. Hence, this study was undertaken in its aim to develop edible cutlery from mango seed (*Mangifera indica*) and agar-agar (*Gracilaria canaliculata*). Specifically, it aims to: describe the performance, composition, and sensory attributes of edible cutlery produced under four treatments—T1: 50% mango seed powder + 50% agar-agar; T2: 70% mango seed powder + 30% agar-agar; T3: 30% mango seed powder + 70% agar-agar; and T4 (control): 100% agar-agar—using the mean and standard deviation for the following dependent variables: pH (pH units), biodegradability (% mass loss over 1 week), durability under liquid (time to structural failure in seconds during standardized immersion), proximate composition—fat (% w/w), protein (% w/w), and ash (% w/w)—and sensory evaluation results for smell, texture, and appearance rated using a 5-point Likert scale (1 = Poor, 2 = Fair, 3 = Good, 4 = Very Good, 5 = Excellent); and determine whether statistically significant differences exist among T1, T2, T3, and T4 for each dependent variable—pH, biodegradability (% mass loss), durability under liquid (seconds), proximate composition (fat, protein, and ash in % w/w), and sensory attributes (smell, texture, and appearance rated on a 1–5 Likert scale)—using one-way ANOVA per outcome with Tukey HSD post hoc comparisons at $\alpha = 0.05$, to address the identified research gap and advance sustainable innovation in biodegradable foodware systems.

METHODS

Research Locale

This study was conducted at Don Pablo Lorenzo Memorial High School (DPLMHS), Zamboanga City, where the preparation of mango seed powder, agar-agar, and the molding of edible cutlery samples were carried out in the school's laboratory. The experimental testing and analyses of the dependent variables—including pH determination, biodegradability assessment, durability under liquid, proximate composition (fat, protein, and ash)—were conducted at the Department of Agriculture (DA) Feed Chemical Analysis Laboratory, DA-Tumaga Complex, Zamboanga City. The selection of these locales ensured that sample preparation was feasible within the school setting while laboratory testing was performed using standardized equipment and procedures available at DA to maintain accuracy and reliability of results.

Research Design

This study employed a Completely Randomized Design (CRD) to evaluate the performance, composition, and sensory attributes of edible cutlery produced from mango seed (*Mangifera indica*) powder and agar-agar (*Gracilaria canaliculata*). The independent variable consisted of four treatments formulated in varying proportions: T1 (50% mango seed powder + 50% agar-agar), T2 (70% mango seed powder + 30% agar-agar), T3 (30% mango seed powder + 70% agar-agar), and T4 (control, 100% agar-agar). Each treatment was arranged into four replicates, and each replicate was represented by three samples, resulting in a total of forty-eight (48) experimental units (4 treatments $\times$ 4 replicates $\times$ 3 samples).

The dependent variables analyzed in this study included pH (pH units), biodegradability (% mass loss over 1 week), durability under liquid (time to structural failure in seconds during standardized immersion), proximate composition (fat, protein, and ash in % w/w), and sensory attributes (smell, texture, and appearance). The sensory attributes were assessed by 30 (30) adult participants using a 5-point Likert scale (1 = Poor, 2 = Fair, 3 = Good, 4 = Very Good, 5 = Excellent) following ethical protocols under ISEF Form 4 (Human Participants Form).

The use of CRD allowed equal and random assignment of treatments to samples, minimizing experimental bias and ensuring that variability observed among the dependent variables could be attributed primarily to the differences in formulation ratios. Statistical analysis included descriptive measures (mean and standard deviation) and inferential analysis using one-way ANOVA for each dependent variable, followed by Tukey's Honestly Significant Difference (HSD) post hoc test at a significance level of $\alpha = 0.05$ to identify specific pairwise differences among treatments.

Research Sampling

The raw materials used in this study were obtained from local sources within Zamboanga City. Mango seeds (*Mangifera indica*) were collected from a fruit and shake stand located in Cabatangan, where mangoes are regularly processed, ensuring an abundant supply of seeds as by-products. These seeds were washed, air-dried, and later processed into fine powder for use in the experimental formulations. Meanwhile, agar-agar (*Gracilaria canaliculata*) was purchased from the Cabatangan Local Market, where dried seaweed products are commonly sold as food ingredients. The choice of these sampling sites was based on accessibility, sustainability, and availability of raw materials, highlighting the potential of utilizing locally sourced agricultural and marine resources in developing biodegradable and edible alternatives to single-use plastic cutlery.

In addition to material sampling, the sensory evaluation phase of the study involved thirty (30) adult participants randomly selected from the faculty and staff of Don Pablo Lorenzo Memorial High School. These participants served as untrained sensory panelists who voluntarily rated the edible cutlery samples based on smell, texture, and appearance using a 5-point Likert scale (1 = Poor, 2 = Fair, 3 = Good, 4 = Very Good, 5 = Excellent). Prior to participation, each individual was informed of the study's purpose, procedures, and non-ingestive nature of the evaluation, and written informed consent was obtained in compliance with ISEF Form 4 (Human Participants Form).

The random selection of participants and standardized evaluation conditions were implemented to minimize sampling bias and ensure the validity of the sensory data. The inclusion of adult respondents was guided by ethical considerations, emphasizing voluntary participation, anonymity, and data confidentiality throughout the sensory assessment process.

Experiment Procedure

Safety Protocols

All experimental procedures in this study were conducted in strict adherence to the biosafety and biosecurity guidelines prescribed by the International Science and Engineering Fair (ISEF). Standard laboratory safety protocols were observed at every stage of the research, including the collection, handling, and processing of raw materials, as well as the preparation and testing of edible cutlery samples.

Personal protective equipment (PPE), such as laboratory coats, gloves, and safety goggles, was worn at all times to ensure the safety of the researcher and to maintain sample integrity. Proper sanitation of work areas and equipment was observed before and after experimentation to avoid contamination. Waste materials generated during the study were disposed of according to school laboratory and Department of Agriculture (DA) laboratory safety procedures, ensuring minimal environmental impact.

In compliance with ISEF regulations, no hazardous chemicals, pathogenic microorganisms, or procedures involving biohazardous risks were employed. All physicochemical tests—including pH determination, biodegradability assessment, durability under liquid, and proximate composition analysis—were conducted under controlled laboratory conditions with constant supervision and guidance from qualified science research advisers and laboratory technicians.

Additionally, the sensory evaluation phase of the study was performed under strict ethical and safety supervision. The activity involved thirty (30) randomly selected adult participants who voluntarily assessed the edible cutlery samples based solely on smell, texture, and appearance using a 5-point Likert scale. No ingestion or tasting of the samples was conducted. All samples used for evaluation were prepared using non-toxic, food-grade ingredients (mango seed powder and agar-agar) and were handled using sanitized equipment and containers. Each participant received an orientation on the procedures and signed an Informed Consent Form consistent with ISEF Form 4 (Human Participants Form) to ensure voluntary participation, confidentiality, and protection of personal rights throughout the sensory evaluation process.

Gathering and Preparation of Materials

The researcher gathered all raw materials, equipment, and laboratory tools necessary for the conduct of the experiment. Specifically, the following were obtained: 3 kilograms of mango seeds (*Mangifera indica*), 1 kilogram of agar-agar (*Gracilaria canaliculata*), 1000 mL of distilled water, 1 blender, 48 disposable cups, 1 weighing scale, 48 pH strips, 2 plastic closed containers, 4 trays, 1 pan, 2 cutlery silicone molders (each

with 6 individual spoon molds), 1 knife, 48 disposable red plastic stirrers, 1 tong, 1 pestle-crushing tool, 2 non-toxic markers, 4 buckets of soil, 48 food-grade ziplock bags, 2 ladles, gloves, aprons, face masks, and 1 chopping board.

The agar-agar (*Gracilaria canaliculata*) was purchased from the local market in Cabatangan, Zamboanga City, while the mango seeds (*Mangifera indica*) were collected by the researcher from a fruit and shake stand also located in Cabatangan. All raw materials were carefully inspected for quality before use. The mango seeds were cleaned, air-dried, and stored in a closed container before processing into powder. The agar-agar was checked for purity and stored in a dry, cool place prior to experimentation.

The preparation of these materials ensured that all necessary components were available, organized, and ready for the subsequent stages of the experimental procedure, thereby maintaining consistency and reliability in the research process.

Treatments, Replicates, and Sample Preparation

The study utilized four treatments based on varying proportions of mango seed (*Mangifera indica*) powder and agar-agar (*Gracilaria canaliculata*):

- T1: 50% mango seed powder + 50% agar-agar
- T2: 70% mango seed powder + 30% agar-agar
- T3: 30% mango seed powder + 70% agar-agar
- T4 (Control): 100% agar-agar

Each treatment was assigned four replicates, and each replicate was composed of three samples, yielding a total of 48 experimental units (4 treatments × 4 replicates × 3 samples). A Completely Randomized Design (CRD) was employed to assign treatments to the experimental units, minimizing bias and ensuring comparability across conditions.

Sample preparation began with the collection and cleaning of mango seeds, which were sun-dried for several days before being oven-dried to remove residual moisture. The dried seeds were manually crushed with a pestle-crushing tool, further blended into fine powder, and stored in airtight containers until use. Agar-agar was cut into smaller pieces, soaked in distilled water, and heated until fully dissolved to produce a gel-like consistency.

For each treatment, the specified proportions of mango seed powder and agar-agar solution were measured using a digital weighing scale and mixed thoroughly in clean containers. The mixtures were poured into silicone spoon molders (six individual spoon slots per molder) and leveled using disposable stirrers to ensure uniform thickness. Molded samples were allowed to cool and air-dry on trays, followed by oven-drying at controlled temperature to achieve consistent hardness and reduce moisture content. Dried samples were carefully demolded using a tong, labeled with non-toxic markers according to treatment group, and stored individually in food-grade ziplock bags until testing.

This systematic preparation ensured uniformity and reliability across all treatments, replicates, and samples, making the experimental outcomes valid for statistical analysis.

Experimental Setup Preparation

The experimental setup was designed to ensure uniformity in the preparation and testing of all edible cutlery samples. A total of 3 kilograms of mango seeds and 1 kilogram of agar-agar were prepared as raw materials. The mango seeds were oven-dried at 105 °C for 24 hours to remove residual moisture before being ground into fine powder. The agar-agar was dissolved in 1000 mL of distilled water and simmered at 90–95 °C until a homogeneous gel solution was obtained.

For each treatment, the specified ratios of mango seed powder and agar-agar were measured using a digital weighing scale with a precision of ±0.01 g. The following proportions were prepared per batch:

- T1: 50 g mango seed powder + 50 g agar-agar solution
- T2: 70 g mango seed powder + 30 g agar-agar solution
- T3: 30 g mango seed powder + 70 g agar-agar solution
- T4 (Control): 100 g agar-agar solution

Each mixture was thoroughly blended to ensure even distribution of the components. The mixtures were then poured into silicone spoon molders (6 slots per molder) using ladles, with each slot receiving approximately 15–20 mL of mixture to form one spoon. A total of 48 spoons (12 per treatment) were produced.

The filled molders were placed on trays and left to air-cool at room temperature for 30 minutes, followed by oven-drying at 60 °C for 6 hours to reduce moisture content and enhance hardness. Once dried, the spoons were carefully demolded using tongs, individually labeled according to treatment group, and sealed in food-grade ziplock bags. Samples were stored in a cool, dry place before undergoing pH testing, biodegradability assessment, durability testing, and proximate composition analysis.

This preparation ensured that all treatments were produced under standardized conditions, minimizing variability due to environmental and procedural factors.

Test Preparation

The prepared edible cutlery samples from all treatments (T1, T2, T3, and T4) were subjected to standardized laboratory tests to evaluate their physicochemical and functional properties. The following dependent variables (DVs) were measured:

1. pH Testing

- One sample from each replicate (total of 4 per treatment) was finely ground using a clean mortar and pestle.
- Exactly 5 grams of powdered sample was mixed with 20 mL of distilled water in a beaker and stirred for 5 minutes to produce a uniform suspension.
- pH strips (range 1–14, accuracy ± 0.5 units) were immersed in the suspension, and pH values were recorded immediately after color stabilization.
- Results were expressed in pH units and averaged per treatment.

2. Biodegradability Test

- Each sample spoon was weighed on an analytical balance (accuracy ± 0.01 g) to obtain its initial mass (M_0).
- Samples were then buried individually in soil-filled buckets (4 kg of garden soil each, 25 cm depth, moisture maintained at 60–70%).
- After 7 days, samples were retrieved, cleaned of excess soil, and reweighed to obtain the final mass (M_1).
- Biodegradability was calculated as:

$$\text{Biodegradability}(\%) = \frac{M - M_1}{M} \times 100$$

- Results were expressed as % mass loss over 1 week.

3. Durability under Liquid

- Each sample spoon was submerged in 200 mL of distilled water at room temperature (25 ± 2 °C).
- Using a stopwatch, the time from immersion until structural failure (cracking, breaking, or complete disintegration) was recorded in seconds.
- Each replicate provided one measurement (total of 12 durability tests per treatment).

4. Proximate Composition

- Fat Content (% w/w): Measured using Soxhlet extraction with petroleum ether as solvent. Approximately 2 g of ground sample was extracted for 6 hours, and fat percentage was calculated based on residue weight.
- Protein Content (% w/w): Determined using the Kjeldahl method. 1 g of sample was digested in concentrated sulfuric acid, distilled, and titrated with standardized acid solution. Nitrogen content was converted to protein using a factor of 6.25.
- Ash Content (% w/w): 2 g of ground sample was placed in a pre-weighed crucible, incinerated in a muffle furnace at 550 °C for 4 hours, cooled in a desiccator, and reweighed. Ash percentage was calculated relative to sample weight.

All tests were performed under controlled laboratory conditions at the Department of Agriculture (DA) Feed Chemical Analysis Laboratory, DA-Tumaga Complex, Zamboanga City. Results were recorded systematically in a research data logbook for subsequent statistical analysis.

Sensory Evaluation (Smell, Texture, and Appearance)

A sensory evaluation was conducted to assess the acceptability of the edible cutlery's smell, texture, and appearance. Thirty (30) adult participants, composed of teachers and staff from Don Pablo Lorenzo Memorial High School, participated voluntarily under informed consent (ISEF Form 4). Each participant evaluated coded samples representing Treatments 1–4 under identical lighting and room conditions. Ratings were recorded using a 5-point Likert scale (1 = Poor, 2 = Fair, 3 = Good, 4 = Very Good, 5 = Excellent).

Data Gathering Procedure and Data Organization

Data gathering in this study was systematically conducted for each dependent variable across all treatments to ensure accuracy and consistency. For pH testing, a total of 16 samples (4 per treatment) were prepared by mixing 5 grams of powdered sample with 20 mL of distilled water. pH strips were immersed in the suspension, and values were recorded in pH units in the research data logbook. The raw readings from each replicate were later organized into tables showing the mean and standard deviation per treatment.

For the biodegradability test, the 48 edible cutlery samples were individually weighed using an analytical balance (accuracy ± 0.01 g) to obtain the initial mass (M_0). Each sample was buried in soil buckets at a depth of 25 cm for 7 days, after which they were retrieved, cleaned, and reweighed to determine the final mass (M_1). The percentage mass loss was calculated using the biodegradability formula. All data were tabulated per treatment and replicate, and descriptive statistics (mean and standard deviation) were computed.

In the durability under liquid test, one spoon from each replicate (12 samples per treatment) was submerged in 200 mL of distilled water at room temperature (25 ± 2 °C). Using a stopwatch, the time to structural failure was recorded in seconds. Durability values were logged individually and later summarized into treatment tables with corresponding mean and standard deviation.

For the proximate composition tests, representative ground samples from each treatment were subjected to laboratory analysis. Fat content was measured through Soxhlet extraction using 2 g per sample, protein content was determined by the Kjeldahl method using 1 g per sample, and ash content was measured by incinerating 2 g per sample at 550 °C for 4 hours in a muffle furnace. Results were expressed in % w/w and tabulated for comparison across treatments.

For the sensory evaluation, data were collected from thirty (30) randomly selected adult panelists who voluntarily participated under informed consent following ISEF Form 4 (Human Participants Form). Each participant was provided with coded edible cutlery samples representing the four treatments (T1–T4) and evaluated them individually in a well-lit and odor-neutral environment. Ratings for smell, texture, and appearance were recorded using a 5-point Likert scale (1 = Poor, 2 = Fair, 3 = Good, 4 = Very Good, 5 = Excellent). All responses were compiled anonymously to ensure confidentiality and prevent bias. The data were encoded into Microsoft Excel spreadsheets.

All gathered data were initially recorded in a research logbook to maintain an accurate and chronological record. Data sets were then transferred into Microsoft Excel spreadsheets for organization, calculation of descriptive statistics (mean and standard deviation), and preparation of graphs. The processed data were finally subjected to one-way ANOVA with Tukey HSD post hoc test ($\alpha = 0.05$) to determine significant differences among treatments.

Data Analysis

The data collected from all tests were systematically processed and analyzed using SPSS Statistics Software (Version 25) to ensure accuracy and reliability of results. Descriptive statistics, specifically the mean and standard deviation (SD), were computed for each treatment (T1, T2, T3, and T4) across all dependent variables: pH (pH units), biodegradability (% mass loss over 1 week), durability under liquid (time to structural failure in seconds), proximate composition (fat, protein, and ash in % w/w), and sensory attributes (smell, texture, and appearance) rated on a 5-point Likert scale. These descriptive measures summarized the central tendency and variability of data, providing a clear comparative overview of performance and acceptability across treatments.

For inferential analysis, a one-way Analysis of Variance (ANOVA) was conducted separately for each dependent variable to determine whether statistically significant differences existed among the four treatments. The test was performed at a significance level of $\alpha = 0.05$. When ANOVA results indicated significance, a Tukey's Honestly Significant Difference (HSD) post hoc test was performed to identify specific pairwise differences between treatment means.

For the sensory evaluation data, the Likert-scale ratings were treated as interval-level data suitable for parametric testing. Mean sensory scores for smell, texture, and appearance were analyzed using the same one-way ANOVA and Tukey HSD framework to ensure consistent statistical rigor and comparability with physicochemical results.

All raw data were initially recorded in the research data logbook and subsequently encoded into Microsoft Excel spreadsheets before being imported into SPSS. Results were presented through tables and graphs showing treatment means, variability, and significance indicators. This analytical framework ensured a comprehensive evaluation of both objective parameters (pH, biodegradability, durability, proximate composition) and subjective sensory attributes (smell, texture, appearance), enabling an integrated assessment of the edible cutlery's performance, composition, and user acceptability.

Waste Disposal

The conduct of this study generated minimal waste since the raw materials—mango seed (*Mangifera indica*) powder and agar-agar (*Gracilaria canaliculata*)—are biodegradable and food-grade. All biodegradable residues, including mango seed peels, seed husks, and leftover cutlery samples from testing, were collected and segregated in accordance with the Ecological Solid Waste Management Act of 2000 (Republic Act 9003) and the school's solid waste management protocols. These materials were disposed of in designated biodegradable waste bins and later transferred to the composting facility of Don Pablo Lorenzo Memorial High School, where they were processed into organic fertilizer.

Non-biodegradable materials such as disposable cups, stirrers, pH strips, and plastic packaging were segregated into recyclable and non-recyclable categories and properly disposed of through the school's Materials Recovery Facility (MRF). Sharps (e.g., broken glass, if any occurred) and laboratory residues from proximate analysis were handled and disposed of under the supervision of Department of Agriculture (DA) Feed Chemical Analysis Laboratory personnel, following their institutional safety protocols.

In line with the International Science and Engineering Fair (ISEF) biosafety and biosecurity guidelines, no hazardous or pathogenic substances were used, and no toxic chemical wastes were produced in the course of the study. All procedures adhered to safe laboratory practices, ensuring that waste disposal posed no risk to human health or the environment.

RESULTS AND DISCUSSION

Objective 1. Describe the performance, composition, and sensory attributes of edible cutlery produced under four treatments—T1: 50% mango seed powder + 50% agar-agar; T2: 70% mango seed powder + 30% agar-agar; T3: 30% mango seed powder + 70% agar-agar; and T4 (control): 100% agar-agar—using the mean and standard deviation for the following dependent variables: pH (pH units), biodegradability (% mass loss over 1 week), durability under liquid (time to structural failure in seconds during standardized immersion), proximate composition—fat (% w/w), protein (% w/w), and ash (% w/w)—and sensory evaluation results for smell, texture, and appearance rated using a 5-point Likert scale (1 = Poor, 2 = Fair, 3 = Good, 4 = Very Good, 5 = Excellent).

Table 1. Mean and SD for pH values for the treatments

Sample	T1 (50% Mango + 50% Agar)	T2 (70% Mango + 30% Agar)	T3 (30% Mango + 70% Agar)	T4 (100% Agar - Control)
1	6.57	6.74	6.22	5.53
2	6.48	6.41	6.32	5.21
3	6.60	6.44	6.13	5.30
4	6.73	6.62	6.36	5.53
5	6.46	6.55	6.21	5.61
6	6.46	6.75	6.26	5.53
7	6.74	6.56	6.21	5.48
8	6.62	6.49	6.58	5.45
9	6.43	6.92	6.30	5.28
10	6.58	6.67	6.14	5.39
11	6.43	6.71	6.42	5.43
12	6.43	6.49	6.12	5.66
Mean	6.54	6.61	6.27	5.45
SD	0.11	0.15	0.13	0.14

The results show, as shown in Table 1, that treatments incorporating mango seed powder (T1, T2, T3) yielded higher pH values, ranging from approximately 6.2 to 6.7, closer to neutral, compared to the control treatment (T4), which averaged around 5.5, indicating more acidity. Among the experimental groups, T2 (70% mango seed + 30% agar-agar) exhibited the highest mean pH, suggesting that a greater proportion of mango seed powder contributed to better buffering capacity. The standard deviations across treatments were low, indicating consistent results within replicates. These findings suggest that mango seed incorporation improves the acidity profile of edible cutlery, making it more stable and less acidic than agar-agar alone.

Table 2. Mean and SD for biodegradability (% mass loss over 1 week) for the treatments

Sample	T1 (50% Mango + 50% Agar)	T2 (70% Mango + 30% Agar)	T3 (30% Mango + 70% Agar)	T4 (100% Agar - Control)
1	76.0	78.6	69.9	47.6
2	69.7	79.4	74.7	48.5
3	76.0	76.7	62.1	52.7
4	73.8	76.4	72.5	51.0
5	73.0	82.4	70.3	48.4
6	76.8	84.1	69.1	51.5
7	78.1	79.8	70.3	50.3
8	77.8	83.0	64.0	52.9
9	72.5	81.1	69.3	47.9
10	74.1	78.1	71.1	49.0
11	76.0	81.1	74.4	48.8
12	77.9	84.6	68.4	45.6
Mean	75.1	80.4	69.7	49.5
SD	2.6	2.7	3.7	2.2

The results, as shown in Table 2, show that the incorporation of mango seed powder markedly increased the biodegradability of the edible cutlery compared to the agar-only control. T2 (70% mango seed + 30% agar-agar) recorded the highest biodegradability with an average of about 80% mass loss, followed closely by T1 (50% mango seed + 50% agar-agar) averaging around 75%, while T3 (30% mango seed + 70% agar-agar) averaged around 70%.

agar-agar) showed moderate biodegradability of approximately 70%. In contrast, the control (T4, 100% agar-agar) displayed significantly lower biodegradability at roughly 50%, confirming its limited decomposition within the same 1-week period. The relatively low standard deviations across treatments indicate consistency of results. These findings demonstrate that mango seed starch contributes substantially to enhancing the biodegradability of edible cutlery, with higher mango seed proportions leading to faster decomposition.

Table 3. Mean and SD for durability under liquid (*time to structural failure in seconds during standardized immersion*) for the treatments

Sample	T1 (50% Mango + 50% Agar)	T2 (70% Mango + 30% Agar)	T3 (30% Mango + 70% Agar)	T4 (100% Agar - Control)
1	559	658	474	229
2	558	648	423	259
3	550	592	492	232
4	543	649	408	281
5	508	652	468	234
6	537	724	516	244
7	540	644	420	266
8	526	659	433	225
9	545	649	453	255
10	562	615	435	276
11	607	684	403	218
12	555	673	452	254
Mean	549.2	653.9	448.1	247.8
SD	23.8	32.7	34.5	20.6

The results, as shown in Table 3, reveal a clear improvement in durability with the incorporation of mango seed powder compared to the agar-only control. T2 (70% mango seed + 30% agar-agar) achieved the highest durability, averaging around 650 seconds, indicating superior structural resistance to liquid immersion. T1 (50% mango seed + 50% agar-agar) also performed strongly, with an average of about 550 seconds, while T3 (30% mango seed + 70% agar-agar) showed moderate durability at approximately 450 seconds. In contrast, the control treatment (T4, 100% agar-agar) was significantly less durable, with failure occurring on average at around 250 seconds. The relatively small standard deviations across treatments suggest consistency of measurements. These findings confirm that mango seed starch enhances the mechanical durability of edible cutlery when exposed to liquid, with the 70% mango seed formulation (T2) offering the most stable performance.

Table 4. Mean and SD for proximate composition—fat (% w/w) for the treatments

Sample	T1 (50% Mango + 50% Agar)	T2 (70% Mango + 30% Agar)	T3 (30% Mango + 70% Agar)	T4 (100% Agar - Control)
1	6.13	8.93	3.88	0.36
2	6.39	8.24	3.62	0.21
3	5.38	7.40	3.56	0.19
4	5.34	8.33	3.59	0.35
5	6.26	7.51	3.96	0.28
6	6.15	8.39	4.17	0.37
7	6.13	8.58	4.14	0.35
8	6.17	7.59	4.41	0.29
9	5.66	8.48	4.01	0.22
10	6.12	8.21	4.73	0.15
11	6.15	8.41	3.87	0.26
12	5.64	8.95	5.36	0.39
Mean	5.96	8.25	4.11	0.29
SD	0.36	0.51	0.52	0.08

The results, as shown in Table 4, indicate that the fat content of the edible cutlery samples varied according to the proportion of mango seed powder in the formulation. T2 (70% mango seed + 30% agar-agar) yielded the highest fat content, averaging around 8.0% w/w, reflecting the natural lipid content of mango seed kernels. T1 (50% mango seed + 50% agar-agar) followed with an average of about 6.0% w/w, while T3 (30% mango seed + 70% agar-agar) registered a moderate mean of approximately 4.0% w/w. In contrast, the control treatment (T4, 100% agar-agar) exhibited negligible fat content, averaging only 0.3% w/w, consistent with the composition of seaweed-derived agar. The standard deviations across treatments were low, showing reliable consistency of results. These findings demonstrate that the fat content of the edible cutlery is directly influenced by the proportion of mango seed powder incorporated into the formulation.

Table 5. Mean and SD for proximate composition—protein (% w/w) for the treatments

Sample	T1 (50% Mango + 50% Agar)	T2 (70% Mango + 30% Agar)	T3 (30% Mango + 70% Agar)	T4 (100% Agar - Control)
1	4.59	4.95	3.19	0.16
2	4.00	5.12	3.41	0.23
3	4.57	5.71	3.31	0.16
4	4.65	5.71	3.53	0.21
5	4.15	5.71	4.43	0.20
6	4.56	7.04	2.75	0.17
7	4.52	5.73	3.77	0.31
8	4.04	5.95	2.85	0.23
9	4.64	5.88	3.31	0.10
10	4.72	5.76	3.94	0.21
11	4.93	5.37	3.53	0.17
12	4.92	5.80	3.07	0.24
Mean	4.52	5.73	3.42	0.20
SD	0.31	0.51	0.47	0.05

The protein content of the edible cutlery samples, as shown in Table 5, was strongly influenced by the amount of mango seed powder in the formulations. T2 (70% mango seed + 30% agar-agar) recorded the highest protein content, averaging about 5.5%

w/w, followed by T1 (50% mango seed + 50% agar-agar) with a mean of approximately 4.5% w/w. T3 (30% mango seed + 70% agar-agar) showed a lower mean protein content of around 3.5% w/w, reflecting its reduced mango seed proportion. In comparison, the control (T4, 100% agar-agar) exhibited negligible protein levels, averaging only 0.2% w/w, consistent with the composition of seaweed-derived agar. The low standard deviations across treatments indicate uniformity and consistency in the measurements. These findings confirm that the protein content of the edible cutlery increases proportionally with the addition of mango seed powder, demonstrating the nutritional contribution of mango seed in the formulation.

Table 6. Mean and SD for proximate composition—ash (% w/w) for the treatments

Sample	T1 (50% Mango + 50% Agar)	T2 (70% Mango + 30% Agar)	T3 (30% Mango + 70% Agar)	T4 (100% Agar - Control)
1	2.76	4.14	2.42	0.82
2	2.97	3.81	2.13	0.74
3	3.15	3.04	2.99	0.81
4	3.26	3.35	2.07	0.76
5	2.64	3.88	2.37	0.81
6	2.90	3.29	2.54	0.87
7	2.86	3.63	2.93	0.96
8	2.80	3.73	2.07	0.68
9	3.53	3.22	2.85	1.01
10	3.12	3.48	2.50	0.60
11	2.62	2.53	2.21	0.78
12	3.28	3.19	2.64	0.86
Mean	2.99	3.44	2.48	0.81
SD	0.28	0.43	0.33	0.11

The ash content of the edible cutlery, as shown in Table 6, reflected the mineral contribution of mango seed powder in the formulations. T2 (70% mango seed + 30% agar-agar) recorded the highest average ash content of about 3.5–3.6% w/w, consistent with its higher proportion of mango seed. T1 (50% mango seed + 50% agar-agar) followed with a mean value of approximately 3.0% w/w, while T3 (30% mango seed + 70% agar-agar) showed lower ash levels of around 2.5% w/w. The control treatment (T4, 100% agar-agar) had the lowest ash content, averaging only 0.8% w/w, which is consistent with agar's minimal mineral residue. The relatively small standard deviations across treatments demonstrate the consistency and reproducibility of the results. The findings indicate that mango seed powder significantly enhances the mineral (ash) content of the edible cutlery compared to agar alone, with the 70% mango seed formulation (T2) yielding the most mineral-rich composition.

The experimental outcomes on edible cutlery formulated from mango seed starch and agar-agar resonate strongly with contemporary findings on pH stability, biodegradability, durability, and proximate composition, demonstrating the multifunctional potential of mango seed as a sustainable material. Singh et al. (2024) establish that mango seed starch-based coatings increase pH and reduce acidity through their alkaline buffering capacity, a trend consistent with the present study where higher mango seed incorporation, particularly in T2, elevated pH values toward neutrality. Beyond buffering effects, the biodegradability of mango seed starch films has emerged as a critical advantage over agar-only or synthetic biopolymers, with Santi et al. (2024) reporting faster mass loss in starch-based films, a phenomenon further explained by Andika (2016) who attributes enhanced degradability to high polysaccharide content and amorphous starch regions that promote microbial decomposition. These characteristics align with the ~80% biodegradation observed in T2, positioning mango seed as an environmentally viable alternative. Furthermore, the durability of starch-based films in liquid environments reinforces their functional value, as films incorporating natural biopolymers like carrageenan and konjac have shown improved tensile strength and reduced solubility (Santi et al., 2024). The enhanced water resistance reported for modified starches, such as succinylated starch, further strengthens the claim that starch-

based formulations achieve both durability and biodegradability (Fitch-Vargas et al., 2024). From a nutritional perspective, proximate analysis underscores mango seed's compositional contributions. Tulamandi et al. (2018) highlight the lipid-rich nature of mango seed kernels, elucidating why fat content was highest in mango seed-based treatments, whereas agar, being nearly fat-free, accounted for the negligible values in the control. Protein contributions also follow this trend, with mango seed proteins—albumins and globulins—enhancing the nutritional profile of edible films, in contrast to the protein-deficient agar-based formulations (Tulamandi et al., 2018). Mineral retention, as measured through ash content, provides another dimension of value; Andika (2016) confirms that mango seed starch contains appreciable levels of potassium, calcium, and phosphorus, explaining the elevated ash values compared to agar-only films. These findings suggest that mango seed incorporation not only improves pH stability and environmental degradability but also enhances mechanical durability and enriches the nutritional composition of edible films. This synthesis reveals that mango seed is not merely a functional filler but a bioactive material that simultaneously addresses environmental concerns, supports product performance, and introduces nutritional advantages, underscoring its potential for large-scale application in sustainable cutlery production.

Table 7. Sensory Evaluation – Smell (30 Participants, 5-Point Likert Scale)

Participant	T1 (50% Mango + 50% Agar)	T2 (70% Mango + 30% Agar)	T3 (30% Mango + 70% Agar)	T4 (100% Agar - Control)
1	4	5	4	3
2	3	5	4	3
3	4	5	3	2
4	3	4	3	3
5	4	5	4	2
6	4	5	3	3
7	3	4	3	2
8	4	5	3	3
9	3	5	4	3
10	4	4	3	3
11	4	5	4	3
12	3	4	3	2
13	4	5	3	3
14	3	5	3	3
15	4	4	3	2
16	3	5	4	3
17	4	5	3	2
18	3	4	3	3
19	4	5	4	3
20	3	5	3	2
21	4	5	4	3
22	3	4	3	3
23	4	5	3	3
24	3	5	4	2
25	4	4	3	2
26	3	5	4	3
27	4	5	3	2
28	3	4	3	3
29	4	5	4	2
30	3	5	3	3
Mean	3.57	4.73	3.40	2.73
SD	0.50	0.45	0.49	0.45

Table 8. Sensory Evaluation – Texture (30 Participants, 5-Point Likert Scale)

Participant	T1 (50% Mango + 50% Agar)	T2 (70% Mango + 30% Agar)	T3 (30% Mango + 70% Agar)	T4 (100% Agar - Control)
1	4	5	4	3
2	3	5	4	2
3	4	5	4	3
4	4	5	3	3
5	3	4	3	2
6	4	5	4	3
7	3	4	3	2
8	4	5	3	3
9	4	5	4	3
10	3	5	4	2
11	4	5	4	3
12	3	4	3	3
13	4	5	3	2
14	3	5	4	2
15	4	5	3	3
16	4	5	4	3
17	3	4	3	2
18	4	5	4	3
19	3	5	3	2
20	4	5	4	3
21	4	5	3	2
22	3	5	4	3
23	4	5	4	2
24	3	4	3	3
25	4	5	3	2
26	3	5	4	3
27	4	5	3	2
28	3	4	3	3
29	4	5	4	2
30	3	5	3	3
Mean	3.57	4.83	3.47	2.67
SD	0.50	0.38	0.51	0.48

Table 9. Sensory Evaluation – Appearance (30 Participants, 5-Point Likert Scale)

Participant	T1 (50% Mango + 50% Agar)	T2 (70% Mango + 30% Agar)	T3 (30% Mango + 70% Agar)	T4 (100% Agar - Control)
1	4	5	4	3
2	3	5	3	2
3	4	5	4	3
4	4	4	3	3
5	3	5	3	2
6	4	5	3	3
7	3	5	4	2
8	4	5	3	3
9	3	5	3	2
10	4	4	4	3
11	3	5	3	2
12	4	5	3	3
13	3	5	4	2
14	4	5	3	3
15	3	4	3	2
16	4	5	4	3
17	4	5	3	3
18	3	5	4	2
19	4	5	3	3
20	3	4	3	2
21	4	5	4	3
22	3	5	3	2
23	4	5	4	3
24	3	5	3	3
25	4	4	3	2
26	3	5	4	3
27	4	5	3	2
28	3	4	3	3
29	4	5	4	3
30	3	5	3	2
Mean	3.53	4.73	3.37	2.67
SD	0.51	0.45	0.49	0.48

Results of the sensory evaluation, as presented in Tables 7–9, reveal that Treatment 2 (70% mango seed + 30% agar-agar) consistently received the highest mean ratings across all three sensory attributes—smell ($M = 4.73 \pm 0.45$), texture ($M = 4.83 \pm 0.38$), and appearance ($M = 4.73 \pm 0.45$)—indicating excellent acceptability among participants. Treatments 1 and 3 followed with moderate ratings ranging from “Good” to “Very Good,” while the control (T4: 100% agar-agar) received the lowest mean scores across all criteria ($M = 2.67$ – 2.73), corresponding to “Fair.” The low standard deviations (0.38–0.51) reflect consistent responses across participants. These findings suggest that increasing the proportion of mango seed powder enhances the sensory quality of edible cutlery, producing a smoother texture, more appealing appearance, and a more natural odor compared to agar-agar alone. Therefore, the 70:30 mango seed-agar formulation (T2) is identified as the most favorable and aesthetically acceptable composition for the edible cutlery prototype.

Sensory evaluation serves as a critical bridge between the technical formulation of novel materials and real-world consumer acceptance of products, particularly in the domain of edible or biodegradable foodware where attributes such as odor, texture, and appearance directly influence usability and market viability. Research emphasizes that sensory factors—such as smell, feel, and visual appearance—substantially shape consumer preference and ultimately product success, especially for biodegradable utensils (Zahra et al., 2022). In edible packaging systems, perceived quality in these sensory attributes drives both immediate usability and future purchase intent (Taylor et al., 2024). Furthermore, sensory evaluation complements physicochemical testing by exposing consumer-oriented improvement opportunities during formulation efforts (Malcolmson, 2005). Integrating these perspectives, one sees that a formulation achieving robust physicochemical performance is insufficient unless its sensory profile aligns with user expectations. In the case of the specific 70 % mango-seed : 30 % agar composition (T2), which received the highest sensory ratings for odor, texture, and appearance, the

finding highlights how leveraging mango seed's natural lipids and polyphenolic aromatics can generate a favorable plant-like aroma that resonates more effectively than the neutral-to-marine odor sometimes associated with pure agar (Thagunna et al., 2023; Ehsani et al., 2019). On the texture dimension, the synergistic interaction between amylose-lipid complexes from the starch fraction and the gelling matrix yields a smoother, firmer surface and improved cohesiveness—attributes that align with consumers' preference for utensils resembling plastic in tactile perception (Malafi et al., 1994; Thagunna et al., 2023; Ehsani et al., 2019). Visually, the mango-seed starch component adds opacity and uniform coloration while the drying process enhances gloss and finish, thus elevating the appearance parameter—an outcome directly linked with elevated purchase intention and quality perception (Thagunna et al., 2023; Taylor et al., 2024; Zahra et al., 2022). Synthesizing these attributes, the strong performance of the 70 : 30 formulation signals how optimizing polysaccharide ratios in tandem with consumer-sensory attributes and underlying material properties yields a formulation that marries environmental benefit and user experience—achieving what Ehsani et al. (2019) describe as improved sensory profiles coupled with enhanced environmental performance. Critically, this case underlines that to actualize the commercial potential of plant-based edible cutlery, sensory evaluation must not be relegated to post-hoc confirmation; rather, it must be integrated as a formative element guiding material selection, compositional balance, and processing parameters. In sum, the purposeful alignment of sensory acceptability with material science considerations elevates not only consumer satisfaction but also the environmental promise of biodegradable utensils.

Objective 2. Determine whether statistically significant differences exist among T1, T2, T3, and T4 for each dependent variable—pH, biodegradability (% mass loss), durability under liquid (seconds), proximate composition (fat, protein, and ash in % w/w), and sensory attributes (smell, texture, and appearance rated on a 1–5 Likert scale)—using one-way ANOVA per outcome with Tukey HSD post hoc comparisons at $\alpha = 0.05$.

Table 10. ANOVA Table (pH Values)

Source	Sum of Squares	df	Mean Square	F	Sig. (p)
Between Groups	10.26	3	3.42	189.78	< 0.001*
Within Groups	0.79	44	0.02		
Total	11.05	47			

*statistically significant at $\alpha=0.05$

Table 11. Tukey HSD Post Hoc Test for pH Values (Comparisons with Control: T4)

Comparison (Group 1 – Group 2)	Mean Difference	Std. Error	Sig. (p)	95% CI Lower	95% CI Upper	Significant
T1 (50% Mango + 50% Agar) – T4 (Control)	+1.09	0.07	< 0.001	+0.95	+1.24	Yes
T2 (70% Mango + 30% Agar) – T4 (Control)	+1.16	0.07	< 0.001	+1.02	+1.31	Yes
T3 (30% Mango + 70% Agar) – T4 (Control)	+0.82	0.07	< 0.001	+0.68	+0.97	Yes

The one-way ANOVA, as shown in Table 10, revealed a statistically significant difference in mean pH values among the four treatments, $F(3,44) = 189.78$, $p < 0.001$. This indicates that the proportion of mango seed powder and agar-agar had a measurable effect on the acidity/alkalinity of the edible cutlery samples.

Post hoc comparisons using Tukey's HSD test, as shown in Table 11, showed that all three treatments containing mango seed powder (T1, T2, T3) had significantly higher pH values compared to the control (T4, 100% agar-agar). The largest increase was observed in T2 (70% mango seed + 30% agar-agar), which had an average pH approximately 1.16 units higher than the control. These results suggest that incorporating mango seed powder improves the acidity profile of edible cutlery, moving it closer to neutral pH levels and potentially enhancing product stability compared to agar-only formulations.

Table 12. ANOVA Table for biodegradability (% mass loss over 1 week)

Source	Sum of Squares	df	Mean Square	F	Sig. (p)
Between Groups	6579.75	3	2193.25	269.41	< 0.001*
Within Groups	358.20	44	8.14		
Total	6937.95	47			

*statistically significant at $\alpha=0.05$

Table 13. Tukey HSD Post Hoc Test for biodegradability (% mass loss over 1 week) (Comparisons with Control: T4)

Comparison (Group 1 – Group 2)	Mean Difference	Std. Error	Sig. (p)	95% CI Lower	95% CI Upper	Significant
T1 (50% Mango + 50% Agar) – T4 (Control)	+25.63%	1.53	< 0.001	+22.51	+28.74	Yes
T2 (70% Mango + 30% Agar) – T4 (Control)	+30.93%	1.53	< 0.001	+27.81	+34.04	Yes
T3 (30% Mango + 70% Agar) – T4 (Control)	+20.16%	1.53	< 0.001	+17.05	+23.27	Yes

The one-way ANOVA, as shown in Table 12, revealed a statistically significant difference in biodegradability values among the four treatments, $F(3,44) = 269.41$, $p < 0.001$. This indicates that the proportion of mango seed powder and agar-agar significantly affected the rate of decomposition of the edible cutlery samples.

Post hoc comparisons using Tukey's HSD test, as shown in Table 13, showed that all mango seed-based treatments (T1, T2, T3) exhibited significantly higher biodegradability compared to the agar-only control (T4). The largest increase was observed in T2 (70% mango seed + 30% agar-agar), which decomposed on average 30.9% more than the control. These results confirm that mango seed incorporation enhances the biodegradability of edible cutlery, with higher mango seed proportions leading to faster decomposition within a 1-week period.

Table 14. ANOVA Table for durability under liquid (time to structural failure in seconds during standardized immersion)

Source	Sum of Squares	df	Mean Square	F	Sig. (p)
Between Groups	1,078,544.00	3	359,514.67	442.36	< 0.001*
Within Groups	35,759.75	44	813.63		
Total	1,114,303.75	47			

*statistically significant at $\alpha=0.05$

Table 15. Tukey HSD Post Hoc Test for durability under liquid (time to structural failure in seconds during standardized immersion) (Comparisons with Control: T4)

Comparison (Group 1 – Group 2)	Mean Difference (sec)	Std. Error	Sig. (p)	95% CI Lower	95% CI Upper	Significant
T1 (50% Mango + 50% Agar) – T4 (Control)	+301.42	15.8	< 0.001	+270.34	+332.49	Yes
T2 (70% Mango + 30% Agar) – T4 (Control)	+406.17	15.8	< 0.001	+375.09	+437.24	Yes
T3 (30% Mango + 70% Agar) – T4 (Control)	+200.33	15.8	< 0.001	+169.26	+231.41	Yes

The one-way ANOVA, as shown in Table 14, revealed a statistically significant difference in durability under liquid among the four treatments, $F(3,44) = 442.36$, $p < 0.001$. This indicates that the proportion of mango seed powder and agar-agar strongly influenced the resistance of edible cutlery to liquid immersion.

Tukey's HSD post hoc comparisons, as shown in Table 15, confirmed that all mango seed-based treatments (T1, T2, T3) were significantly more durable than the agar-only control (T4). The greatest improvement was observed in T2 (70% mango seed + 30% agar-agar), which withstood immersion for an average of 406 seconds longer than the control. These results provide strong evidence that mango seed powder substantially enhances the mechanical durability of edible cutlery when exposed to liquid, with higher mango seed proportions yielding superior performance.

Table 16. ANOVA Table for proximate composition—fat (% w/w)

Source	Sum of Squares	df	Mean Square	F	Sig. (p)
Between Groups	408.42	3	136.14	817.38	< 0.001*
Within Groups	7.33	44	0.17		
Total	415.74	47			

*statistically significant at $\alpha=0.05$

Table 17. Tukey HSD Post Hoc Test for proximate composition—fat (% w/w) (Comparisons with Control: T4)

Comparison (Group 1 – Group 2)	Mean Difference (% fat)	Std. Error	Sig. (p)	95% CI Lower	95% CI Upper	Significant
T1 (50% Mango + 50% Agar) – T4 (Control)	+5.68%	0.22	< 0.001	+5.23	+6.12	Yes
T2 (70% Mango + 30% Agar) – T4 (Control)	+7.97%	0.22	< 0.001	+7.52	+8.41	Yes
T3 (30% Mango + 70% Agar) – T4 (Control)	+3.82%	0.22	< 0.001	+3.38	+4.27	Yes

The one-way ANOVA, as shown in Table 16, revealed a statistically significant difference in fat content among the four treatments, $F(3,44) = 817.38$, $p < 0.001$. This indicates that the proportion of mango seed powder and agar-agar significantly affected the fat composition of the edible cutlery samples.

Tukey's HSD post hoc comparisons, as shown in Table 17, showed that all mango seed-based treatments (T1, T2, T3) contained significantly higher fat content compared to the agar-only control (T4). The greatest difference was observed in T2 (70% mango seed + 30% agar-agar), which had an average fat content nearly 8.0% higher than the control. These findings confirm that mango seed powder is the main contributor of lipid content in the cutlery formulations, while agar-agar alone provides negligible fat.

Table 18. ANOVA Table for proximate composition—protein (% w/w)

Source	Sum of Squares	df	Mean Square	F	Sig. (p)
Between Groups	202.90	3	67.63	465.62	< 0.001*
Within Groups	6.39	44	0.15		
Total	209.29	47			

*statistically significant at $\alpha=0.05$

Table 19. Tukey HSD Post Hoc Test for proximate composition—protein (% w/w) (Comparisons with Control: T4)

Comparison (Group 1 – Group 2)	Mean Difference (% protein)	Std. Error	Sig. (p)	95% CI Lower	95% CI Upper	Significant
T1 (50% Mango + 50% Agar) – T4 (Control)	+4.33%	0.21	< 0.001	+3.91	+4.74	Yes
T2 (70% Mango + 30% Agar) – T4 (Control)	+5.53%	0.21	< 0.001	+5.11	+5.94	Yes
T3 (30% Mango + 70% Agar) – T4 (Control)	+3.23%	0.21	< 0.001	+2.81	+3.64	Yes

The one-way ANOVA, as shown in Table 18, revealed a statistically significant difference in protein content among the four treatments, $F(3,44) = 465.62$, $p < 0.001$. This

demonstrates that the proportion of mango seed powder and agar-agar had a substantial effect on the protein composition of the edible cutlery samples.

Tukey's HSD post hoc test, as shown in Table 19, further indicated that all mango seed-based treatments (T1, T2, T3) contained significantly higher protein levels than the agar-only control (T4). The most pronounced increase was found in T2 (70% mango seed + 30% agar-agar), which had an average protein content 5.5% greater than the control. These results confirm that mango seed powder is the primary source of protein in the edible cutlery formulations, whereas agar contributes negligible amounts.

Table 20. ANOVA Table for proximate composition—ash (% w/w)

Source	Sum of Squares	df	Mean Square	F	Sig. (p)
Between Groups	47.62	3	15.87	164.29	< 0.001*
Within Groups	4.25	44	0.10		
Total	51.87	47			

*statistically significant at $\alpha=0.05$

Table 21. Tukey HSD Post Hoc Test for proximate composition—ash (% w/w) (Comparisons with Control: T4)

Comparison (Group 1 – Group 2)	Mean Difference (% ash)	Std. Error	Sig. (p)	95% CI Lower	95% CI Upper
T1 (50% Mango + 50% Agar) – T4 (Control)	+2.18%	0.17	< 0.001	+1.84	+2.52
T2 (70% Mango + 30% Agar) – T4 (Control)	+2.63%	0.17	< 0.001	+2.29	+2.97
T3 (30% Mango + 70% Agar) – T4 (Control)	+1.67%	0.17	< 0.001	+1.33	+2.01

The one-way ANOVA, as shown in Table 20, revealed a statistically significant difference in ash content among the four treatments, $F(3,44) = 164.29$, $p < 0.001$. This indicates that the mineral content of the edible cutlery was significantly influenced by the proportion of mango seed powder and agar-agar in the formulations.

Tukey's HSD post hoc test, as shown in Table 21, confirmed that all mango seed-based treatments (T1, T2, T3) contained significantly higher ash content compared to the agar-only control (T4). The most substantial increase was observed in T2 (70% mango seed + 30% agar-agar), which had an average ash content 2.63% higher than the control. These results demonstrate that mango seed powder provides the majority of the mineral content in the edible cutlery, while agar alone contributes only minimal ash.

The integration of mango seed powder into edible cutlery formulations demonstrates a multidimensional impact on physicochemical properties, nutritional value, and environmental sustainability, with findings that resonate strongly with contemporary literature. The observed pH modification, where mango seed incorporation raises acidity levels toward neutrality, can be attributed to buffering components such as stearic acid, oleic acid, and proteins inherent in the seed kernel (Cárdenas-Hernández et al., 2024), which is advantageous for both shelf stability and microbial resistance compared to agar-only blends that typically remain acidic (Duarte et al., 2025). Beyond chemical stability, the biodegradability of the mango seed-based composites highlights their ecological relevance, as the starch and fiber fractions (58–80%) of mango seed kernels are easily metabolized by microorganisms (Diarra, 2014), while the presence of polyphenols and carbohydrates accelerates microbial activity, thereby reducing environmental persistence (Duarte et al., 2025). Complementing biodegradability, the enhanced durability in liquid environments can be linked to the fats and structural polysaccharides in mango seed, which establish a hydrophobic matrix that lowers water absorption and degradation (Wu et al., 2015), with oleic and stearic acids further reinforcing moisture resistance and structural stability (Sikdar et al., 2017). Proximate analysis supports these findings, as the significant increase in fat content aligns with the reported 6–16% lipid composition of mango seed kernels, primarily oleic and stearic acids, which not only enrich texture and sensory qualities but also function as natural plasticizers that improve mechanical performance (Diomande et al., 2021; Sikdar et al., 2017). Likewise, the protein content increase observed in the formulations is consistent

with the 6–13% protein reported for mango seed, with lysine and tryptophan enriching the amino acid profile (Diarra, 2014), a stark contrast to the protein-deficient agar matrix, thereby enhancing the nutritional potential of the cutlery. Furthermore, the rise in ash content corroborates the mineral richness of mango seed, particularly in potassium, magnesium, and phosphorus (Egbunu & Oriji, 2017), positioning these composites not only as functional utensils but also as carriers of micronutrients that may contribute to dietary fortification. The convergence of these properties suggests that mango seed-based edible cutlery represents an innovative approach that addresses environmental concerns, augments durability and nutritional value, and enhances the practical viability of sustainable foodware solutions, thereby bridging scientific, ecological, and societal dimensions of material innovation.

Table 22. ANOVA Table for Sensory Evaluation – Smell

Source	Sum of Squares	df	Mean Square	F	Sig. (p)
Between Groups	66.81	3	22.27	111.35	< 0.001*
Within Groups	23.92	116	0.21		
Total	90.73	119			

*Statistically significant at $\alpha = 0.05$

Table 23. Tukey HSD Post Hoc Test for Sensory Evaluation – Smell (Comparisons with Control: T4)

Comparison (Group 1 – Group 2)	Mean Difference	Std. Error	Sig. (p)	95% CI Lower	95% CI Upper
T1 (50% Mango + 50% Agar) – T4 (Control)	+0.84	0.09	< 0.001	+0.62	+1.06
T2 (70% Mango + 30% Agar) – T4 (Control)	+2.00	0.09	< 0.001	+1.78	+2.22
T3 (30% Mango + 70% Agar) – T4 (Control)	+0.67	0.09	< 0.001	+0.45	+0.89

Table 24. ANOVA Table for Sensory Evaluation – Texture

Source	Sum of Squares	df	Mean Square	F	Sig. (p)
Between Groups	82.91	3	27.64	190.13	< 0.001*
Within Groups	16.87	116	0.15		
Total	99.78	119			

*Statistically significant at $\alpha = 0.05$

Table 25. Tukey HSD Post Hoc Test for Sensory Evaluation – Texture (Comparisons with Control: T4)

Comparison (Group 1 – Group 2)	Mean Difference	Std. Error	Sig. (p)	95% CI Lower	95% CI Upper
T1 (50% Mango + 50% Agar) – T4 (Control)	+0.90	0.08	< 0.001	+0.71	+1.09
T2 (70% Mango + 30% Agar) – T4 (Control)	+2.16	0.08	< 0.001	+1.97	+2.35
T3 (30% Mango + 70% Agar) – T4 (Control)	+0.80	0.08	< 0.001	+0.61	+0.99

Table 26. ANOVA Table for Sensory Evaluation – Appearance

Source	Sum of Squares	df	Mean Square	F	Sig. (p)
Between Groups	65.12	3	21.71	103.52	< 0.001*
Within Groups	24.33	116	0.21		
Total	89.45	119			

*Statistically significant at $\alpha = 0.05$

Table 27. Tukey HSD Post Hoc Test for Sensory Evaluation – Appearance (Comparisons with Control: T4)

Comparison (Group 1 – Group 2)	Mean Difference	Std. Error	Sig. (p)	95% CI Lower	95% CI Upper
T1 (50% Mango + 50% Agar) – T4 (Control)	+0.86	0.09	< 0.001	+0.64	+1.08
T2 (70% Mango + 30% Agar) – T4 (Control)	+2.06	0.09	< 0.001	+1.84	+2.28
T3 (30% Mango + 70% Agar) – T4 (Control)	+0.70	0.09	< 0.001	+0.48	+0.92

The one-way ANOVA results (Tables 22, 24, and 26) reveal that there were statistically significant differences ($p < 0.001$) among the four treatments in all sensory parameters—smell, texture, and appearance. These results indicate that the varying proportions of mango seed powder and agar-agar substantially influenced the sensory qualities of the edible cutlery.

Post hoc comparisons using Tukey's HSD test (Tables 23, 25, and 27) showed that all mango seed-based treatments (T1, T2, and T3) had significantly higher mean ratings than the agar-only control (T4) across all sensory dimensions. Among these, Treatment 2 (70% mango seed + 30% agar-agar) recorded the most favorable mean differences—+2.00 (smell), +2.16 (texture), and +2.06 (appearance)—compared to the control, demonstrating the highest level of sensory acceptability.

The superior ratings of T2 may be attributed to the optimal balance between starch granule density, lipid composition, and gel uniformity, which produced a neutral natural odor, smooth and firm surface texture, and visually appealing opaque finish. These findings validate the hypothesis that the inclusion of mango seed powder significantly enhances the sensory quality of edible cutlery and support its viability as an eco-friendly, consumer-acceptable alternative to conventional plastic utensils.

The statistical findings from the sensory evaluation of edible cutlery formulations derived from mango seed (*Mangifera indica*) starch and agar-agar (*Gracilaria canaliculata*) reveal that the proportion of these biopolymers exerts a significant influence on consumer-perceived quality, specifically in the domains of smell, texture, and appearance, as evidenced through ANOVA and Tukey HSD results showing highly significant differences across treatments ($p < 0.001$). This aligns with Serrano-Santos et al. (2022), who demonstrated that edible films composed of starch-agar blends present substantial sensory variation dependent on formulation ratios, affirming that starch-to-agar balance critically determines product appeal. The optimized blend, exemplified by T2 (70% mango seed and 30% agar), achieved the highest ratings across all sensory dimensions, corroborating the findings of Fakhouri et al. (2019) that an intermediate ratio between plant-based starches and seaweed-derived polysaccharides promotes superior consumer acceptability. Specifically, in odor acceptability, the statistical output $F(3,116) = 111.35$, $p < 0.001$ indicates a pronounced distinction among treatments, with T2 scoring markedly higher (+2.00 vs. T4). This can be attributed to the biochemical profile of mango seed starch, which contains oleic and stearic acids alongside phenolic compounds contributing to its mild, natural scent (Fakhouri et al., 2019), effectively neutralizing the marine aroma typical of agar, a phenomenon supported by Chiralt et al. (2015), who observed odor masking effects in starch-polysaccharide films. Consumer research further confirms that neutral or organic-smelling edible materials are perceived as cleaner and safer (Marzlan et al., 2022), reinforcing the olfactory desirability of T2. In tactile perception, texture registered the highest F-value, $F(3,116) = 190.13$, $p < 0.001$, with T2 outperforming other treatments (+2.16 vs. control), consistent with Serrano-Santos et al. (2021), who linked textural smoothness and elasticity to balanced amylose content. Mango seed's lipid and protein fractions act as intrinsic plasticizers, enhancing flexibility and cohesion (Thagunna et al., 2023), while surface analyses have shown that formulations with optimal starch-agar integration yield microstructurally smooth surfaces that improve tactile comfort (Fakhouri et al., 2019). Correspondingly, consumer studies reveal that cutlery perceived as smooth, sturdy, and non-sticky aligns with higher usability satisfaction (Malafi et al., 1994). Visual assessment followed similar statistical trends ($F(3,116) = 103.52$, $p < 0.001$), with T2 receiving superior ratings (+2.06 vs. control) due to its uniform, opaque appearance—a quality attributed to starch granule size and natural pigmentation that impart a plastic-like beige tone preferred by consumers (Zahra et al., 2022). Maran et al. (2013) noted that agar-starch composites modulate gloss and transparency, crucial factors in perceived quality, while Mukherjee and Raju (2023) emphasized that visual uniformity directly affects marketability and consumer trust. The interrelationship among the three sensory attributes illustrates a synergistic effect where biochemical composition (lipids, proteins, and polysaccharide ratios) and microstructural smoothness jointly determine holistic sensory appeal (Serrano-Santos et al., 2022; Thagunna et al., 2023). This convergence underscores the principle that sensory attributes should not be evaluated in isolation since tactile, olfactory, and visual perceptions are inherently intertwined in shaping consumer judgment (Malafi et al., 1994). The data substantiate that the 70:30 mango seed-agar formulation achieves a statistically and perceptually optimal balance, simultaneously enhancing odor neutrality, textural smoothness, and visual uniformity. Beyond laboratory validation, these outcomes hold practical implications for advancing biodegradable and edible foodware design, providing empirical grounding for sustainable alternatives that can compete with

	conventional plastics in both functionality and sensory appeal (Zahra et al., 2022). Such convergence of statistical evidence, biochemical mechanisms, and consumer behavior establishes T2 as a benchmark formulation for edible cutlery development and positions mango seed starch as a promising local resource for promoting eco-innovative material solutions.
CONCLUSIONS AND RECOMMENDATIONS	Conclusions Based on the results of the study, it is concluded that: - Based on the descriptive results of the study, the incorporation of mango seed (<i>Mangifera indica</i>) powder into agar-agar (<i>Gracilaria canaliculata</i>) formulations enhanced the overall physicochemical performance, nutritional composition, and sensory acceptability of the edible cutlery compared to the agar-only control. Treatments with mango seed exhibited higher pH values (closer to neutral), greater biodegradability (% mass loss over one week), longer durability under liquid immersion (seconds to structural failure), and higher fat, protein, and ash contents (% w/w) than the control. In addition, the sensory evaluation revealed that formulations containing mango seed powder were consistently rated more favorably in terms of smell, texture, and appearance, with the T2 formulation (70% mango seed + 30% agar-agar) attaining the highest mean sensory scores ($M = 4.73\text{--}4.83$, interpreted as “Very Good”). These findings conclude that the 70:30 ratio provides the optimal balance between material performance, nutritional quality, and consumer acceptability, establishing mango seed powder as an effective primary biopolymer for developing eco-friendly edible cutlery. - Based on the inferential results of the study, statistical analyses using one-way ANOVA and Tukey’s HSD post hoc test ($\alpha = 0.05$) confirmed that the variations in mango seed and agar-agar proportions produced significant differences ($p < 0.001$) across all dependent variables: pH, biodegradability, durability under liquid, proximate composition (fat, protein, ash), and sensory attributes (smell, texture, and appearance). All mango seed-based formulations (T1, T2, T3) outperformed the agar-only control (T4), with T2 consistently showing the most favorable outcomes in both laboratory and sensory parameters. The significant F-values for the sensory evaluation—Smell ($F = 111.35$), Texture ($F = 190.13$), and Appearance ($F = 103.52$)—demonstrate that the sensory improvement due to mango seed incorporation is statistically verifiable. These results confirm that the inclusion of mango seed powder enhances not only the structural and compositional characteristics of the edible cutlery but also its sensory appeal, validating the 70% mango seed : 30% agar-agar formulation as the most efficient, sustainable, and consumer-acceptable configuration for large-scale production of biodegradable edible utensils. Recommendations Based on the conclusions of the study, it is recommended that: - Adopt the T2 formulation (70% mango seed powder : 30% agar-agar) as the baseline recipe for future production and demonstrations, since it achieved the highest overall performance across all physicochemical, nutritional, and sensory parameters—particularly exhibiting superior pH stability, biodegradability, durability, and the most favorable sensory ratings in smell, texture, and appearance. - Standardize the production and sensory evaluation protocol to ensure repeatability and product consistency. The recommended procedure includes oven-drying mango seeds at 105 °C for 24 hours, dissolving agar-agar in 1000 mL of distilled water at 90–95 °C, molding 15–20 mL per spoon cavity, and post-drying at 60 °C for 6 hours. In addition, replicate the sensory evaluation using the 5-point Likert scale (1–5) and random coded samples with at least 30 untrained panelists following ethical guidelines (ISEF Form 4). - Incorporate sensory optimization and consumer acceptability testing as an integral part of future research. Subsequent studies should assess taste, mouthfeel, and usability in addition to smell, texture, and appearance to obtain a comprehensive sensory profile. Conduct hedonic scaling and preference mapping to evaluate perception across demographic groups, ensuring the product’s market readiness and acceptability. - Expand analytical parameters for quality assurance and food safety before potential commercialization. Recommended future tests include microbial load assessment (TPC, yeast and mold count), water activity (a_w), and shelf-life evaluation under varying storage conditions. These analyses will determine product safety, stability, and suitability for consumption.

- Pursue small-scale manufacturing and user-based trials through partnerships with local enterprises, school canteens, and food vendors. Collect quantitative and qualitative feedback on sensory satisfaction, handling ease, and performance in hot or acidic foods, and integrate these findings into iterative design improvements. This operational approach will help transition the innovation from a laboratory prototype into a sustainable and marketable eco-friendly product.
- Develop product benchmarking and sensory standard references by comparing the edible cutlery's performance with commercial biodegradable or edible utensils. Establish baseline sensory thresholds for acceptable odor, firmness, and appearance to serve as quality benchmarks in future development and scaling.

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