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Physical and mechanical properties of egg tray made from rosella plant stems (*Hibiscus sabdariffa*)

[Karakteristik fisik dan mekanik nampan telur berbahan dasar batang tanaman rosella (Hibiscus sabdariffa)]

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ABSTRACT

Roselle stems contain natural fibers that are rich in cellulose, which can be processed into pulp, which is the basic ingredient in making egg trays. This research aims to determine the characterization of egg trays made from rosella stem fiber at different concentrations of glue. The study uses six treatment variations of Rosella Stem and glue percentages: P0 (100% stem pulp, 0% glue), P1 (97.5% stem pulp, 2.5% glue), P2 (95% stem pulp, 5% glue), P3 (92.5% stem pulp, 7.5% glue), P4 (90% stem pulp, 10% glue), and P5 (87.5% stem pulp, 12.5% glue). The use of organically grown rosella stems at the Astungkara Way Foundation ensures that the material is free from contaminants that pose a risk to food safety. The concentration of glue had a significant effect on the water content and absorbency, but did not significantly affect the thickness of the paper. The optimal concentration of glue on egg trays is 5%, as seen from the rigidity of the egg trays that meet the standard, which is 14,100 mN·m. Egg trays with 5% glue (P2) showed a 9.746% moisture content, 19.136% water absorption, 3.870 mm thickness, 10.220 Nm/g tensile strength, and 677.880 mN tear resistance. Roselle stem egg trays are light to dark brown in color, with textures varying from loose to stiff depending on the glue concentration. All treatments showed that the egg trays were odorless. Roselle plant byproducts have the potential to be used as an alternative material for egg trays.

Keywords: eco-friendly, egg tray, glue, Rosella stem

ABSTRAK

Batang rosella mengandung serat alami yang dapat diolah menjadi pulp, yang merupakan bahan dasar pembuatan nampan telur. Serat ini kaya akan selulosa, yang adalah komponen utama dalam pembuatan nampan telur. Penelitian ini bertujuan untuk menentukan karakterisasi nampan telur berbahan dasar serat batang rosella pada konsentrasi lem yang berbeda. Penelitian ini menggunakan enam perlakuan variasi persentase batang rosella dan lem: P0 (100% batang, 0% lem), P1 (97,5% batang, 2,5% lem), P2 (95% batang, 5% lem), P3 (92,5% batang, 7,5% lem), P4 (90% batang, 10% lem), dan P5 (87,5% batang, 12,5% lem). Penggunaan batang rosella yang ditanam secara organik di Yayasan Astungkara Way memastikan bahwa bahan bebas dari kontaminan yang berisiko bagi keamanan pangan. Analisis statistik menunjukkan bahwa konsentrasi lem memiliki pengaruh signifikan terhadap kadar air dan daya serap nampan telur, tetapi tidak berpengaruh signifikan terhadap ketebalan nampan telur. Konsentrasi optimal lem pada nampan telur adalah 5% yang dilihat dari kekakuan nampan telur yang memenuhi standar (7-24 720 mN·m) yaitu sebesar 14,100 ± 0,720 mN·m. Karakteristik nampan telur dengan konsentrasi 5% lem yaitu kadar air sebesar 9,746 ± 0,567%, daya serat air sebesar 19,136 ± 0,456%, ketebalan sebesar 3,870 ±0,018 mm, kuat tarik sebesar 10,220 ± 0,245 Nm/g, dan daya sobek sebesar 677,880 ± 22,655 mN. Nampan telur batang rosella berwarna coklat muda hingga coklat tua, dengan tekstur yang bervariasi dari tidak kaku hingga kaku tergantung pada konsentrasi lem. Semua perlakuan menunjukkan bahwa nampan telur tidak berbau. Hasil samping tanaman rosella berpotensi sebagai bahan alternatif nampan telur.

Kata-kata kunci: batang rosella, lem, nampan telur, ramah lingkungan

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Introduction

Indonesia's poultry industry has experienced significant growth over the past decade (Darjanto & Indrawan, 2023). As one of the key subsectors of livestock production, poultry farming has achieved self-sufficiency through its ability to meet domestic demand for meat and eggs. This progress is reflected in the positive gap between production and consumption: national egg production is estimated at approximately 6,117,905 tons, while consumption reaches 5,883,434 tons, resulting in a surplus of around 234 thousand tons. These figures indicate that domestic production is able to meet, and even exceed, national consumption needs (Kementerian Pertanian, 2023). Despite this achievement, the Indonesian poultry industry continues to face several challenges, including limited availability of raw materials, rising fuel prices, limited human resource capacity, restricted access to capital and policy support, unstable feed prices, technological limitations, environmental concerns, and packaging issues.

The food packaging industry has continued to grow in response to increasing consumer demand for food and livestock-based products. According to BPS (2023), the Gross Domestic Product (GDP) of the food and beverage industry grew by 4.62% in the second quarter of 2023. Packaging, particularly for poultry products such as eggs, plays a crucial role in protecting the product from physical and environmental damage. Effective egg packaging must be sturdy, strong, thermally stable, durable, and environmentally friendly.

Egg trays in Indonesia are generally made from recycled cardboard, primarily due to its wide availability and easy accessibility. The pulp used to produce egg cartons is derived from recycled newspapers, cardboard scraps, and other unused paper materials—high-volume recycled resources collected from various regions across the country (Debnath et al., 2022). Paper, the primary raw material for egg trays, is a thin, flat material produced through the densification of fibers originating from pulp. These fibers are typically natural in origin and contain cellulose and hemicellulose (Huang et al., 2021).

Among the various plant materials explored for pulp production, roselle (*Hibiscus sabdariffa*) stem waste has attracted the attention of researchers. Roselle stems contain natural fibers rich in cellulose, making them a strong candidate for pulp and paper production. Historically, roselle stem fibers have been used for making ropes and jute sacks (Kiari et al., 2024). Research on the utilization of roselle stems as raw material for egg trays represents a novel contribution, as no prior scientific publications have specifically examined this topic. The average fiber length of roselle stems ranges from 1.2 to 6.3 millimeters, with fiber diameters between 10 and 44 micrometers (Kiari et al., 2024). These dimensions indicate that roselle fibers possess sufficient length and strength to serve as a viable raw material for egg tray manufacturing, supporting both the structural integrity and durability of the final product. This opens opportunities to develop alternative, plant-based, locally sourced materials that can substitute less environmentally friendly conventional sources.

The utilization of roselle stems offers several advantages, including reducing dependence on wood-based raw materials—thereby contributing to lower deforestation rates—and providing a sustainable alternative resource. Roselle fibers can also be combined with wastepaper to improve production efficiency and reduce waste generation. Roselle stems, which are often discarded, can be converted into value-added products. Kiari et al. (2024) noted that red roselle stem fibers have potential applications in rope and jute sack production, thereby increasing the economic value of roselle plants. Such innovations provide additional benefits to roselle farmers, who traditionally harvest only the flowers, while simultaneously promoting waste reduction and the use of renewable materials in the egg packaging industry.

All roselle stems used in this study were sourced from organically cultivated roselle fields owned by the Astungkara Way Foundation, located in Subak Uma Lambing, Sibang Kaja, Abiansemal District, Badung Regency, Bali Province. Roselle stems contain strong natural fibers with structural characteristics suitable

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for egg tray production and other fiber-based materials. The bark (epidermis) also contributes to the strength and durability of the final product (Rusdianto et al., 2020). This research aligns with the principles of circular economy and sustainability, in which underutilized roselle stem waste is transformed into a value-added product. The aim of this study is to determine the characteristics of roselle-stem-fiber-based egg trays produced with different concentrations of glue. Adhesive concentration influences the physical and mechanical properties of egg trays because the glue acts as a binding agent that enhances fiber cohesion, thereby affecting the performance of the final product (Dohr & Hirn, 2022).

Materials and method

Time and place

The research was carried out in the Agriculture Laboratory, Faculty of Agriculture, Science and Technology, Universitas Warmadewa from September 2024 to March 2025. The roselle stem waste used in this study was collected from Jalan Raya, Sibang Kaja, Abiansemal, Badung Bali (80352).

Materials and equipments

The materials used were roselle stem waste collected from the Astungkara Foundation located at Jalan Raya, Sibang Kaja, Abiansemal, Badung Bali (80352), sodium hydroxide NaOH (Merck, Germany), nitric acid (Merck, Germany), adhesive glue (Fox), and distilled water. The equipment used in this study included an electric stove, volumetric flasks (Iwaki), measuring cylinders (Iwaki), an analytical balance (Ohaus), spatulas, glass stirring rods, an oven (Memmert, Germany), a blender (Philips, Indonesia), an egg tray molding device, a micrometer screw gauge (Mitutoyo, Japan), a Tensile Strength Tester (Testindo UT 2080, Indonesia), a Tear Tester (UCAN, Indonesia), and a Bending Stiffness Tester (Thwing Albert, United States).

Research method

This study utilized a Completely Randomized Design (CRD) with one factor consisting of 6 treatments that were each replicated 4 times, resulting in a total of 24 experimental units. The treatments were mixtures of roselle stems and glue: P0 represented 100% roselle stems and 0% glue; P1 used 97.5% roselle stems and 2.5% glue; P2 consisted of 95% roselle stems and 5% glue; P3 contained 2.5% roselle stems and 7.5% glue; P4 was 90% roselle stems and 10% glue; and finally, P5 represented 87.5% roselle stems and 12.5% glue.

Analysis of variance ANOVA was performed according to the experimental design. If the ANOVA results indicated significant effects ($p<0.05$) or highly significant effects ($p<0.01$), the analysis was continued using Duncan Multiple Range Test DMRT. The optimal treatment was determined based on the stiffness value of the egg tray, which must meet the standard range of 7 to 24 mN·m (Wulandari et al., 2022), because tray stiffness is an important parameter for absorbing shocks and impacts in order to ensure egg safety during distribution.

Preparation of roselle stem

Roselle stems were obtained from the Astungkara Foundation, located at Jalan Raya, Sibang Kaja, Abiansemal, Badung, Bali, Indonesia (80352). The leaves, branches, and outer bark of the stems were manually removed. The cleaned stems were then cut into small pieces measuring approximately 2–3 cm and thoroughly washed with distilled water to remove adhering impurities.

Pulp production

Pulp production from roselle stems was conducted using a chemical pulping method following the procedure described by Pardi et al. (2023), with minor modifications. The chopped stems were immersed and boiled in an alkaline solution, where the liquor-to-solid ratio corresponded to 20% (w/v) of stem mass relative to the solution volume, containing 7% (w/v) sodium hydroxide (NaOH). The pulping process was

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carried out for 90 minutes. After cooking, the fibers were neutralized by immersion in a 0.3% (v/v) nitric acid (HNO_3) solution for 5 minutes and subsequently washed with distilled water until a neutral pH was achieved. The neutralized fibers were then mechanically disintegrated using a blender to obtain a homogeneous pulp.

Egg trays preparation

The egg trays were fabricated by mixing the roselle stem pulp with a polyvinyl acetate–based adhesive glue according to the designated treatment ratios. The resulting slurry was poured into egg tray molds and oven-dried at a controlled temperature until completely dry, with a total drying time of 48 hours. The experimental treatments consisted of six formulations based on different pulp-to-adhesive proportions: 100% roselle stem pulp and 0% adhesive (P0); 97.5% pulp and 2.5% adhesive (P1); 95% pulp and 5% adhesive (P2); 92.5% pulp and 7.5% adhesive (P3); 90% pulp and 10% adhesive (P4); and 87.5% pulp and 12.5% adhesive (P5). These formulations were evaluated to determine the effect of adhesive content on the physical and mechanical properties of the roselle stem–based egg trays. The observed parameters, including water content (AOAC, 2025), thickness (SNI 1306 : 2009), water absorption (SNI 1306 : 2009), tensile strength (SNI 1306 : 2009), tear resistance (SNI 0436 : 2009), stiffness test (SNI 1306 : 2009) and sensory evaluation.

Water absorption test

Water absorption was determined using the Cobb sizing test. Paper specimens were clamped securely in a Cobb tester equipped with a cylindrical ring having a test area of 100 cm^2. A volume of 100 cm^3 of distilled water was poured into the ring and allowed to remain in contact with the paper surface for 105 s. After the exposure period, the water was drained, the ring was removed, and the paper surface was immediately pressed once with blotting paper using a rolling press. The pressing and surface drying process lasted 15 s, resulting in a total test duration of 120 s. Water absorption was calculated based on the mass of water absorbed per unit area of paper and expressed in g/cm^2.

Tensile strength test

Tensile strength was measured in accordance with SNI 1306:2009. Specimens were prepared with dimensions of 15 × 300 mm. Prior to testing, the width and thickness of each specimen were measured and recorded. The samples were clamped in a universal testing machine in either a horizontal or vertical orientation. The test was conducted at a constant crosshead speed of 20 mm/min until sample rupture occurred. The maximum tensile force recorded during the test was used to determine the tensile strength.

Tear resistance test

Tear resistance was evaluated following SNI 0436:2009. Specimens were prepared with dimensions of 50 × 76 mm. An initial tear was introduced using the cutting blade provided with the tear testing apparatus, leaving a remaining tear length of 43.0 ± 0.5 mm. The specimen was then clamped into the tear testing machine and pulled at a constant speed until tearing propagated. The maximum force required to continue the tear was recorded as the tear resistance.

Stiffness test

Stiffness was determined according to SNI 1306:2009 using specimens measuring 15 × 300 mm. The samples were placed in a stiffness testing apparatus and subjected to a bending load or bending moment. The bending angle and the force required to bend the specimen were measured. Stiffness values were calculated based on the applied force and the resulting deformation. Higher stiffness values indicate greater rigidity and resistance to deformation during handling and packaging applications.

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Sensory evaluation

Sensory evaluation of roselle stem–based paper was conducted to assess texture, fiber appearance, color, and odor. The test aimed to evaluate the physical characteristics and sensory perception of the produced paper. Prior to evaluation, dried paper samples were cut into uniform dimensions (10 × 10 cm) and ensured to be clean and free from contamination. Sensory evaluation was carried out by 10 semi-trained or trained panelists using a scoring method. The evaluation criteria were defined as follows: color (1 = light brown, 2 = moderately dark brown, 3 = dark brown), fiber appearance (1 = visible fibers, 2 = no visible fibers), texture (1 = not stiff, 2 = slightly stiff, 3 = stiff, 4 = very stiff), and odor (1 = noticeable odor, 2 = odorless).

Results and discussion

Water content

The concentration of glue had a highly significant effect ($P < 0.01$) on the moisture content of roselle stem–based egg trays. The highest moisture content was observed in the treatment without adhesive (0% glue), reaching 11.865 ± 0.865%, which was not significantly different from the 2.5% glue treatment (11.156 ± 0.566%) but was significantly higher than the treatments containing 5% and 7.5% glue, which exhibited moisture contents of 9.746 ± 0.567% and 9.211 ± 0.988%, respectively (Table 1). The addition of 5% glue resulted in a marked reduction in the moisture content of the egg trays. Overall, increasing adhesive concentration led to progressively lower moisture content in roselle stem–based egg trays. During egg tray fabrication, the adhesive affects moisture content by altering pore structure and inter-fiber interactions within the tray matrix. The adhesive used in egg tray production can form a protective coating on the fibers, thereby affecting the material's ability to absorb and retain water (Francolini et al., 2023). As adhesive concentration increases, a greater proportion of fibers becomes coated, reducing the number and size of pores available for water uptake. Consequently, the moisture content of the egg trays decreases. This observation is consistent with the principle that the incorporation of binding agents such as adhesives reduces material permeability to water (Gadhave & Gadhave, 2022).

Tabel 1. Water content (%), water absorption (%), and thickness (mm) of egg trays from rosella stem

Treatment	Water content (%)	Water absorption (%)	Thickness (mm)
P0 (100% roselle stem pulp and 0% glue)	11.865± 0.865^{a}	25.295± 0.277^{a}	3.520 ± 0.042^{a}
P1 (97.5% roselle stem pulp and 2.5% glue)	11.156 ± 0.566^{ab}	24.592 ± 0.455^{a}	3.730 ± 0.024^{a}
P2 (95% roselle stem pulp and 5% glue)	9.746 ± 0.567^{b}	19.136 ± 0.456^{b}	3.870 ±0.018^{a}
P3 (92.5% roselle stem pulp and 7.5% glue)	9.211 ± 0.988^{b}	11.060 ± 0.524^{c}	3.553 ± 0.022^{a}
P4 (90% roselle stem pulp and 10% glue)	8.746 ± 0.346^{c}	8.082 ± 0.388^{d}	3.486 ± 0.018^{a}
P5 (87.5% roselle stem pulp and 12.5% glue)	5.245 ± 0.288^{d}	3.145 ± 0.455^{e}	3.689 ± 0.012^{a}

Note: Numbers followed by the same lowercase letter within the same column are not significantly different at the 5% level according to the DMRT (Duncan's Multiple Range Test) (n=4)

Water absorption

The concentration of glue had a highly significant effect ($P < 0.01$) on the water absorption capacity of roselle stem–based egg trays. The highest water absorption was observed in the treatment without adhesive (0% glue), reaching 25.295 ± 0.277%, which was not significantly different from the 2.5% glue treatment (24.592 ± 0.455%) but was significantly higher than all other treatments. The lowest water absorption was recorded at a glue concentration of 12.5%, with a value of 3.145 ± 0.455%, which differed significantly from the other formulations. The observed reduction in water absorption with increasing adhesive concentration can be explained by the role of the adhesive in modifying the internal structure of the egg trays. The adhesive used in egg tray production is generally polymer-based and forms a cross-linked network within the fiber matrix. This network strengthens inter-fiber bonding and limits the ability of the fibers to interact with water molecules. As a result, egg trays containing higher adhesive

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concentrations exhibit a denser structure with reduced water uptake compared to those with lower adhesive content (Dohr & Hirn, 2022). Furthermore, adhesives tend to fill and seal the pores within the egg tray structure, thereby decreasing the overall water absorption capacity (Savov et al., 2022; Jalali et al., 2023). Chemical interactions between the adhesive and fiber surfaces may also form bonds that restrict the penetration of water molecules into the fiber network.

The reduction in water absorption induced by higher adhesive concentrations has important practical implications for the egg tray industry. Controlling the water absorption behavior of egg trays is essential to ensure product quality and consistency. Adjusting adhesive concentration allows manufacturers to tailor the moisture resistance of egg trays to specific application requirements (Esmaeeli & Sarrafzadeh, 2023). Egg trays with lower water absorption are particularly suitable for applications where resistance to humid conditions is critical (Silveira et al., 2021). Overall, roselle fiber–based egg trays demonstrate favorable water absorption characteristics combined with sufficient strength to protect eggs, making them a promising alternative material for egg packaging.

Thickness

The results further indicated that the thickness of roselle stem–based egg trays did not differ significantly among treatments ($P > 0.05$). Variations in glue concentration had no significant effect on egg tray thickness. The treatment containing 5% glue exhibited a thickness of 3.870 ± 0.018 mm, which was not significantly different from the other formulations. The result of tensile strength, tear resistance, and stiffness test of egg trays presented in Table 2.

Table 2. Tensile strength (Nm/g), tear resistance (mN), and stiffness (mN·m) of egg trays from roselle stem

Treatment	Tensile strength (Nm/g)	Tear resistance (mN)	Stiffness (mN·m)
P0 (100% roselle stem pulp and 0% glue)	3.220 ± 0.122^{f}	204.420 ± 8.677^{f}	6.200 ± 0.560^{f}
P1 (97.5% roselle stem pulp and 2.5% glue)	5.140 ± 0.182^{e}	445.280 ± 12.655^{e}	8.600 ± 0.680^{e}
P2 (95% roselle stem pulp and 5% glue)	10.220 ± 0.245^{d}	677.880 ± 22.655^{d}	14.100 ± 0.720^{d}
P3 (92.5% roselle stem pulp and 7.5% glue)	14.140 ± 0.312^{c}	1052.010 ± 82.215^{c}	25.100 ± 0.650^{c}
P4 (90% roselle stem pulp and 10% glue)	16.280 ± 0.345^{b}	1455.200 ± 78.431^{b}	34.500 ± 0.560^{b}
P5 (87.5% roselle stem pulp and 12.5% glue)	18.450 ± 0.268^{a}	1788.200 ± 56.882^{a}	38.500 ± 0.560^{a}

Note: Numbers followed by the same lowercase letter within the same column are not significantly different at the 5% level according to the DMRT (Duncan's Multiple Range Test) (n=4)

Egg tray thickness is an important parameter influencing mechanical strength and durability during handling and transportation. Thickness can be affected by several factors, including the amount and type of adhesive used during fabrication (Gadhave & Gadhave, 2022). However, recent studies have shown that, in certain cases, variations in adhesive concentration do not significantly alter thickness. This may occur when the adhesive primarily acts as a fiber-bonding agent rather than contributing to volumetric expansion of the material. If the adhesive predominantly coats the fiber surfaces without substantially filling void spaces or increasing bulk volume, changes in adhesive concentration may not result in measurable differences in thickness. Moreover, when adhesive concentrations are insufficient to significantly increase the solid content of the egg tray matrix, thickness remains relatively unchanged. During the drying process, egg trays undergo shrinkage, which can further minimize any potential differences in thickness caused by adhesive addition. Consequently, even higher adhesive levels may not significantly influence the final thickness of the egg trays (Xu et al., 2020).

Tensile strength

Glue concentration had a highly significant effect ($P < 0.01$) on the tensile strength of roselle stem–based egg trays. The highest tensile strength was obtained at a glue concentration of 12.5%, reaching 18.450 ± 0.268 N·m/g, which was significantly higher than that of all other treatments. The superior tensile

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strength observed at this concentration indicates the formation of optimal inter-fiber bonding within the egg tray structure. At this level, the adhesive effectively binds the fibers, resulting in enhanced mechanical integrity of the tray. The improved tensile performance can be attributed to the increased number of adhesive bonds that reinforce the fiber network, allowing tensile forces to be more evenly distributed throughout the structure. This enhanced force distribution increases resistance to mechanical stress during handling and transportation (Huang et al., 2021). Notably, the tensile strength of roselle stem–based egg trays with glue addition was substantially higher than that reported for paper materials composed of recycled paper, sugarcane bagasse, and coconut fiber, which exhibited tensile strengths of approximately 0.608 N·m/g (Sundari & Apriani, 2020). Similarly, the highest tensile strength reported for recycled paper blended with sugarcane bagasse reached only 0.608 N/mm^2 (Sundari et al., 2020). These comparisons highlight the mechanical superiority of roselle fiber–based egg trays reinforced with an appropriate adhesive concentration.

Tear resistance

Glue concentration also exerted a highly significant effect ($P < 0.01$) on the tear resistance of roselle stem–based egg trays. The highest tear resistance was recorded at a glue concentration of 12.5%, with a value of 1788.20 ± 56.882 mN, which was significantly higher than those of the other treatments. In contrast, egg trays produced without adhesive exhibited the lowest tear resistance, indicating a high susceptibility to tearing. Egg trays with low tear resistance are unable to adequately support the weight of eggs, rendering them unsafe for practical use. The observed increase in tear resistance with increasing adhesive concentration demonstrates the critical role of the adhesive as a binding agent that enhances cohesion among fibers. Higher adhesive concentrations result in stronger and more uniform inter-fiber bonding, enabling the material to withstand greater tearing forces before failure. This behavior is consistent with fundamental principles of material mechanics, where improved fiber adhesion directly contributes to enhanced mechanical strength, including tear resistance (Çiçekler et al., 2024).

Stiffness

The stiffness of roselle stem–based egg trays was significantly affected by glue concentration ($P < 0.01$). Egg trays containing 12.5% glue exhibited the highest stiffness value, measuring 34.500 ± 0.560 mN·m, which was significantly higher than those of all other treatments. Conversely, egg trays without adhesive displayed the lowest stiffness, with a value of 6.200 ± 0.560 mN·m. These results indicate that increasing adhesive concentration substantially enhances tray stiffness. The increase in stiffness is attributed to the adhesive's role in strengthening and homogenizing inter-fiber bonding, resulting in a more rigid structural network that resists bending and mechanical deformation (Utagawa et al., 2022). As adhesive concentration increases, inter-fiber bonding becomes stronger, thereby increasing resistance to flexural stress and yielding maximum stiffness. However, excessively high stiffness may be undesirable for egg tray applications. Highly rigid trays are less capable of absorbing shocks or vibrations during storage and transportation, which may increase the risk of egg breakage. In contrast, trays with moderate flexibility can dissipate impact energy more effectively, providing better protection against cracking or breakage. Therefore, although stiffness is essential for maintaining tray shape and structural stability, excessive stiffness may compromise the protective function of the egg tray.

According to Wulandari et al. (2022), the ideal stiffness range for egg trays lies between 7 and 24 mN·m. Stiffness values within this range ensure that the tray is sufficiently strong while remaining flexible enough to absorb mechanical stresses during handling and transportation. Consequently, optimizing adhesive concentration is crucial to achieving a balance between mechanical strength and functional performance in roselle stem–based egg trays.

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Sensory evaluation

Roselle stem–based egg trays exhibited color characteristics ranging from light brown to dark brown and showed the presence of coarse fiber textures across all treatments (Table 3). Egg trays produced without adhesive (0%) and with 2.5% glue were perceived as not stiff, while those containing 5% glue were classified as slightly stiff. Increasing the adhesive concentration to 7.5% resulted in stiff egg trays, whereas the addition of 10% and 12.5% glue produced very stiff egg trays. These observations indicate that increasing adhesive concentration leads to a progressive increase in tray stiffness. All roselle stem–based egg trays were characterized as odorless, regardless of adhesive concentration. Stiffness, or flexural strength, is an important parameter influencing the applicability of egg trays in various packaging applications. The increase in stiffness with higher adhesive concentration can be attributed to the role of the adhesive as a binding agent that enhances inter-fiber bonding. Stronger and more numerous inter-fiber bonds increase the rigidity of the fiber network, resulting in higher stiffness of the egg trays (Xu et al., 2020).

Table 3. Sensory properties of roselle stem–based egg trays

Treatment	Color	Fiber appearance	Texture	Odor
P0 (100% roselle stem pulp and 0% glue)	Light brown	Fibers visible	Not stiff	Odorless
P1 (97.5% roselle stem pulp and 2.5% glue)	Light brown	Fibers visible	Not stiff	Odorless
P2 (95% roselle stem pulp and 5% glue)	Slightly dark brown	Fibers visible	Slightly stiff	Odorless
P3 (92.5% roselle stem pulp and 7.5% glue)	Dark brown	Fibers visible	Stiff	Odorless
P4 (90% roselle stem pulp and 10% glue)	Dark brown	Fibers visible	Very stiff	Odorless
P5 (87.5% roselle stem pulp and 12.5% glue)	Dark brown	Fibers visible	Very stiff	Odorless

An increase in adhesive concentration also influenced the color of the egg trays, with higher glue levels resulting in a darker appearance. Depending on its chemical composition, the adhesive can alter tray color through chemical interactions with the fiber matrix or by modifying the way light is absorbed and reflected from the tray surface (Liu et al., 2022). Higher adhesive concentrations may lead to greater accumulation of binder on the tray surface, thereby intensifying color darkening. Previous studies have reported that such color changes can arise from chemical interactions between adhesives and paper-based materials or from modifications to surface structure (Zhang et al., 2023).

The odorless characteristic observed across all treatments can be attributed to both the adhesive formulation and the raw material used. The glue applied in this study is formulated to produce minimal volatile emissions, while roselle stem fibers are naturally low in odor-forming volatile compounds (Ojewumi et al., 2021). Additionally, the fiber processing steps, including washing, chemical treatment, and drying, effectively removed potential odor-causing substances. Chemical treatments applied during fiber processing have also been reported to contribute to the elimination of odor-related compounds (Richter et al., 2020).

From a food safety perspective, particularly for packaging animal-based products such as eggs, roselle stem–based egg trays can be considered safe for use. Odorless packaging materials are highly desirable for food applications, as unwanted odors may negatively affect consumer perception and product acceptance (Dhebora et al., 2022). The use of low-odor adhesives and naturally odorless raw materials not only enhances product safety but also reduces potential environmental impacts associated with volatile organic compound emissions (Nurjanah et al., 2023).

Determination of the optimal glue concentration

The optimal concentration of glue for roselle stem–based egg trays was determined to be 5%, based on achieving a stiffness level that is sufficiently strong yet not excessively rigid to ensure egg safety. Egg trays produced with 5% glue exhibited balanced physical and mechanical properties, including a moisture content of 9.746 ± 0.567%, water absorption of 19.136 ± 0.456%, thickness of 3.870 ± 0.018 mm, tensile

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strength of 10.220 ± 0.245 N·m/g, tear resistance of 677.880 ± 22.655 mN, and stiffness of 14.100 ± 0.720 mN·m. To further validate functional performance, a vibration resistance test was conducted using egg trays composed of 95% roselle stem fiber and 5% glue. The trays were subjected to transportation conditions by placing them in a vehicle traveling at a speed of 40 km/h over a distance of 10 km on a road surface that was approximately 75–80% smooth with minor irregularities. The results demonstrated that the egg trays effectively withstood mechanical vibrations, and no egg breakage was observed during the test. These findings confirm that roselle stem–based egg trays formulated with 5% glue provide an optimal balance between mechanical strength and flexibility, making them suitable for practical egg packaging applications. The appearance of the egg tray produced at the optimal adhesive concentration is shown in Figure 1.

Figure 1. Egg trays from roselle stem

Conclusions

Adhesive concentration significantly affected the moisture content, water absorption, tensile strength, tear resistance, and stiffness of roselle stem–based egg trays, while no significant effect was observed on tray thickness. Increasing adhesive concentration resulted in a reduction in moisture content and water absorption, accompanied by improvements in tensile strength, tear resistance, and stiffness. The egg trays exhibited color characteristics ranging from light brown to dark brown, with textures varying from flexible to stiff depending on adhesive concentration. All treatments produced odorless egg trays, which can be attributed to the inherent properties of the roselle stem fibers and the low-odor formulation of the adhesive used. The optimal glue concentration for egg tray production was determined to be 5%, based on achieving a stiffness value within the recommended range for egg packaging applications (7–24 mN·m). At this concentration, the egg trays exhibited a stiffness of 14.100 ± 0.720 mN·m, indicating an appropriate balance between structural rigidity and flexibility. The corresponding physical and mechanical properties included a moisture content of 9.746 ± 0.567%, water absorption of 19.136 ± 0.456%, thickness of 3.870 ± 0.018 mm, tensile strength of 10.220 ± 0.245 N·m/g, and tear resistance of 677.880 ± 22.655 mN. Overall, the results demonstrate that roselle stem waste has strong potential as a sustainable and environmentally friendly raw material for egg tray production, contributing to waste valorization and the development of biodegradable packaging alternatives..

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