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Effect of Pectin and Sucrose Concentrations on the Physical Characteristics of Seablite (*Suaeda maritima*) Vegetable Leather

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A B S T R A C T

Suaeda maritima, a coastal plant, has potential as a functional food ingredient due to its high antioxidant content (80.36%) and the presence of vitamin A, beta-carotene, and vitamin E. The innovation of processing Suaeda maritima leaves into vegetable leather aims to enhance their utility and consumer acceptability. Vegetable leather is a plant-based product made by grinding and drying vegetables into flexible sheets. Adding pectin and sucrose is necessary to develop the texture and improve flavor. This study aimed to check the moisture content, pH, plastic texture (1st fracture deformation), and lightness of Suaeda maritima vegetable leather using different amounts of pectin (1%, 2%, 3%) and sucrose (15%, 20%, 25%). The experimental design used was a two-factor, completely randomized design (CRD) with two replications, followed by ANOVA and 5% DMRT analysis. The results showed that the best treatment was the combination of 3% pectin and 25% sucrose, which produced vegetable leather with a moisture content of 19.48%, pH of 3.67, 1st fracture deformation value of 0.03 mm, and a lightness value of 32.01.

Contribution to Sustainable Development Goals (SDGs):
SDG 2: Zero hunger
SDG 3: Good Health and Well-being
SDG 9: Industry, Innovation and Infrastructure
SDG 12: Responsible Consumption and Production
SDG 14: Life Below Water

1. INTRODUCTION

1.1. *Research Background*

Suaeda maritima (seablite) is a halophytic plant that naturally grows in coastal regions and saline wetlands, particularly in mangrove ecosystems. Its young leaves are commonly consumed as fresh vegetables or processed in traditional dishes. Due to its salty habitat, the leaves of *S. maritima* have a naturally salty taste, with a reported salt content of up to 4.02% [1]. Although nutritionally promising, the utilization of *S. maritima* remains limited to conventional culinary processes, such as boiling or mixing in traditional dishes like *urap* [2].

Nutritionally, *S. maritima* leaves contain dietary fiber, vitamins A and E, protein, calcium, and iron [3]. Additionally, these leaves possess strong antioxidant activity, with inhibition percentages reaching up to 91.70%, an IC_{50} value of 0.017 mg/mL, and a total phenolic content of 13 mg GAE/g [1][4]. These phytochemical properties indicate the potential of *S. maritima* as a functional food ingredient. However, limited public awareness and lack of technological exploration hinder its broader utilization [5]. To enhance its functional and economic potential, *S. maritima* is processed into vegetable leather—a chewy, sheet-like food product made from mashed and dried vegetables [6]. This product belongs to the category of dried vegetable snacks and is generally consumed as a snack or a complementary food. An ideal vegetable leather typically contains 10–20% moisture, has a flexible sheet structure, and retains the distinct flavor of its raw material [7][8].

One of the main challenges in vegetable leather production is achieving a plastic and flexible texture. Unlike fruits, vegetables generally have lower natural pectin content; thus, additional gelling agents are required to achieve the desired texture [9][10]. Pectin is a natural plant polysaccharide that acts as a thickener and gelling agent. High methoxyl pectin (HMP) is commonly used in products with low pH and high sugar content, such as jams, as it can form stable gels under acidic conditions (pH ≈ 3) [11].

Based on these considerations, this study aimed to evaluate the effects of varying pectin and sucrose concentrations on the physicochemical characteristics of vegetable leather made from

Suaeda maritima, and to determine the optimal formulation for producing a product with desirable quality attributes.

1.2. Literature Review

Suaeda maritima, locally known in Indonesia as alur, malur, or pedangan, is an annual halophytic plant from the Amaranthaceae family that naturally grows in muddy coastal areas and high-salinity wetlands [5]. Local communities, especially in coastal regions of East Java, utilize their young leaves as vegetables in traditional dishes, such as urap [2]. The young leaves of S. maritima vary in color from green to reddish and can be consumed fresh or cooked.

Phytochemical tests have shown that S. maritima leaves contain active compounds such as flavonoids, alkaloids, and saponins, contributing to their antioxidant and antimicrobial properties [12]. Leaf color correlates with environmental salinity; higher salt concentrations induce a red pigmentation in the leaves, with a saltier taste and a crisper texture. Green leaves are generally preferred for consumption due to their milder flavor than red ones [13].

Geographically, S. maritima is widely distributed along coastal areas in Europe, East Asia, Eastern India, and Russia. In Indonesia, the plant can be found in coastal areas of Gresik, Sidoarjo, Madura, and several mangrove forests in Surabaya [2]. The natural salty taste of the leaves is due to the salt-rich environment in which they grow. Soaking the leaves is recommended to reduce the salinity before consumption [1].

The nutritional content of S. maritima leaves suggests potential for development as a functional food source. The leaves are rich in vitamin A and exhibit antioxidant activity up to 80.46% [13]. Their mineral and antioxidant content also makes them a potential alternative raw material for functional salt products.

Fig. 1. Fresh seablite (*Suaeda maritima*) leaves

Developing an optimal texture in vegetable leather depends heavily on the balance between pectin and sugar content in the formulation. Raw materials with low natural pectin content require additional pectin to achieve the desired elasticity. Sugar also plays a key role by binding water, thus influencing the firmness of the final product [14].

Simultaneously adding pectin and sucrose is crucial in optimizing vegetable leather's mechanical and organoleptic properties. Insufficient pectin may result in brittle, non-elastic textures, while a lack of sucrose can reduce tenderness and accelerate moisture loss, ultimately decreasing product quality during storage [14]. Therefore, the concentrations of both components must be adjusted proportionally to achieve the desired product texture, flexibility, and taste.

1.3. Research Objective

This study aims to evaluate the effect of varying pectin and sucrose concentrations on the physical characteristics of vegetable leather made from Suaeda maritima leaves and to determine the optimal formulation for achieving the desired product quality.

2. MATERIALS AND METHODS

2.1. Materials

2.1.1. Raw Material

The main raw material used in this study was *Suaeda maritima* leaves, sourced from aquaculture farmers in the Gresik region, East Java. Additional ingredients included water, high methoxyl pectin (HMP) purchased online under Surabaya's Shenghui Kangze Biotechnology brand, and granulated sugar (Rose Brand) obtained from a local grocery store.

2.1.2. Analytical Material

Samples of *Suaeda maritima* vegetable leather, aquadest, citric acid, DPPH (Sigma), methanol (Merck), sodium carbonate (Na_2CO_3, Merck), Folin–Ciocalteu reagent (Merck), gallic acid (Merck), sulfuric acid (H_2SO_4, Merck), sodium hydroxide (NaOH, Merck), potassium sulfate (K_2SO_4, Merck), and ethanol (Merck) were used in this study.

2.2. Methods

2.2.1. Experimental Design

This study employed a completely randomized factorial design consisting of two factors. The first factor was pectin concentration (1%, 2%, 3%), and the second factor was sucrose concentration (15%, 20%, 25%). Each treatment combination was performed in duplicate, resulting in 18 experimental units. The data obtained were analyzed using Analysis of Variance (ANOVA). If significant differences were found among treatments, Duncan's Multiple Range Test (DMRT) was conducted at a 95% confidence level ($\alpha = 0.05$).

2.2.2. Vegetable Leather Production

Suaeda maritima vegetable leather production was adapted from the method described by Fauziyah et al. (2022), with several modifications. Fresh leaves were separated from twigs and dried leaves, then washed under running water to remove adhering dirt. The clean leaves were subjected to steam blanching at 80 °C for 5 minutes. The blanched leaves were blended with water at a 1:1 ratio using a high-speed blender for 3 minutes until a homogeneous puree was obtained.

A total of 40 g of the leaf puree was mixed with pectin (1%, 2%, 3%), sucrose (15%, 20%, 25%), and citric acid (0.3%) according to the treatment formulation. The mixture was heated at 70 °C for 2 minutes with constant stirring until homogeneous. It was then poured into a mold (10 × 8 × 3 cm) lined with non-stick baking paper. Drying was carried out in a cabinet dryer at 70 °C for 6 hours. The resulting vegetable leather was subsequently analyzed based on the predefined parameters.

3. RESULT AND DISCUSSION

3.1 Moisture Content

The average moisture content values for all treatment combinations are presented in Table 1. The moisture content of the *Suaeda maritima*-based vegetable leather ranged from 10.85% to 19.48%. The lowest moisture content was observed in the formulation containing 1% pectin and 15% sucrose, whereas the highest value was found in the sample with 3% pectin and 25% sucrose.

Table 1. Moisture content of *Suaeda maritima* vegetable leather

Pectin (%)	Sucrose (%)	Moisture Content (% ± SD)
1	15	10.85 ± 0.15[a]
	20	12.54 ± 0.28[c]
	25	12.45 ± 0.20[b]
2	15	12.67 ± 0.16[c]
	20	13.78 ± 0.23[d]
	25	13.91 ± 0.20[e]
3	15	15.88 ± 0.52[f]
	20	17.89 ± 0.14[g]
	25	19.48 ± 0.20[h]

Different superscript letters indicate significant differences ($p \leq 0.05$).

All samples produced moisture content levels within the acceptable range. According to the Indonesian National Standard (SNI 01-4317-1996), the maximum allowable moisture content for dried candied products is 25%. For fruit leather, an ideal range is 10–20%. Therefore, the moisture content of this study's Suaeda maritima vegetable leather products falls within the acceptable range for quality standards.

The increasing trend of moisture content in line with higher pectin and sucrose concentrations can be attributed to their physicochemical properties involved in gel formation. Pectin forms a fibrous three-dimensional network that traps water during drying [15]. When sucrose is added at higher concentrations, its hygroscopic nature supports hydrophobic interactions among pectin molecules, reinforcing the gel structure. This more complex and tighter gel network retains more water, reducing moisture loss during drying and thus increasing final moisture content.

3.2 Nilai pH

The pH of the vegetable leather was measured using a standard glass electrode pH meter after dissolving the sample in distilled water, following the method of Sudarmadji (1997), which is suitable for semi-solid and solid food matrices. The resulting data reflect the pH of the aqueous extract and are used for comparative analysis among treatments.

The average pH values obtained for each pectin and sucrose concentration are presented in Table 2. The pH ranged from 3.61 to 3.82, with the lowest value observed at 3% pectin and the highest at 1% pectin.

Table 2. pH of *Suaeda maritima* vegetable leather

Pectin (%)	pH ± SD
1	3.82 ± 0.07[b]
2	3.73 ± 0.05[ab]
3	3.61 ± 0.10[a]

Sucrose (%)	pH ± SD
15	3.69 ± 0.22[a]
20	3.71 ± 0.20[a]
25	3.77 ± 0.19[a]

Different superscript letters indicate significant differences ($p \leq 0.05$).

The decrease in pH with increasing pectin concentration can be attributed to the acidic nature of pectin. Pectin contains carboxylic acid groups (–COOH) that partially ionize, releasing protons (H^+) and forming carboxylate ions ($–COO^-$), thereby increasing the acidity and lowering the pH of the product [16].

On the other hand, sucrose concentration did not significantly affect the pH of the vegetable leather. Although a slight upward trend in pH was observed with increasing sucrose content (3.69–3.77), the differences were statistically insignificant. Sucrose does not directly influence pH; however, its hygroscopic nature may indirectly increase pH by enhancing osmotic pressure and reducing water activity. This reduction in water activity can suppress the dissociation of hydrogen ions (H^+), leading to a lower concentration of free protons and a marginally higher pH [17]. Nevertheless, this effect was insufficient to produce statistically significant changes.

3.3 Plastic Texture (1st Fracture Deformation)

The physical properties of Suaeda maritima-based vegetable leather were evaluated based on two key parameters: plastic texture, represented by the 1st fracture deformation (1FD), and color brightness, indicated by the lightness (L*) value.

Statistical analysis indicated a significant interaction effect ($p \leq 0.05$) between pectin and sucrose concentrations on the 1FD value of the resulting vegetable leather (Table 3). The mean values of 1FD for each treatment combination are presented in Table 3.

Table 3. 1st Fracture deformation and color lightness of *Suaeda maritima* vegetable leather

Pectin (%)	Sucrose (%)	1st Fracture Deformation (mm ± SD)	Lightness (L) ± SD
1	15	2,97 ± 0,02[b]	33,88 ± 0,10[d]
	20	2,95 ± 0,03[b]	32,96 ± 0,11[c]
	25	0,06 ± 0,01[a]	33,03 ± 0,10[c]
2	15	3,61 ± 0,02[c]	34,17 ± 0,11[e]
	20	3,74 ± 0,02[d]	34,94 ± 0,13[f]
	25	0,02 ± 0,01[a]	32,38 ± 0,12[b]
3	15	4,66 ± 0,01[e]	32,86 ± 0,13[c]
	20	4,79 ± 0,02[f]	32,97 ± 0,10[c]
	25	0,03 ± 0,01[a]	32,01 ± 0,08[a]

Different superscript letters indicate significant differences ($p \leq 0.05$).

Table 3 shows that increasing the concentrations of pectin (1–3%) and sucrose (15–20%) generally led to a significant increase in the 1st fracture deformation (1FD) values of the *Suaeda maritima*-based vegetable leather. However, a further increase in sucrose concentration to 25% resulted in a marked decline in 1FD.

The 1FD parameter represents the initial deformation point under applied force before the first structural fracture occurs [18]. It reflects the plasticity and flexibility of the product, where higher values indicate a more pliable and flexible matrix capable of withstanding bending or rolling without cracking [7,19].

A synergistic interaction between pectin and sucrose was observed at specific concentrations. Combining 3% pectin and 20% sucrose produced the highest 1FD value, forming a flexible and resilient gel network. Conversely, using 25% sucrose significantly reduced 1FD, likely due to sucrose recrystallization and disruption of the gel matrix.

Pectin contributed to improved mechanical strength and elasticity by forming a dense three-dimensional gel network, primarily via ionic interactions and hydrogen bonding among carboxyl groups [20]. At 15–20% concentrations, sucrose acted as a plasticizer that interfered with interchain interactions, enhancing the gel's flexibility. However, at 25%, sucrose likely underwent recrystallization during cooling, destabilizing the gel matrix by increasing osmotic pressure and viscosity, thus producing a brittle texture [21].

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3.4 Lightness (L*) Value

The lightness (L*) values of the vegetable leather also decreased with increasing concentrations of pectin and sucrose (Table 3), indicating a shift toward darker product coloration. The lightness values, measured on a 0–100 scale, remained within the lower range, signifying limited brightness and a darker visual appearance.

This decline in lightness is attributed to the dense and complex gel matrix formed by the interaction of pectin and sucrose, which reduced light transmission and increased light scattering on the product surface. Pectin reduces lightness by forming a compact gel structure that decreases surface reflectance [22]. Concurrently, sucrose, acting as a plasticizer, increases the density of the gel matrix, amplifying light scattering and further reducing brightness [23]. This effect occurred without prominent Maillard browning.

Despite the relatively low processing temperature (70 °C), prolonged heat exposure likely contributed to gradual color changes through interactions between sucrose and natural compounds in the leaves. Additionally, degradation of chlorophyll pigments—catalyzed by chlorophyllase, which is active at 60–75 °C—may have played a role. This enzymatic activity converts chlorophyll into darker-coloured pheophytin compounds, leading to decreased lightness and a brownish appearance of the final product [24].

4 CONCLUSION

Vegetable leather is an innovative food product dehydrated from vegetable purée into thin, flexible sheets. Recent developments have expanded its raw materials beyond fruits to include vegetables such as broccoli, tomatoes, and carrots. As a novel food form, vegetable leather offers a promising strategy for dietary diversification and increasing vegetable intake among both children and adults. In this study, the optimal formulation was achieved with a combination of 3% pectin and 25% sucrose, yielding a final product with moderate moisture content (19.48%), acidic pH (3.67), low plastic texture (1st fracture deformation of 0.03 mm), and low lightness (L* value of 32.01).

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