



## GC-MS Analysis of *Suaeda maritima* and its Application as a Salt Substitute in Fish Marinade Powder

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### ABSTRACT

This study aims to identify bioactive compounds in seablite (*Suaeda maritima*) and develop seablite-based fish powder seasoning and marinade as an alternative low-sodium product. The chemical composition of edible seablite extract was analyzed using gas chromatography-mass spectrometry (GC-MS). Production process: powder preparation from dried seablite leaves and dried herbal powder including 5% lemongrass, 5% galangal, 5% garlic, and 5% kaffir lime leaves. Sensory evaluation and consumer acceptance test were conducted on 30 participants. GC-MS results showed that seablite extract contains phytochemicals, with the main components including phytol (43.19%), Myo-Inositol (7.06%), 9,12,15-Octadecatrienoic acid, (Z,Z,Z)- (6.32%), 9-Octadecenamide, (Z)- (5.36%) and Palmitoleamide (5.21%). The final product contained 320.87 kcal, 8.65 g protein, 68.62 g carbohydrate, 1.31 g fat, 15.19 g ash, 6.23 g water per 100 grams, and 46,431.25 mg/kg sodium. This formulation offers a healthier alternative with reduced sodium while maintaining flavor and nutritional value. The optimal formulation for seasoning and marinating fish powder consisted of 50% dried seablite powder. Sensory evaluation scores indicated consumer preferences ranging from "somewhat liked" to "quite liked." These findings indicate that the developed seasoning powder is a promising, tasty, and healthier alternative for low-sodium fish products, while maintaining acceptable sensory qualities.

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## 1. INTRODUCTION

Salt plays a crucial role in seasonings, sauces, and various commercially available seasoning and marinade powders. However, high salt intake can cause health issues. Excessive sodium intake contributes to elevated blood pressure and an increased risk of cardiovascular disease, which is among the top three leading causes of mortality globally, accounting for approximately 18 million deaths each year [1-2]. The global average salt intake is estimated at 10.78 g/day (equivalent to 4,310 mg/day of sodium), substantially exceeding the World Health Organization's recommended limit of less than 5 g/day for adults (equivalent to less than 2 g of sodium) [3]. Several techniques have been used to reduce salt content in food products, for example, using KCl, reducing salt addition, odor-induced saltiness enhancement, and flavor enhancers [4-6]. Studies have reported the use of plant-derived seasoning as a salt-replacement technique in various food products. Examples of this include the use of garlic in rice and meat products, rosemary in vegetable products, and herb blends in ready-meal products [7]. Seablite has been used as a partial substitute for sodium chloride in bread recipes, with replacement levels up to 50%, while maintaining acceptable physical and chemical properties and gaining consumer acceptance [8].

Seablite (*Suaeda maritima*) is a native plant in many parts of Thailand and thrives in mangrove forests with saline, moist soils. It appears as a low shrub, with succulent green leaves that turn reddish-purple as it matures. Seablite is commonly utilized in cooking and manufacturing various products. For culinary purposes, the young green leaves are typically preferred because they are less salty than the purple-red leaves. The plant is used in diverse dishes, such as seablite chili paste, seablite jelly, seablite gyoza, and seablite meatballs [9]. In addition, a research report has identified the use of seablite salt extraction for mineral salt products [10]. Part of the seablite stalk is used for cooking and as a natural food source for animals [11]. Considering the nutritional value of seablite, Sudjaroen [12] reported the nutritional content of the plant in Samut Sakhon Province. For 100 g, green seablite leaves contain 189.62±13.10 kcal, 2.26±0.03 g of fat, 12.96±2.31 g of protein, 29.36±3.68 g of carbohydrate, 21.99±1.44 g of dietary fiber, 0.93±0.001 mg of vitamin C, and 3882.85±32.50 mg of sodium. Seablite is also a medicinal plant containing antioxidants such as vitamin C, flavonoids, and beta-carotene. Pornpitakdamrong and Sudjaroen [11] illustrated that seablite leaves extracted with water had a total phenolic content of 14.47 ± 2.85 mg/g DW. This extract could inhibit DPPH at 20.60 µmol TEAC/g extract. Meanwhile, seablite root extract was found to strongly inhibit DPPH radical and lipid peroxidation with IC<sub>50</sub> = 0.22 ± 0.2 and 2.75 ± 0.5 mg/ml [13]. Furthermore, seablite has been reported used as traditional medicine widely in Asia. Biological activities of edible seablite have been reported from previous research including antimicrobial, antioxidant, antidiabetic, anti-cancer, anti-inflammation, antiviral [14-15]. The main groups of biologically active compounds reported to be found in seablite include phenolic acid, hydroxycinnamic acids, flavonoids, tannins, fatty acids, steroids and essential oils [15].

Based on these findings, the application of seablite as a salt substitute in meat marinades represents a promising alternative. Marinades are widely used for pork, chicken, fish, and beef to improve tenderness, reduce toughness, and enhance juiciness. Typically, meat marinades contain ingredients such as salt, dextrose, garlic powder, and monosodium glutamate [16]. In addition, commercial formulations often include functional additives such as sodium tripolyphosphate, sodium acid pyrophosphate, and sodium erythorbate, which facilitate the marination process and improve water-holding capacity, particularly in poultry products. Natural plant-derived enzyme sources, including pineapple peel and ginger, have

also been incorporated into marinades to enhance meat tenderization [16-17]. Recently, halophytic plant has attracted increasing interest as a potential natural salt substitute due to its distinctive salty taste and mineral-rich composition [18-19]. Beyond its inherent saltiness, this halophytic plant may contain a range of volatile compounds that contribute to the overall flavor profile of food products. However, current information regarding the chemical composition and volatile constituents of seablite, particularly in relation to its potential application in low-sodium food systems, remains limited. A comprehensive characterization of its chemical profile is therefore necessary to better understand its functional and sensory contributions. Gas chromatography–mass spectrometry (GC–MS) is widely used for the identification of volatile and bioactive compounds in plant matrices. Accordingly, the present study aimed to characterize the chemical composition of seablite using GC–MS to understand its flavor-contributing compounds and to explore its potential as a natural ingredient in the development of a low-sodium marinade powder for fish products prior to frying.

## 2. METHODS

### 2.1. GC-MS Analysis Method of Dried Seablite Ethanol Extract

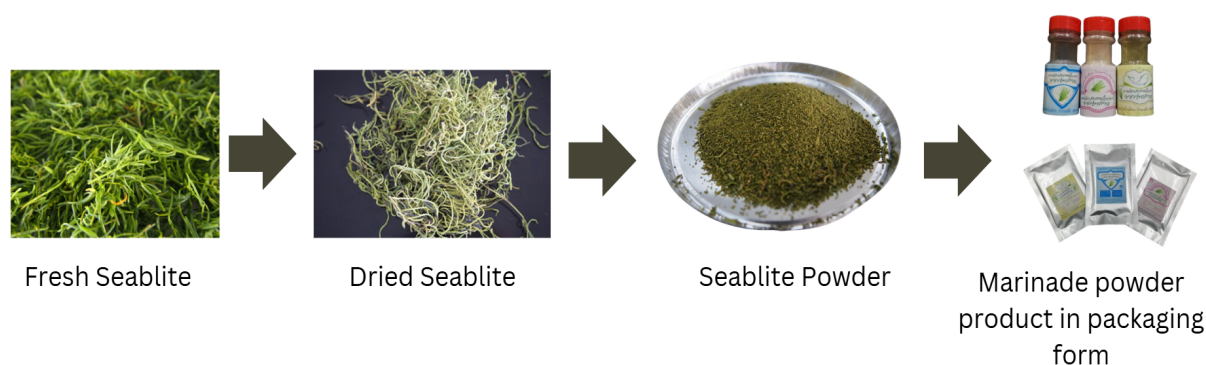
For sample extract preparation, samples of seablite harvested in Samut Sakhon Province, Thailand, the edible part, which is the leaf part, were washed, drained, and dried in a hot air oven at 80 °C for 6 hours [20]. The dried seablite was grinded to a fine powder, weighed 3.30 g, mixed with 10 mL of absolute ethanol solution, soaked with shaking for 1.30 hours, and filtered with a 0.45 µm Nylon filter before GC-MS analysis.

For GC-MS conditions, the edible part of the extract of seablite was analyzed using a GC (Agilent Technology, model GC 6890A, USA). The extract was injected at a volume of 0.2 µL (split ratio 1: 50) and the injection temperature was set at 250 °C. A column was used, HP-5, 30 m long, ID 0.25 mm., Film 0.25 µm (non-polar fused silica capillary with a 5 phenyl-methylpolysiloxane stationary phase) (Agilent Technology, model HP-5MS, USA). The helium gas flow rate into the column was set to 1.0 ml/min. The column temperature was programmed to start at 40°C for 5 min, then raised up at a rate of 5°C/min to 160°C for 10 min, then raised up at a rate of 20°C/min to 250°C for 10 min. The MS section (Agilent Technology, model 5973N mass selective detector, EIMS, electron energy, 70 eV, USA) was a quadrupole MS directly connected to the GC. The scan mass range was 30 to 500 m/z, and the solvent delay was 3 minutes. Processing was performed with Agilent MassHunter Unknowns Analysis against the NIST Mass Spectrometry Data Center.

### 2.2. Investigation Into the Optimal Ratio of Dried Seablite in Marinade Seasoning Powder Products for Health Purposes

The development process of fish marinade powder utilizing *Suaeda maritima* is illustrated in **Figure 1**. The main stages included the use of fresh seablite, drying, grinding into seablite powder, formulation of the marinade powder, and final packaging. The preparation of raw materials followed the method described by [Tongkam et al. \[20\]](#). Seablite used in this study was sourced from Samut Songkhram Province, Thailand. The process involved carefully selecting and collecting only the leaves and edible shoots. The seablite was then dried at 80 °C for six hours. The herbal ingredients required for this experiment were purchased in dried from a manufacturer of spices and dried herbs. These ingredients were subsequently separated and finely ground before being used as raw materials for the seablite marinade seasoning powder. The dried seablite contained carbohydrates, ash, protein, fat, and moisture at levels of 44.75, 30.96, 17.26, 2.98, and 4.05 g/100 g, respectively, while the

sodium content was 8,680.50 mg/100 g. In addition, it exhibited an antioxidant capacity of 1,307.23 mg Trolox equivalents (TE) per 100 g [20].



**Figure 1.** Schematic representation of *Suaeda maritima* marinade powder development.

The prepared seablite powder replaced salt in the basic formula for the fish meat marinade, as obtained from the first experiment. A comparative experiment was planned for each formula, with each product tested three times. The salt substitute in the formula comprised the following variations: 0% (control formula), 50%, and 75%. **Table 1** shows the calculations of the amounts of sodium reduction obtained when using the seablite marinade seasoning formula, considering the sodium-content reduction claims in the product. The Ministry of Public Health Announcement No. 182, 1998, stipulates that products claiming to have reduced nutrients must contain at least a 25% reduction in the amount of that nutrient (in this case, sodium) compared to the original formula [21]. The fish were cut into portions weighing 100 g each. Each portion was marinated with 5 g of seasoning powder for 30 min. After marination, the samples were fried in oil at 170 °C for 10 min. The amount of fish used in each treatment was standardized to ensure sample uniformity. After frying, the samples were cut into uniform sizes before being served for sensory evaluation. All experiments were conducted in triplicate.

Thirty consumer panelists participated in the sensory evaluation. The panelists were recruited from among staff and general public who were familiar with the consumption of similar food products. The participants were between 20 and 60 years old and included both males and females. All panelists were screened to ensure that they had no food allergies or sensory impairments. Prior to the evaluation, the purpose of the study and the evaluation procedure were explained, and informed consent was obtained from all participants. Each participant received coded fish samples and evaluated them for color, odor, taste, texture and overall liking using a nine-point hedonic scale according to Peryam and Pilgrim [22]. The mean liking scores for each sensory attribute were calculated. The experiment was conducted using a randomized complete block design (RCBD). Data were analyzed using SPSS, and mean differences among treatments were evaluated using Duncan's multiple range test (DMRT) at a significance level of  $p < 0.05$ .

**Table 1.** Ingredients of salt and dried *Suaeda maritima* for fish marinade powder.

Ingredients	Percentage (%)		
	Formulation 1	Formulation 2	Formulation 3
Sodium Chloride (NaCl)	100	50	25
Dried <i>Suaeda maritima</i>	0	50	75

### 2.3. Study on Consumer Acceptance of Herbal Seasoning Marinade Powder for Fish Meat Derived from Seablite

To study the consumer acceptance of the herb-based seablite marinade fish fillet powder, three formulas of herbs that are used as ingredients in Tom Yum [23-25] were mixed into the marinade powder formula shown in **Table 2**. Seablite fish meat was obtained from an experiment to find a seasoning marinade product formula for seablite fish meat by substituting the amount of spices commonly used in the recipe. The fish were cut into portions weighing 100 g each. Each portion was marinated with 5 g of seasoning powder for 30 min. After marination, the samples were fried in oil at 170 °C for 10 min. The amount of fish used in each treatment was standardized to ensure sample uniformity. After frying, the samples were cut into uniform sizes before being served for sensory evaluation. All experiments were conducted in triplicate.

**Table 2.** Ingredients of Thai spicy soup (Tom Yum) herbs used in the marinade powder for marinating fish from dried *Suaeda maritima*.

Treatment	Ingredients of Thai spicy soup herbs	Research
1	2 % galangal, 2% lemongrass, 2% kaffir lime	[23]
2	5% ground dried lemongrass, 5% ground dried galangal, 5% dried garlic, 5% dried kaffir lime leaves	[24]
3	25% lemongrass, 10% kaffir lime leaves, 15% galangal, 10% chili, 10% coriander	[25]

### 2.4. Analysis of The Final Quality of Marinade Seasoning Products for Seablite Fish Meat and Basic Seasoning Marinade Products

The basic nutritional components were subject to a proximate analysis, which consists of determining the moisture (in-house method T923 base on AOAC (2019) 925.10), ash (AOAC (2019) 925.51), protein (in-house method T927 base on AOAC (2019) 991.20), fat (in-house method T966 base on AOAC (2019) 922.06), and carbohydrates fat (Methods of Analysis for Nutrition Labeling 1993, Chapter 1,5) via the AOAC (2019) method [26]. A Bomb calorimeter was used to calculate the differences and analyzed the total energy values (Methods of Analysis for Nutrition Labeling 1993, Chapter 1,5).

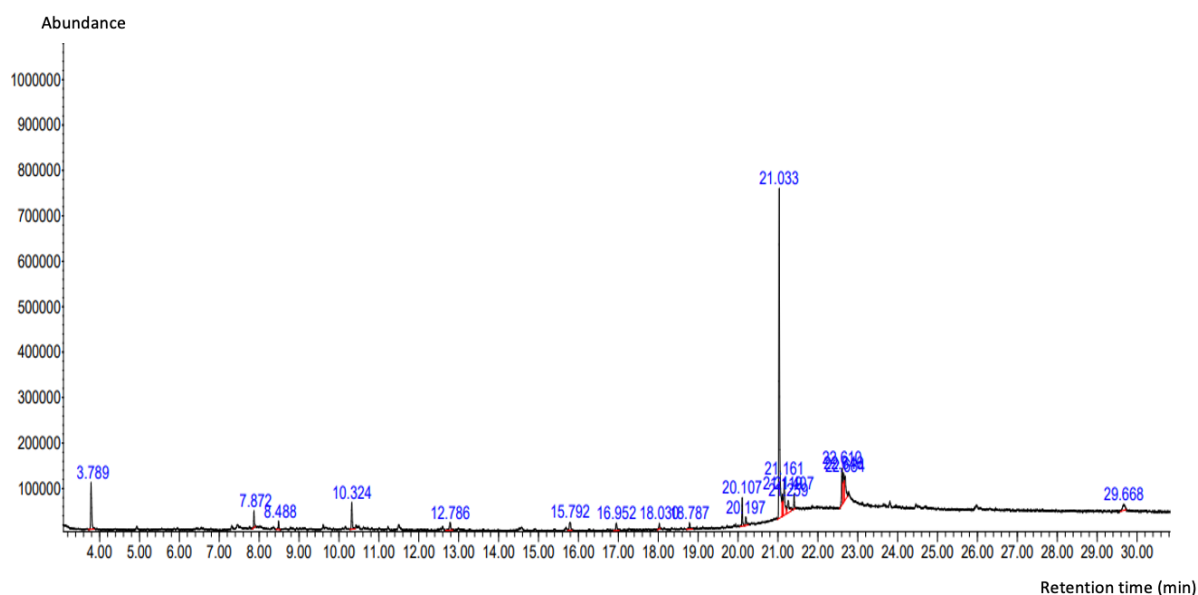
The sodium content was analyzed using the inductively coupled plasma (ICP) method applied [26]. Weighed approximately 1 gram of the dried sample and place in a 100 mL beaker. Add 5 mL of distilled water, 5 mL of concentrated nitric acid, 3 mL of concentrated hydrogen peroxide, and 3 mL of concentrated sulfuric acid. Digested on a hot plate until half of the sample volume is reduced. The solution was allowed to cool, filtered using Whatman No. 39 filter paper, and the volume was adjusted to 50 mL with distilled water. Sodium content was subsequently analyzed using Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES).

## 3. RESULTS AND DISCUSSION

### 3.1. GC-MS Profile of Dried Seablite Ethanol Extract

The chemical composition of the ethanol extract of seablite was analyzed using Gas Chromatography-Mass Spectrometry (GC-MS). The analysis revealed that the compounds eluted from the column within a retention time range of 4 to 30 minutes, as illustrated in **Figure 2** and **Table 3**. Based on the chromatogram, a total of 20 compounds were identified in the ethanol extract. Compound identification was achieved by comparing retention times

and mass spectra with reference data from a standard library. The identified constituents are presented in **Table 3** in order of increasing retention time. Among the identified chemical constituents, phytol was the predominant compound, accounting for 43.19% of the total composition.



**Figure 2.** Chromatogram of chemical composition of seablite ethanol extract.

**Table 3.** Compound identified of *Suaeda maritima* using GC-MS.

Peak No.	Compound Name	M. F. (M. W.)	Retention time	% Peak area	Uses/Bioactivity	Reference
1	Myo-Inositol	C <sub>6</sub> H <sub>12</sub> O (180.16)	3.789	7.06	Anti-cancer	[27]
2	Pentane, 1,1-diethoxy-	C <sub>9</sub> H <sub>20</sub> O <sub>2</sub> (160.25)	7.872	1.67	Flavoring agent	[28]
3	Benzeneacetaldehyde	C <sub>8</sub> H <sub>8</sub> O (120.15)	8.488	1.08	No report	
4	Benzofuran, 2,3-dihydro-	C <sub>8</sub> H <sub>8</sub> O (120.15)	10.324	3.54	Anti-inflammatory Antifungal Antileishmanial	[29-30]
5	α-citronellol	C <sub>10</sub> H <sub>20</sub> O (156.26)	12.786	1.71	Flavoring agent	[31]
6	2-Amino-5-fluorophenol	C <sub>6</sub> H <sub>6</sub> FNO (127.12)	15.792	1.71	No report	
7	Tridecanal	C <sub>13</sub> H <sub>26</sub> O (198.34)	16.952	1.52	Flavoring agent	[32]
8	Pentadecafluorooctanoic acid, dodecyl ester	C <sub>20</sub> H <sub>25</sub> F <sub>15</sub> O <sub>2</sub> (582.39)	18.030	0.71	Antimicrobial	[33]
9	Loliolide	C <sub>11</sub> H <sub>16</sub> O <sub>3</sub> (196.24)	18.787	1.12	Antioxidant Antimicrobial Anti-cancer	[34-36]

**Table 3 (Continue).** Compound identified of *Suaeda maritima* using GC-MS.

Peak No.	Compound Name	M. F. (M. W.)	Retention time	% Peak area	Uses/Bioactivity	Reference
10	n-Hexadecanoic acid	C <sub>16</sub> H <sub>32</sub> O <sub>2</sub> (256.42)	20.107	3.10	Antioxidant Antimicrobial Anti-inflammatory	[37-38]
11	Phthalic acid, cycloheptyl ethyl ester	C <sub>17</sub> H <sub>22</sub> O <sub>4</sub> (290.36)	20.197	1.40	No report	
12	Phytol	C <sub>20</sub> H <sub>40</sub> O (296.53)	21.033	43.19	Antioxidant Anti-inflammatory Antinociceptive Anti-cancer Antimicrobial	[39]
13	Acetamide, N-(4-fluoro phenyl)-2,2, 2-trifluoro-	C <sub>8</sub> H <sub>5</sub> F <sub>4</sub> NO (207.13)	21.119	3.06	No report	
14	9,12,15-Octadecatrienoic acid, (Z,Z,Z)-	C <sub>18</sub> H <sub>30</sub> O <sub>2</sub> (278.23)	21.161	6.32	Antimicrobial	[40]
15	2-isopropyl-5-methyl phenol	C <sub>13</sub> H <sub>22</sub> OSi (222.39)	21.259	3.27	Antimicrobial Antioxidant Anti-cancer Anti-leishmaniosis activity Anticholinesterase activity Tyrosinase inhibitor	[41]
16	Octadecanamide	C <sub>18</sub> H <sub>37</sub> NO (283.49)	21.407	1.66	Used for detection of colorectal cancer	[42]
17	9-Octadecanamide, (Z)-	C <sub>18</sub> H <sub>35</sub> NO (281.48)	22.610	5.36	Sleep induction, immunosuppression, and serotonin and GABA receptor activation Antinociceptive	[43-44]
18	3,5-di-tert-butylcatechol	C <sub>14</sub> H <sub>22</sub> O <sub>2</sub> (222.32)	22.646	5.16	No report	
19	Palmitoleamide	C <sub>16</sub> H <sub>31</sub> NO (253.42)	22.684	5.21	Antimicrobial	[45]
20	2-Methyl-7-phenylindole	C <sub>15</sub> H <sub>13</sub> N (207.27)	29.668	2.15	Antimicrobial Antioxidant	[46]

Based on the chemical composition analysis of the ethanol extract of seablite (**Table 3**), phytol was identified as the predominant compound. Previous studies on active compounds in plants of the genus *Suaeda* [47-48] have shown that phytol exhibits a wide range of biological activities, including antioxidant, anti-inflammatory, antinociceptive, anti-cancer, antimicrobial, diuretic, and chemopreventive properties. The extract also contained compounds classified as flavoring agents, such as pentane, 1,1-diethoxy-,  $\alpha$ -citronellol, and tridecanal. Additionally, volatile compounds like octadecanamide were identified, which have also been found in halophytic plants such as *Zostera marina* [49]. Other compounds reported in halophytes include pentane, 1,1-diethoxy-, previously found in *Atriplex lindleyi* [50] and

loliolide, which occurs in sea heath (*Frankenia laevis*) [51]. Among the fatty acid group, hexadecanoic acid (3.10%), also known as palmitic acid, was detected. This compound has been previously reported in the hexane extract of seablite stems [52] and is known to exhibit antimicrobial, antioxidant, and anti-inflammatory properties [37-38]. Another fatty acid, linolenic acid (9,12,15-octadecatrienoic acid) at 6.32%, was also found and is known for its antimicrobial activity [40] and it has likewise been reported in seablite [52]. Notably, some compounds, including phthalic acid, cycloheptyl ethyl ester and acetamide, N-(4-fluorophenyl)-2,2,2-trifluoro, were identified in this study but have not been previously reported in seablite. Some compounds detected by GC-MS such as phthalate derivatives and fluorinated aromatic compounds may originate from laboratory contamination or analytical artifacts rather than true plant metabolites. Phthalates are widely reported contaminants derived from plastic laboratory ware, while fluorinated compounds are rarely produced naturally by plants.

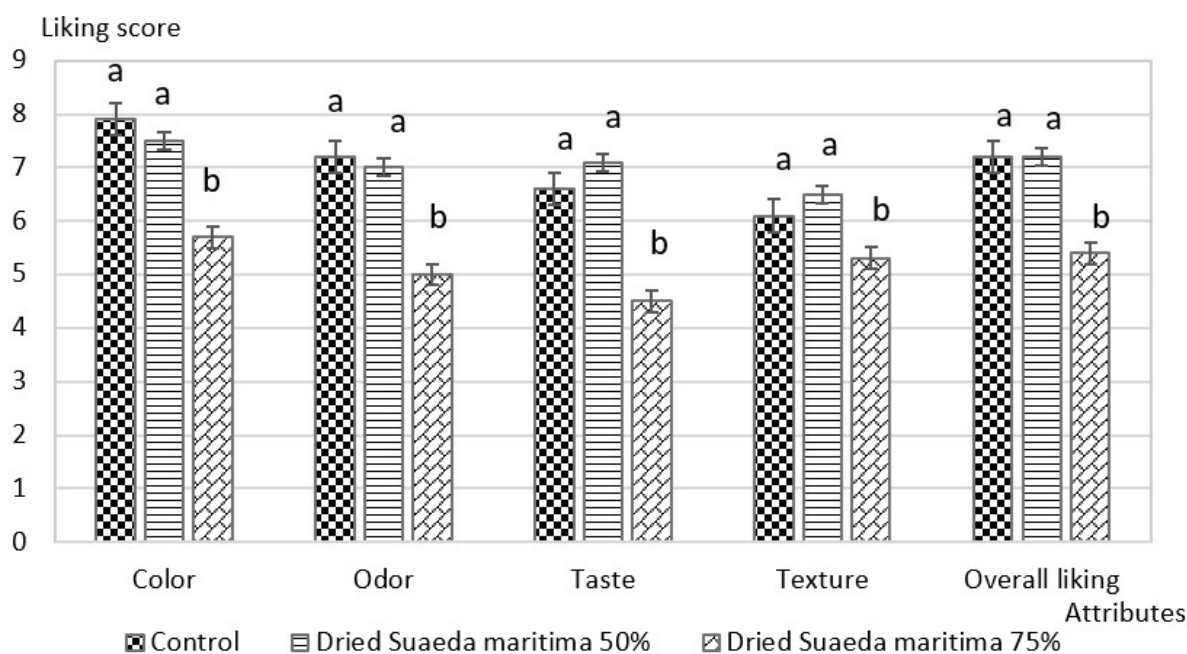
Key compounds in medicinal plants have attracted increasing attention due to their potential relationship with salty taste perception. For example, the compound (9S,12S,13S)-trihydroxy-octadeca-10E,15Z-dienoic acid has been reported as a key component in thyme that can enhance salty taste perception [53]. In addition, major flavor compounds from Mediterranean herbs, spices, and fruits identified using gas chromatography-flame ionization-mass spectrometry (GC-FID-MS) have been suggested to influence saltiness perception and flavor enhancement [54]. Volatile compounds from herbs may enhance the perception of saltiness through several sensory interaction mechanisms. One mechanism is odor-induced saltiness enhancement, in which volatile compounds enter the nasal cavity during consumption and interact with the olfactory system. The brain integrates these aromatic cues with salty taste signals from the tongue, leading to an increased perception of saltiness. In addition, cross-modal sensory perception may occur when certain volatile compounds stimulate the trigeminal nerve, producing sensations such as cooling, heat, or tingling, which enhance overall flavor perception. Cognitive associations with strong herbal aromas may also shift sensory attention toward the overall flavor profile, allowing foods to be perceived as flavorful even when sodium content is reduced [4, 8, 54].

This study analyzed the chemical composition of seablite using GC-MS and identified several compounds that may contribute to the enhancement of food taste perception. Although these compounds do not directly impart saltiness in the same way as sodium chloride, they may enhance flavor intensity and perceived saltiness through aroma-related mechanisms and overall flavor enhancement. Fatty acids and their derivatives, such as n-hexadecanoic acid and 9,12,15-octadecatrienoic acid, can serve as precursors of volatile compounds that produce fatty or savory aromas, thereby contributing to increased flavor intensity in foods [55]. Meanwhile, terpenes and plant-derived aromatic compounds, including phytol, loliolide, and  $\alpha$ -citronellol, have been reported to increase aroma complexity, which may influence the perception of saltiness through cross-modal interactions between olfactory and gustatory sensory systems [56]. In addition, phenolic compounds such as 2-isopropyl-5-methylphenol may also contribute to enhancing the overall flavor profile of food. However, this study has several limitations. GC-MS analysis provides information on the chemical composition of the detected compounds but does not directly confirm their functional role in saltiness perception. Therefore, further studies involving sensory evaluation and investigations in real food matrices are necessary to validate these potential effects. In addition, the optimal concentrations of these compounds for salt replacement, as well as their stability during food processing conditions such as high-temperature treatments, may

influence the chemical characteristics and overall quality of food products, which could ultimately affect consumer acceptance.

### 3.2. Optimal Ratio of Dried Seablite in Marinade Seasoning Powder Products

A study was conducted to ascertain the optimal ratio of dried seablite in marinade seasoning powder products derived from seablite, with a focus on health considerations. The prepared seablite powder was used to replace salt in the basic formula for fish meat marinating powder, and a comparative experiment was planned for each formula. Each trial was conducted three times per product, with the salt substitute levels set at 0% (control formula), 50%, and 75%. The products were tested among consumers, with the corresponding results presented in **Figure 3**.



**Figure 3.** The liking score of fried fish with marinade powder from dried *Suaeda maritima*.

\* N= 30; Mean  $\pm$  SD. Means within each column followed by different lowercase letters differ significantly ( $P < 0.05$ ).

The substitution of salt with dried seablite powder at different levels significantly affected the sensory acceptance of fried fish samples ( $p < 0.05$ ). Fried fish prepared using seasoning powder in which dried seablite replaced 50% of the total salt content received mean hedonic scores ranging from 6.5 to 7.5, corresponding to the levels of “slightly like” to “moderately like”. These scores were not significantly different from those of the control sample ( $p > 0.05$ ), indicating that partial replacement of salt with halophytic plant powder did not negatively affect consumer acceptance. In contrast, increasing the substitution level to 75% significantly reduced the sensory scores ( $p < 0.05$ ), with values ranging from 4.5 to 5.7, corresponding to “slightly dislike” to “neither like nor dislike”.

The decrease in consumer acceptance at higher substitution levels may be related to changes in flavor intensity, herbal aroma, or mineral taste associated with halophyte plants. Halophytes and related species contain high levels of minerals, amino acids, and bioactive compounds that can influence the perception of saltiness and overall flavor in food products [8, 57]. The observed trend suggests that moderate substitution of salt with halophyte-derived ingredients can maintain acceptable sensory quality, whereas excessive substitution

may negatively influence product flavor. Similar findings have been reported in previous studies in which halophyte plants were used as salt substitutes in food products. For example, the incorporation of *Sarcocornia perennis* as a salt substitute in snack products showed good sensory acceptance at moderate levels, while higher concentrations resulted in changes in color and sensory properties that could limit consumer acceptance [18]. In addition, studies on the use of seablite as a partial salt substitute in bread products have demonstrated that halophyte powder can reduce sodium content while maintaining acceptable physicochemical and sensory characteristics when used at moderate levels. These findings support the concept that halophyte plants can serve as natural salt substitutes in food products, particularly when used at optimized substitution ratios [8]. Therefore, based on the sensory evaluation results, replacing 50% of the total salt content with dried seablite powder was considered the most suitable formulation for developing seasoning powder for fish marination. At this level, the product still maintained consumer acceptability comparable to that of the control sample while potentially contributing to sodium reduction in the formulation.

Seablite is a halophytic plant naturally adapted to high-salinity environments and capable of accumulating substantial amounts of inorganic ions in its tissues. The characteristic salty taste of halophytes is primarily attributed to their mineral composition, particularly sodium ( $\text{Na}^+$ ), potassium ( $\text{K}^+$ ), magnesium ( $\text{Mg}^{2+}$ ), and calcium ( $\text{Ca}^{2+}$ ) salts [58-59]. Among these minerals, sodium chloride ( $\text{NaCl}$ ) is the primary contributor to saltiness perception, while potassium salts, such as potassium chloride ( $\text{KCl}$ ), may also contribute to the salty taste, although high concentrations can produce a slightly bitter or metallic aftertaste. Experimental results indicate that seablite can replace up to 50% of salt in fish marinade formulations however achieving the desired level of saltiness may require flavor adjustments or the incorporation of flavor enhancers, or the use of other sodium reduction techniques.

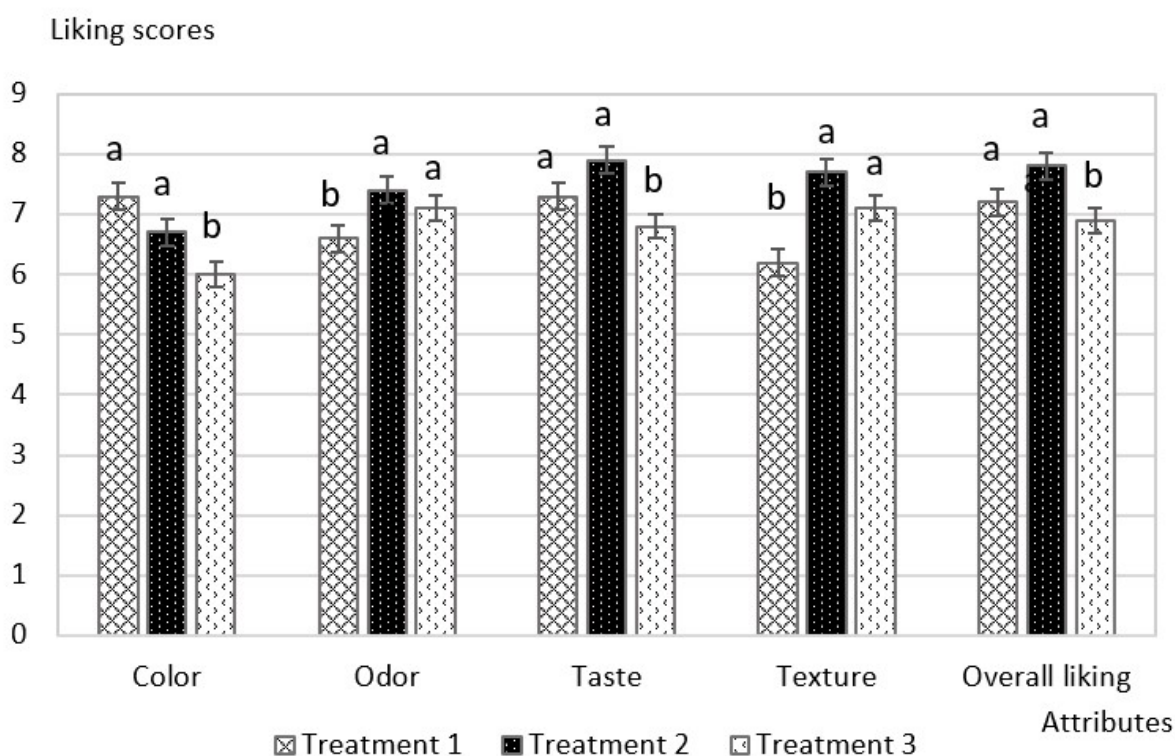
### 3.3. Assessing Consumer Acceptance of Herbal Seasoning Marinade Powder for Fish Meat Derived from Seablite

Consumer acceptance of herb-based seablite meat marinade was investigated by incorporating herbs that are key ingredients in Tom Yum. Three formulas - Formula 1: Deesawat [23], Formula 2: Somaly and Pichayarat [24], and Formula 3: Boonbamrung [25] were mixed into the seablite fish marinade recipe by replacing the usual amount of common spices. The resulting product was used to marinate and cook the fish. Consumer acceptance was then tested, and the results are presented in Figure 4.

The consumers rated all the attributes in the range of like slightly to like moderately for the seasoning powder used in marinating fish meat from seablite. This formulation contained herbs such as 5% ground dried lemongrass, 5% dried galangal, 5% garlic, and 5% kaffir lime leaves. The values for color, odor, taste, texture, and overall liking ranged from 6.7 to 7.9 points. The seasoning powder for fish meat from seablite using herbal treatment 1, which consisted of 2% Galangal, 2% lemongrass, and 2% kaffir lime, received consumer ratings in the range of 6.6 to 7.3 points for color, smell, taste, texture, and overall liking. The seasoning marinade powder products for marinating fish meat from seablite using herbal treatment 3, comprising 25% lemongrass, 10% kaffir lime leaves, 15% galangal, 10% chili, and 10% coriander. Consumers assigned liking scores in the range of 6.0 to 7.1 points for color, smell, taste, texture, and overall liking. Based on these results, the odor and texture scores for treatment 2 were significantly higher than those for treatment 1 ( $p < 0.05$ ). Additionally, treatment 2 received significantly higher scores for color and overall liking compared with treatment 3 ( $p < 0.05$ ). The formulated products containing 5% ground dried lemongrass, 5%

ground dried galangal, 5% garlic, and 5% kaffir lime leaves demonstrated potential for further development.

Replacing salt with herbs and spices can enhance consumer acceptance [60-61]. Tomić-Obrdalj *et al.* [61] illustrated that the saltiness of sodium-reduced foods in ready meals for the elderly. The sample with sodium was reduced by 30% and a blend of herbs and spices was added. It was significantly lower than that of the control without sodium reduction. However, the addition of herbs and spices enhanced perceived saltiness, resulting an intensity comparable to the non-sodium reduced sample. Overall, liking of the sodium-reduced meals was also comparable to that of the control.



**Figure 4.** Consumer acceptant score of fried fish with marinade powder from dried *Suaeda maritima* and Thai spicy soup (Tom Yum) herbs.

\* N= 30; Mean  $\pm$  SD. Means within each column followed by different lowercase letters differ significantly ( $P < 0.05$ ).

### 3.4. Analysis of The Final Quality of Marinade Seasoning Powder for Fish Meat Derived from Seablite

The results of the quality analysis of the developed marinade seasoning powder for fish from seablite and control seasoning powder products are presented in **Table 4**. As **Table 4** illustrates, the developed marinade seasoning powder for fish meat from seablite had an energy value of 320.87 kcal/100 g, protein content of 8.65 g/100g, carbohydrate content of 68.62 g/100g, fat content of 1.31 g/100g, ash content of 15.19 g/100g, moisture content of 6.23 g/100g, and sodium content of 46,431.25 mg/kg. In comparison, the basic flavored marinade products had an energy value of 275.01 kcal/100g, protein content of 7.21 g/100g, carbohydrate content of 59.45 g/100g, fat content of 0.93 g/100g, ash content of 27.60 g/100g, moisture content of 4.81 g/100g, and sodium content of 100,255.94 mg/kg. Based on the quality analysis of the seasoning powder for fish meat from seablite made for health purposes, the developed formula can claim to reduce the sodium content in the product.

According to the Ministry of Public Health Announcement No. 182, 1998, products claiming to contain reduced nutrients must have at least a 25% reduction in the amount of that nutrient (in this case, sodium) compared to the original formula. The developed formula for seasoning marinade for fish meat from seablite produced a 53.69% reduction in sodium compared to the powdered product's basic seasoning marinade. Consumer acceptance of the developed seasoning marinade powder for fish meat from seablite fell within the mild to moderate range. Consumers gave a liking score of 6.3 points for color, 6.9 points for odor, 7.1 points for taste, 7.0 points for texture, and 7.1 points for overall liking. Comparatively, consumers rated their liking for color at 7.6 points, odor at 7.2 points, taste at 6.9 points, texture at 6.6 points, and overall liking at 7.1 points.

**Table 4.** Quality of marinade powder from dried *Suaeda maritima* with Thai spicy soup (Tom Yum) herbs.

Qualities	Control samples	Marinade powder from dried <i>Suaeda maritima</i> with Thai spicy soup (Tom Yum) herbs
Energy (kcal/100g)	275.01	320.87
Protein (g/100g)	7.21	8.65
Carbohydrate(g/100g)	59.45	68.62
Fat (g/100g)	0.93	1.31
Ash (g/100g)	27.60	15.19
Moisture content (g/100g)	4.81	6.23
Sodium content (mg/kg)	100,255.94	46,431.25
Sensory Quality		
Color	7.6±0.8 <sup>a</sup>	6.3±0.8 <sup>b</sup>
Odor <sup>ns</sup>	7.2±0.8	6.9±0.9
Taste <sup>ns</sup>	6.9±0.8	7.1±0.8
Texture <sup>ns</sup>	6.6±0.9	7.0±1.2
Overall liking <sup>ns</sup>	7.1±0.9	7.1±0.8

#### 4. CONCLUSION

In conclusion, this study demonstrates that seablite (*Suaeda maritima*) contains various bioactive phytochemical compounds that may contribute to its functional properties as a food ingredient. The incorporation of seablite powder as a 50% salt substitute, combined with selected herbal ingredients in a marinated meat powder formulation, resulted in a product with favorable sensory acceptance among consumers. These findings highlight the potential of seablite as a natural salt alternative for the development of low-sodium food formulations. Moreover, the study provides scientific evidence regarding the phytochemical profile of seablite and its practical application in marinated food products. Overall, the results support the feasibility of utilizing seablite as a partial salt substitute in seasoning or marinade powder systems, thereby contributing to the development of healthier sodium-reduced food products.

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## 6. AUTHORS' NOTE

The authors declare that there is no conflict of interest regarding the publication of this article. The authors confirmed that the paper was free of plagiarism.

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