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Sweetener-Mediated Modulation of Physicochemical and Sensory Properties of a Fucoidan-Pectin Functional Syrup

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ABSTRACT: Sweetener selection can influence the physicochemical properties and sensory acceptance of functional syrups containing bioactive polysaccharides. This study investigated the effects of sucrose, sorbitol, honey, and stevia on the physicochemical and sensory characteristics of a pectin-fucoidan functional syrup formulated at equivalent sweetness levels. Total dissolved solids (TDS), density, viscosity, pH, color characteristics, hedonic properties, and descriptive sensory profiles were evaluated. Sweetener type significantly influenced the physicochemical characteristics of the formulations. Sorbitol produced the highest TDS (30.72 °Brix), density (1.12 g/mL), and viscosity (96.00 cP), whereas stevia resulted in the lowest values for these parameters, particularly TDS (2.88 °Brix) and viscosity (56.80 cP). The honey-based formulation exhibited the highest pH (3.60) and the most distinctive color profile, characterized by the highest chroma and a lower lightness value. Sensory evaluation indicated that sorbitol provided the most favorable overall acceptance, while honey received the lowest acceptance. Descriptive sensory analysis further distinguished the formulations through differences in sweetness, viscosity, clarity, honey-like flavor, color intensity, bitterness, and aftertaste. These findings demonstrate that equivalent sweetness does not ensure comparable physicochemical or sensory properties. Sorbitol provided the most balanced combination of physical characteristics and sensory acceptance under the conditions tested, whereas stevia may require additional formulation strategies to improve body and taste quality. This study highlights sweetener selection as a critical consideration in developing pectin–fucoidan functional syrups.

1. INTRODUCTION

Functional beverages and syrups containing bioactive ingredients have received increasing attention because they can serve as convenient food matrices for incorporating functional compounds. Among marine-derived polysaccharides, fucoidan has attracted considerable research interest because of its reported antioxidant, anti-inflammatory, immunomodulatory, and other biological activities [1] . Fucoidan is a sulfated polysaccharide predominantly obtained from brown macroalgae, with structural features that vary according to species, extraction conditions, and molecular composition [2]. These structural characteristics are relevant to its functional performance and interactions with other food components. Pectin is a plant-derived polysaccharide widely used as a thickening, stabilizing, and structuring agent in food systems. In addition to its technological functions, pectin has been investigated for prebiotic and other physiological effects and has potential as a matrix for the incorporation of bioactive compounds [3]. Combining fucoidan and pectin therefore provides a useful model for developing a polysaccharide-based functional syrup. However, the physicochemical behavior and sensory performance of such a system can be strongly influenced by the composition of the sweetener phase.

Sweetener selection is a critical formulation factor in syrup-based functional foods because different sweeteners contribute not only to sweetness intensity but also to the physical structure, appearance, and sensory characteristics of the final product. Sucrose, a conventional nutritive sweetener, contributes substantial dissolved solids and can influence viscosity, density, and

mouthfeel. Sorbitol, a polyol widely used as a bulk sweetener and humectant, provides sweetness while also contributing to the mass and physical properties of the syrup matrix [4]. Honey represents a more complex natural sweetener composed predominantly of fructose and glucose together with minor constituents, including phenolic compounds and minerals, which may affect product color, flavor, and sensory perception [5]. In contrast, steviol glycosides are high-intensity sweeteners that can provide the desired sweetness at substantially lower concentrations and therefore contribute little to total dissolved solids and bulk viscosity [6] . These fundamental differences are particularly relevant in hydrocolloid-based systems containing pectin and fucoidan, where changes in the composition and concentration of the sweetener phase may alter the continuous phase, flow behavior, optical properties, and perception of texture and aftertaste. Thus, replacing one sweetener with another cannot be considered merely a change in sweetness source but represents a modification of the overall formulation environment.

Despite the extensive use of sucrose, polyols, honey, and high-intensity sweeteners in food product development, their comparative effects have predominantly been investigated in conventional food and beverage matrices [4], [7], [8], while limited attention has been given to their behavior in complex polysaccharide systems containing both plant-derived pectin and marine-derived fucoidan. In particular, comparative evidence on how different sweetener types affect the physicochemical characteristics and sensory acceptance of fucoidan-pectin syrups under equivalent sweetness conditions remains limited. This knowledge gap is important because a sweetener that provides desirable sweetness may not necessarily produce the optimal viscosity, color, mouthfeel, or overall acceptability of a hydrocolloid-based functional syrup. Therefore, systematically comparing sucrose, sorbitol, honey, and stevia is necessary to elucidate how sweetener type shapes the physicochemical and sensory performance of the fucoidan-pectin matrix and to identify formulation strategies that achieve an appropriate balance between product quality and consumer acceptance. This study aimed to determine how sweetener type influences the physicochemical and sensory properties of a fucoidan-pectin syrup.

2. MATERIALS AND METHODS

2.1 Study Material

The materials used in this study were apple pectin with the species name *Malus sylvestris* (IR & Co, Surabaya), brown seaweed fucoidan with the species name *Cladosiphon okamuranus* (Pyridam Farma, Cianjur), liquid sorbitol, sucrose, liquid stevia, rubber honey (Honey Hevea, Bekasi), propylene glycol, citric acid, apple flavor, and distilled water.

Table 1. Pectin-Fucoidan Functional Syrup Formula

Ingredient	Concentration (%)
Apple pectin (w/v)	0.25
Brown seaweed fucoidan (w/v)	0.10
Distilled water (v/v)	16.65
Propylene glycol (v/v)	1.00
Apple flavor (v/v)	1.80
Citric acid (w/v)	0.20
Sweetener solution (v/v)	80.00

2.2 The making of Fucoidan-Pecting syrup

The making of Fucoidan-Pectin syrup refers to [9]. The Fucoidan-Pecting syrup formula is shown in Table 1. Sweetener solutions were prepared to achieve equivalent sweetness levels relative to a 20% sucrose solution [10] , used as the control. Based on sweetness equivalence calculations, 37.5 mL of sorbitol, 17 mL of honey, and 0.1 mL of stevia were each diluted with distilled water to a final volume of 100 mL. 80 mL of syrup formulation was used for each solution.

Apple pectin (0.25%, w/v) was dissolved in 16.65% (v/v) distilled water using an Ultra-Turrax homogenizer (IKA, Germany) at 9000 rpm for 10 minutes at 70°C. After cooling to 25°C, 80% (v/v) sweetener solution, 0.1% (w/v) fucoidan, 1% (v/v)

propylene glycol, 0.2% (w/v) citric acid, and 1.8% (v/v) apple flavor were gradually added while homogenized at the same speed for an additional 10 minutes at room temperature. The resulting mixture was left undisturbed for 10 minutes to remove air bubbles, then bottled and labeled according to treatment group.

2.3 Measurement of Physicochemical Properties

2.3.1 Color Measurement: Color parameters (L*, a*, and b*) were measured using a color reader (Konica Minolta, Japan). Chroma (C*) and hue angle (h°) were subsequently calculated from the measured a* and b* values 2 using the following equations:

$$C^* = \sqrt{a^{*2} + b^{*2}}$$

$$H^\circ = \tan^{-1}\left(\frac{b^*}{a^*}\right)$$

2.3.2 Total Dissolved Solids (TDS) : TDS was measured using a refractometer (Atago, Japan) calibrated with distilled water. Two drops of the syrup sample were placed on the prism surface, and °Brix readings were taken.

2.3.3 Density: Determined using a pycnometer. The pycnometer was weighed empty (A), then filled with distilled water and weighed (B), and finally filled with the syrup sample and weighed again (C). Density was calculated using the following formula:

$$\text{Density (g/mL)} = \frac{\text{(C-A)}}{\text{(B-A)}}$$

A= Weight of empty pycnometer

B= Weight of pycnometer + aquadest

C= Weight of pycnometer + sample

2.3.4 Viscosity: Viscosity was measured using a Brookfield viscometer at 30 rpm with spindle no. 2. A 200 mL sample was placed in a beaker, and measurements were taken after 30 seconds once the dial reading stabilized.

2.3.5 pH Measurement: pH was measured with a calibrated pH meter (Ohaus, USA). The device was calibrated with pH 4 and pH 7 buffer solutions. Then, 30 mL of each syrup sample was placed in a beaker, and the pH electrode was immersed for 5 minutes until the reading stabilized.

2.4 Sensory Properties

2.3.6 Hedonic Analysis :Hedonic testing was conducted according to the method described by [11]. A total of 15 mL of each syrup sample was placed into plastic cups and labeled with randomized three-digit codes. Samples were served undiluted and presented to 25 untrained panelists under controlled sensory evaluation conditions. Panelists assessed five sensory attributes (taste, color, viscosity, aftertaste, and overall acceptability), using a 4-point hedonic scale (1 = dislike, 2 = slightly like, 3 = like, 4 = very like). Responses were recorded using standardized evaluation forms.

2.3.7 Descriptive Sensory Profiles : Sensory profile was analyzed based on method of [11]. Trained panelists were selected based on their sensory acuity and ability to recognize and describe basic sensory attributes. A total of 5 trained panelists participated in the evaluation of four pectin-fucoidan functional syrup formulations containing sucrose, sorbitol, honey, and stevia. The samples were evaluated for eight attributes: sweetness, sourness/acidity, bitterness, honey-like flavor, aftertaste, color intensity, viscosity, and clarity. Each attribute was rated using a 0–10 intensity scale, with 0 indicating the lowest intensity and 10 indicating the highest intensity. The mean scores were calculated for each formulation and presented as a radar chart to illustrate the descriptive sensory profiles.

2.5 Data Analysis

Physicochemical data were analyzed using a completely randomized design (CRD) with three replications and expressed as mean ± standard deviation. Differences among formulations were evaluated using one-way analysis of variance (ANOVA), with statistical significance set at $p < 0.05$. Hedonic data from 25 untrained panelists were analyzed to compare the acceptance of the syrup formulations. Descriptive sensory profiling (DSP), conducted by five trained panelists, was summarized to characterize the sensory attributes of each formulation. All statistical analyses were performed using IBM SPSS Statistics.

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3. RESULTS AND DISCUSSION

3.1 Color Characteristics

The color differences (C* and h°) among the formulations are count and further illustrated by the CIELAB polar plot (Figure 2). The polar plot showed clear differences in chroma (C*) and hue angle (h°) among the sweetener treatments (Figure 1). Honey exhibited the highest chroma, indicating the most intense and saturated color, whereas sorbitol and stevia were positioned closest to the center of the plot, reflecting their relatively low color saturation. The hue angles of the formulations were within approximately 70-80°, indicating that all samples remained within the yellow hue region. Honey showed the highest hue angle, while stevia and sorbitol showed the lowest values.

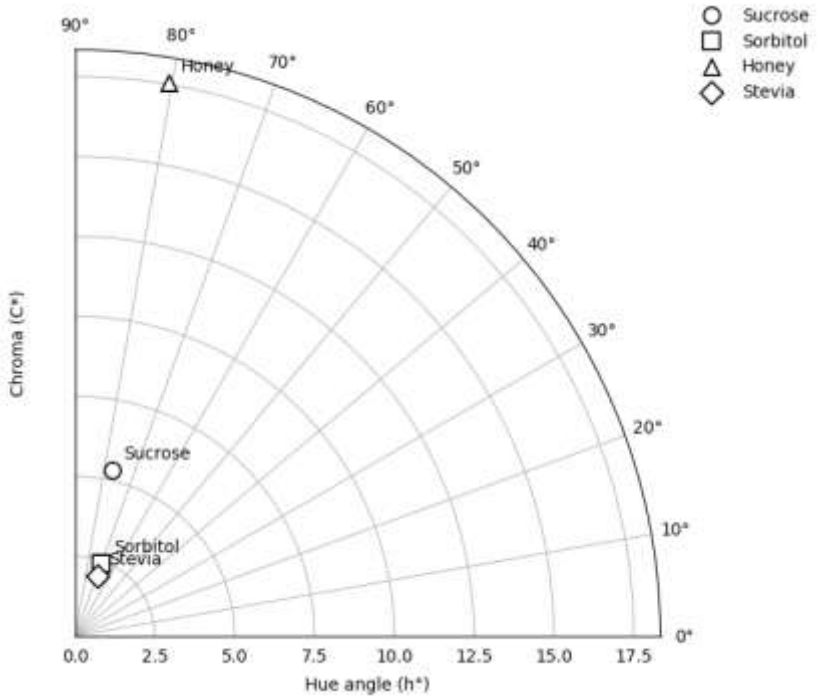


Figure 1. Polar plot chroma (C*) and hue angel (ho)

3.2 Density

Density values varied significantly among the formulations ($p < 0.05$) and demonstrated a trend consistent with the TDS results (Table 3). The highest density was observed in the sorbitol-based syrup, followed by sucrose and honey, while the lowest density was recorded in the stevia formulation. The parallel trend between density and TDS suggests a strong relationship between dissolved solids concentration and mass per unit volume within the system. These findings indicate that variations in sweetener type influence not only compositional attributes but also the physical compactness of the syrup matrix.

Table 2. Total Dissolved Solids (TDS), Density, and Viscosity of Fucoidan-Pectin Syrup

Parameters	Sweetener			
	Sucrose	**Sorbitol**	**Honey**	**Stevia**
TDS (°Brix)	21.64±0.08b	30.72±03a	17.08±0.10c	2.88±0.04d
Density (g/mL)	1.09±0.00b	112±0.00a	1.06±0.00c	1.01±0.00d
Viscocity (cP)	92.00±29b	96.00±2.50a	88.60±2.60b	56.80±2.28c

*Data are presented as mean ± standard deviation (n = 5). Different superscripts in the same column and row indicate significant differences ($p < 0.05$).

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3.3 Viscosity

Viscosity measurement results in Table 3 revealed significant differences across all treatments ($p < 0.05$), indicating that sweetener type strongly influences the flow behavior of the Fucoidan-Pectin syrup. The sorbitol-based formulation exhibited the highest viscosity, followed closely by sucrose and honey, while the stevia-based syrup showed a substantially lower viscosity. This gradient suggests that sweeteners differ in their ability to contribute to the system's structural consistency, with bulk sweeteners enhancing resistance to flow. In contrast, non-bulking sweeteners result in a thinner, less structured liquid. Overall, these results demonstrate that sweetener selection plays a critical role in determining the rheological characteristics of fucoidan-pectin-based syrups.

3.4 pH

The pH values of Fucoidan-Pectin syrups varied slightly but significantly across treatments (Figure 2). The honey-based formulation had the highest pH, indicating lower acidity than the other samples. In contrast, sorbitol, sucrose, and stevia formulations showed lower and relatively similar pH values, suggesting that these sweeteners exert minimal influence on the intrinsic acidity of the fucoidan-pectin system.

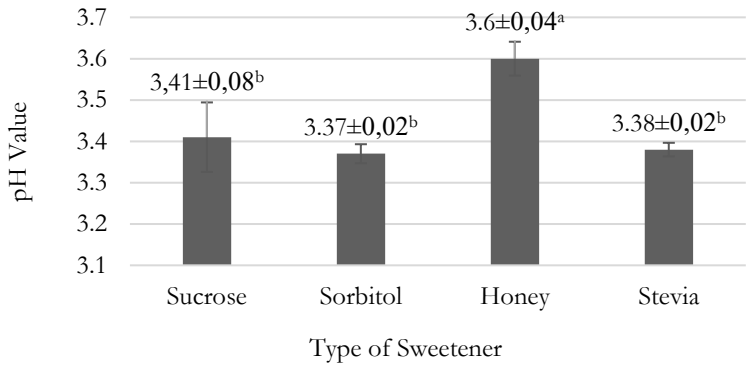


Figure 2. pH Value of of Fucoidan-Pectin Syrup

Although the differences were not extreme, this variation indicates that sweetener type can subtly influence the formulation's acid-base balance, which may have implications for product stability and shelf life.

3.5 Sensory (Hedonic) Properties

Hedonic evaluation showed that sweetener type significantly affected all sensory attributes of Fucoidan-Pectin syrup ($p < 0.05$), as indicated by distinct superscript groupings (Table 4). For taste, sorbitol achieved the highest score and differed significantly from honey, while sucrose and stevia occupied intermediate positions with overlapping groups. A similar pattern was observed in viscosity perception, where sorbitol was rated highest, honey lowest, and sucrose and stevia showed no significant difference. In terms of aftertaste, sorbitol again formed the highest group, honey the lowest, and sucrose and stevia remained in intermediate overlapping categories.

Table 4. Hedonic Test of Fucoidan-Pectin Syrup

Hedonic Atributes	Sweetener			
	Sucrose	Sorbitol	Honey	Stevia
Taste	2,80±1,02ab	3,20±0,57a	1,68±0,79c	2,52±0,94b
Color	2,76±0,76	2,84±0,78	2,20±1,06	2,80±0,94
Viscosity	2,92±0,80a	3,04±0,72a	2,40±0,75b	2,64±0,74ab
Aftertaste	2,88±0,82ab	3,08±0,69a	1,92±0,89c	2,56±0,90b
Over all	3,00±0,85ab	3,04±0,77a	1,72±0,78c	2,60±0,69b

*Data are presented as mean ± standard deviation (n = 25). Different superscripts in the same column and row indicate significant differences ($p < 0.05$).

For color, most treatments shared overlapping superscripts, indicating no strong sensory discrimination despite instrumental differences. In overall acceptability, sorbitol and sucrose were grouped in the highest category, stevia showed moderate acceptance, and honey was significantly lower than all other treatments. Overall, the DMRT patterns indicate that sorbitol provides the most consistently favorable sensory profile, followed by sucrose. At the same time, stevia remains moderately acceptable and honey exhibits the lowest sensory performance across attributes.

3.6 Descriptive sensory profiles

The sensory profiles of the pectin-fucoidan functional syrup varied according to the type of sweetener used (Figure 3). Overall, the formulations showed distinct sensory patterns across sweetness, sourness/acidity, bitterness, honey-like flavor, aftertaste, color intensity, viscosity, and clarity. The sucrose and sorbitol formulations exhibited relatively high sweetness, while the honey formulation was characterized by a more pronounced honey-like flavor and higher color intensity.

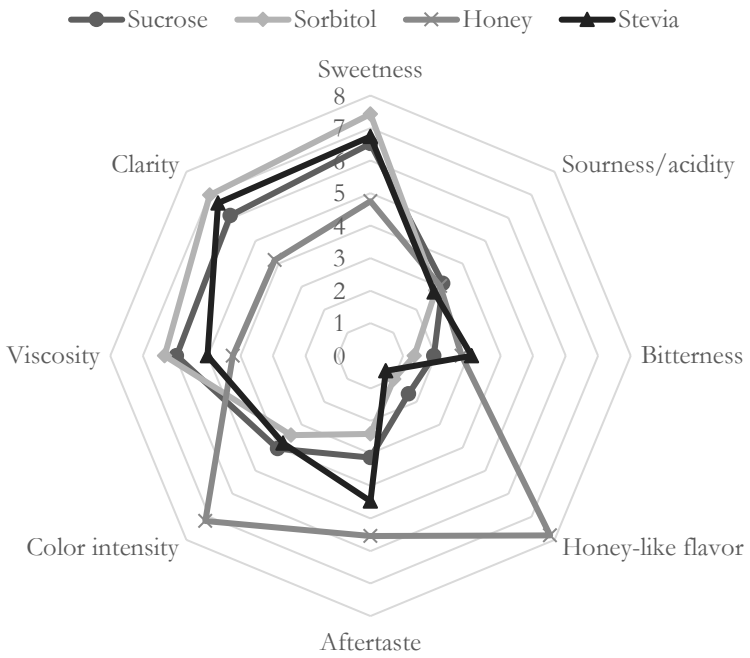


Figure 3. Descriptive sensory profiles of pectin-fucoidan functional syrup formulated with different sweeteners.

The honey formulation also showed a distinct sensory profile in terms of aftertaste and color intensity, whereas the sorbitol formulation exhibited relatively high clarity and viscosity. The stevia formulation showed a relatively pronounced sweetness accompanied by higher bitterness and aftertaste compared with the other formulations. These differences indicate that the type of sweetener influenced not only sweetness perception but also the overall sensory characteristics of the functional syrup.

3.7 Discussion

The results demonstrate that sweetener type substantially influenced the physicochemical and sensory characteristics of the pectin-fucoidan functional syrup. Although the formulations were prepared at equivalent sweetness levels, the different sweeteners contributed distinct amounts of dissolved solids and differed in their chemical composition and functional properties. Consequently, sweetener substitution affected not only sweetness perception but also the physical structure, optical properties, and sensory characteristics of the syrup matrix.

The total dissolved solids (TDS) showed significant differences among formulations, with sorbitol producing the highest value, followed by sucrose and honey, whereas stevia resulted in a markedly lower TDS. This difference can be explained by the amount of sweetener required to achieve equivalent sweetness. Sorbitol is a bulk sweetener that contributes substantially to the

dissolved solids of the formulation, whereas steviol glycosides are high-intensity sweeteners that provide sweetness at much lower concentrations [12]. The low TDS of the stevia formulation is therefore consistent with its substantially lower contribution to the bulk composition of the syrup. However, equivalent sweetness does not necessarily imply equivalent sweetener concentration or total dissolved solids, because sweeteners differ in sweetness potency and chemical composition. These differences were also reflected in density, with sorbitol producing the highest density and stevia the lowest. The parallel trends between TDS and density suggest that the amount of dissolved material contributed by the sweetener was an important determinant of the mass per unit volume of the syrup [13] . This is consistent with the different physicochemical roles of bulk and high-intensity sweeteners in food matrices. Viscosity followed a similar formulation-dependent pattern. Sorbitol produced the highest viscosity, whereas stevia resulted in the lowest viscosity, with sucrose and honey occupying intermediate positions. The higher viscosity of sorbitol can be associated with its relatively high contribution to dissolved solids and its role as a bulk sweetener [14]. In a hydrocolloid-based system containing pectin and fucoidan, the concentration of dissolved solids can influence the continuous phase and resistance to flow. Conversely, the very low concentration of steviol glycosides contributes little bulk material, resulting in a less viscous matrix. The intermediate TDS and viscosity observed in the honey formulation may be related to its composition, particularly its glucose and fructose content, which contributes to dissolved solids, as well as its intrinsic moisture content, which can dilute the syrup matrix. The relative proportions of these constituents and the amount of honey incorporated may therefore influence the resulting TDS and viscosity. In addition, honey contains minor constituents, including organic acids, minerals, and other soluble compounds, which may contribute to its physicochemical characteristics, although their individual effects cannot be established from the present data. The close relationship among TDS, density, and viscosity indicates that sweetener selection can modify the structural characteristics of the syrup even when sweetness is standardized across formulations [15].

Although all formulations contained the same citric acid and functional polysaccharide components, the significant differences in pH suggest that sweetener type influenced the acid-base equilibrium of the syrup. Honey is a complex matrix containing organic acids, minerals, amino acids, and other minor constituents, whose composition varies with botanical origin and processing conditions (Ringele et al., 2022) . These constituents may interact with citric acid and other formulation components, potentially contributing to the higher pH observed in the honey-based syrup [17]. However, this explanation remains tentative without further compositional analysis. In contrast, the relatively similar pH values of the sucrose, sorbitol, and stevia-based formulations indicate that replacing these sweeteners had a comparatively limited effect on the formulation's acid-base balance. Nevertheless, pH should be distinguished from titratable acidity and buffering capacity, as the latter describes a formulation's resistance to pH changes following acid or base addition [18]. Although the narrow pH range suggests that sweetener substitution did not fundamentally alter the acidic character of the syrup, pH may still influence the stability of acid-sensitive compounds, hydrocolloid behavior, and microbial growth potential [19]. Therefore, pH alone is insufficient to establish product safety or shelf stability, which should be confirmed through complementary acidity measurements and appropriate microbiological and storage studies.

The differences in chroma and hue angle suggest that sweetener type influenced not only the intensity of the syrup's color but also its tonal characteristics. The honey-based formulation exhibited the highest chroma, indicating a more saturated and visually pronounced color than the other formulations. This may be attributed to the natural pigments and other minor constituents present in honey, which can contribute to its characteristic coloration [20] . In contrast, the markedly lower chroma values of the sorbitol- and stevia-based formulations indicate less saturated colors, potentially reflecting the limited contribution of these sweeteners to color development. The sucrose-based formulation showed an intermediate chroma, suggesting a moderate degree of color saturation. Despite these differences in saturation, the hue angles of all formulations fell within a relatively narrow range of approximately 70-80°, corresponding to yellowish hues in the CIELAB color space [21]. The slightly higher hue angle of the honey-based syrup indicates a shift toward a more yellow-oriented tone, whereas the lower values for sorbitol and stevia suggest a comparatively different balance between the red-green and yellow-blue color components. Overall, these findings indicate that sweetener selection affected color intensity more markedly than the general hue direction, with honey producing the most distinctive color profile.

The hedonic evaluation suggests that sweetener selection influenced the acceptability of pectin-fucoidan functional syrup, reflecting differences in taste quality, mouthfeel, and aftertaste. The favorable acceptance of sorbitol may be associated with its ability to provide sweetness and contribute to the body of the syrup without introducing a pronounced characteristic flavor. As a polyol, sorbitol can contribute to the dissolved solids content and influence the perception of mouthfeel, potentially

supporting a more balanced sensory experience [22]. In contrast, the lower acceptance of the honey formulation may reflect its distinctive flavor and color, which could have altered the sensory profile of the syrup relative to the other formulations. Although honey contains diverse volatile compounds, organic acids, minerals, and other minor constituents that contribute to its characteristic sensory properties, the specific compounds responsible for the observed acceptance pattern cannot be established without further compositional analysis [23] . Stevia presents a different formulation challenge because sweetness intensity does not necessarily correspond to greater liking. Steviol glycosides can produce bitter, licorice-like, or lingering aftertaste sensations depending on their composition, concentration, and interactions with the food matrix, potentially affecting the perceived quality of the final product [24]. These findings highlight that sweetener selection should consider not only sweetness provision but also flavor compatibility, mouthfeel, and aftertaste.

The descriptive sensory profiles provide further insight into the hedonic differences among formulations by revealing how sweetener type shaped the intensity and balance of individual sensory attributes. Sorbitol exhibited relatively high sweetness, viscosity, and clarity, consistent with its favorable hedonic ratings for taste and viscosity. The concurrence of these attributes suggests that sorbitol may have provided a more balanced sensory experience, in which sweetness was accompanied by sufficient body and a visually clear appearance. Because viscosity contributes to perceived thickness and mouthfeel, its relatively high value may have enhanced the perception of fullness, potentially supporting consumer acceptance. Sucrose showed a comparatively balanced profile, with moderate sweetness, viscosity, and clarity and no strongly dominant flavor characteristic. This relatively even sensory profile suggests that sucrose provided a familiar reference for sweetness and mouthfeel without pronounced secondary flavor notes, although a balanced profile does not necessarily translate into the highest preference. In contrast, honey was distinguished by its pronounced honey-like flavor and high color intensity, consistent with its high chroma and low lightness observed instrumentally. These characteristics may reflect the contribution of honey-derived pigments and volatile compounds [17]. Although these attributes may contribute to product identity and sensory complexity, their intensity may also shift the overall flavor balance away from the expected profile of a conventional syrup, potentially influencing individual preferences. The stevia formulation exhibited relatively high sweetness alongside noticeable bitterness and aftertaste, a sensory pattern consistent with the known potential of steviol glycosides to produce lingering and bitter sensations [24] . Its lower instrumental viscosity and total dissolved solids may also have contributed to a lighter mouthfeel than that of the bulk-sweetener formulations [25]. This combination indicates that sweetness intensity alone may be insufficient to ensure acceptability; bitterness, lingering aftertaste, and limited body may collectively influence the perceived quality of the formulation. Taken together, the descriptive findings help explain the acceptance patterns observed in the hedonic evaluation: sorbitol's relatively balanced sweetness and mouthfeel coincided with the highest overall acceptance, whereas honey's distinctive flavor and color and stevia's potential taste-related limitations coincided with lower acceptance. However, these associations should not be interpreted as direct causal relationships, as multiple sensory attributes varied simultaneously.

Overall, the findings indicate that sweetener type acts as a key formulation variable affecting multiple quality attributes simultaneously. The results demonstrate a clear distinction between bulk sweeteners, particularly sorbitol and sucrose, and the high-intensity sweetener stevia, while honey provides additional flavor and color characteristics derived from its more complex composition. The agreement between physicochemical and sensory measurements is particularly evident for viscosity, color intensity, and sweetness-related characteristics. Among the tested formulations, sorbitol provided a relatively balanced combination of physicochemical properties and sensory acceptance, whereas honey generated a more distinctive color and flavor profile and stevia produced a lower-viscosity syrup with more noticeable bitterness and aftertaste. These findings emphasize that sweetener selection in pectin-fucoidan functional syrup should be considered as a multidimensional formulation decision rather than solely as a means of adjusting sweetness.

4. CONCLUSION

Sweetener type substantially influenced the physicochemical and sensory properties of pectin-fucoidan functional syrup, even when the formulations were prepared at equivalent sweetness levels. Sorbitol contributed the highest total dissolved solids, density, and viscosity and provided the most favorable overall sensory acceptance, indicating its potential to produce a syrup with desirable body and sensory balance. In contrast, stevia contributed limited dissolved solids and viscosity and exhibited a sensory profile characterized by more noticeable bitterness and aftertaste, suggesting the need for further formulation optimization. Honey produced the most distinctive color and honey-like flavor characteristics but showed the lowest hedonic acceptance, indicating that pronounced natural flavor and color do not necessarily translate into greater liking. Sucrose provided

an alternative with comparatively balanced physicochemical and sensory characteristics. Overall, sweetener selection should be considered a multidimensional formulation strategy rather than solely a means of adjusting sweetness. Further research should investigate sweetener concentration, sensory optimization, and storage stability to improve product quality and establish the suitability of the developed syrup for practical applications. In addition, the functional efficacy and health-related benefits of the pectin-fucoidan syrup require direct evaluation before specific physiological benefits can be claimed

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AUTHOR CONTRIBUTIONS

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Anang M. Legowo: Methodology, Supervision, Writing, Review & Editing.
Yoyok Budi Pramono: Supervision, Writing, Review & Editing.
Hega Bintang P. Putra: Investigation, Data Curation.
Siti Susanti: Conceptualization, Supervision, Project Administration, Writing, Review & Editing.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

ETHICS STATEMENT

Ethical approval was not required for this study.

DATA AVAILABILITY STATEMENT

All data supporting the findings of this study are presented within the manuscript.

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