ดัชนีบ่งชี้ความหวานของน้ำมะพร้าว

Indicators for Assessing the Sweetness of Coconut Water

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Abstract: Ensuring the desired sweetness of coconut water is crucial for consumer satisfaction. In this study, a total of 290 young aromatic coconuts were analyzed for soluble solids content (SSC), titratable acidity (TA), flesh thickness (FT), and sensory qualities. We also introduced the concept of BrimA, representing the difference between SSC and TA as an indicator of the flavor of coconut water. Our correlation analysis revealed that sweetness in coconut water was significantly correlated with BrimA (r=0.70) followed by SSC/TA (r = 0.54), TA (r = -0.51) and SSC (r = 0.41). Stepwise discriminant analysis (SDA) was performed to develop a model with optimally selected classifying variables. The overall classification accuracy of the SDA model for predicting sweetness was 70.78 %. Regarding BrimA and TA parameters as the greatest significant contributors of this coconut sweetness, the 'not sweet' samples were correctly predicted at 61%, while the 'sweet' samples were correctly predicted at 78 %.

Keywords: soluble solids content, titratable acidity, BrimA, quality index

บทคัดย่อ: รสหวานเป็นคุณสมบัติที่สำคัญสำหรับความพอใจของผู้บริโภคน้ำมะพร้าวน้ำหอม ในการศึกษานี้ผู้วิจัยได้นำมะพร้าวน้ำหอมจำนวน 290 ผล มาวิเคราะห์ปริมาณของแข็งที่ละลายน้ำได้ (SSC) ค่าปริมาณกรดที่สามารถไทเทรตได้ (TA) ความหนาของเนื้อ (FT) และคุณภาพทางประสาทสัมผัส และคำนวณค่า BrimA ซึ่งเป็นค่าที่แสดงความแตกต่างระหว่าง SSC และ TA เป็นตัวบ่งชี้ของรสหวานของน้ำมะพร้าว พบว่าความหวานในน้ำมะพร้าวมีความสัมพันธ์สูงสุดกับ BrimA (r=0.70) รองลงมาคือ SSC/TA (r = 0.54), TA (r = -0.51) และ SSC (r = 0.41) นอกจากนั้นเมื่อนำค่า SSC, TA และ FT ไปสร้างโมเดลทำนายด้วยวิธี stepwise discriminant

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analysis โมเดลที่ได้ สามารถทำนายความหวานได้แม่นยำ 70.78 % จากตัวแปรที่ใช้ทำนายในโมเดลนี้ ได้แก่ BrimA และ TA พบว่าสามารถทำนายน้ำมะพร้าวกลุ่มที่ไม่หวาน ถูกต้อง 61 % และทำนายกลุ่มหวาน ถูกต้อง 78 %

คำสำคัญ: ของแข็งที่ละลายน้ำได้, กรดที่สามารถไทเทรตได้, BrimA, ดัชนีคุณภาพ

Introduction

Young aromatic coconut (*Cocos nucifera* L.) is popular for its refreshing water and tender meat. In Thailand, an aromatic coconut variety known as 'Nam Hom' has become an important economic crop, with its young fruit ranking third among all fruit exported from Thailand in 2023. The main export markets for this coconut are China and USA, and the total export value increases greatly from 69 to 275 million USD from 2018–2022 (Office of the Permanent Secretary Ministry of Commerce, 2023).

For fresh young aromatic coconuts, ensuring the desirable taste of coconut water influences consumer satisfaction and purchasing decisions. Typically, soluble solids content (SSC) and the SSC/ titratable acidity (TA) ratio have been used as sweetness indices (Vásquez-Caicedo *et al*., 2005; Terdwongworakul *et al*., 2009; Tan *et al*., 2014; Nikhontha *et al*., 2019;). In addition, TA and flesh thickness (FT) have shown some degree of correlation with the sweetness of coconut water (Terdwongworakul *et al*., 2009). However, these parameters have not consistently demonstrated a strong correlation with sweetness in some fruits (Saftner *et al*., 2008; Schwieterman *et al*., 2014). As an alternative, an index called BrimA, which involves subtracting of TA from SSC, has been proposed (Jordan *et al*., 2001; Cheepsomsong *et al*. 2023). This index allows smaller amounts of acid than sugar to make the same numerical change to BrimA, but in the opposite direction. While the SS/TA ratio is widely used, the difficulties in correlating sensory preferences with chemical data are widely recognized (Jordan *et al*., 2001). Some researchers argue that BrimA better describes taste trends for fruits and juices such as pomegranates (Fawole and Opara, 2013a, b), oranges (Obenland *et al*., 2009) and citrus and grapes (Jordan *et al*., 2001). However, different fruits and varieties have significantly different acid and sugar compositions, requiring varied coefficient values of BrimA. Nevertheless, the best index of sweetness in coconut water has remained relatively unexplored. This study aimed 1) to develop the best index for determining sweetness in young aromatic coconut water and 2) to determine whether sweetness can be accurately predicted using SSC, TA and FT.

Materials and methods

1. Sample preparation

A total of 290 young aromatic coconut fruits were harvested in May 2023, approximately at 7 months after inflorescence opening, from a plantation in Damnoen Saduak district, Ratchaburi, Thailand. After harvesting, the samples were transported to the laboratory and analyzed for water quality and sensory within the same day.

2. Determination of physiological and sensory properties

Coconut water was discharged through the hole made in the soft eye, located

at the largest carpel at the stem end of the coconut shell Soluble solids content (SSC) of the coconut water was determined using a hand refractometer (N-3000E, Atago, Japan) and expressed in percentage.

Titratable acidity (TA, %) was determined following the method described in A.O.A.C. (1990) by titrating 2 mL of the coconut water CW with 0.01N NaOH using phenolphthalein as an indicator until pink color was perceptible for 30 s. TA was calculated using malic acid as an equivalent following:

$$TA\ (\%) = \frac{\text{Volume of NaOH (mL)} \times \text{Normality of NaOH} \times 0.067}{\text{Volume of the sample (mL)}}$$

Then, the coconut was halved along the equatorial plane and coconut flesh thickness (FT) was measured as the depth of the coconut flesh, using a depth probe on the vernier caliper to penetrate the coconut flesh until it reached the shell. The thickness was expressed in millimeters from an average of two positions: stem end, and stylar end.

BrimA was expressed as (SS - k × TA), where the constant value (k) reflects the tongue's higher sensitivity to TA compared to SSC (Jordan et al., 2001). The constant k in this study was determined as 35 with the integer best correlated with sweetness of the coconut water (r = 0.7014). In addition, using k factors of 35, 36, 37 or 38 provided similar values of R^2 as calculated from the linear regression of sweetness score versus BrimA (Figure 1).

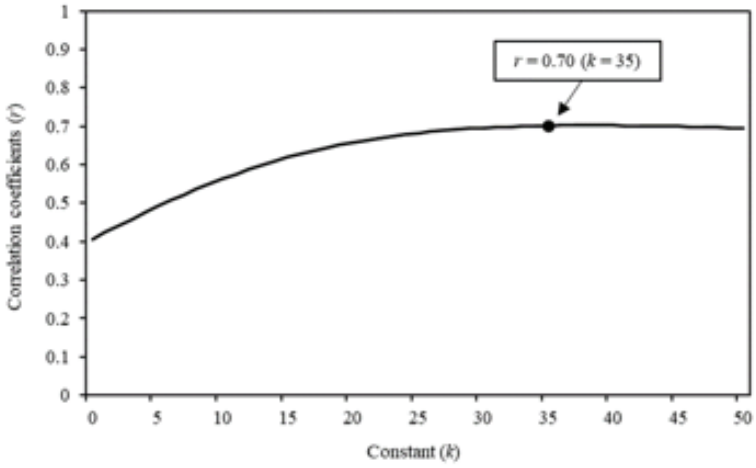

Figure 1 Correlation coefficients between BrimA and sweetness with different constant (k) values in the formula.

3. Sensory evaluation

Sensory evaluation of sweetness and sourness of the coconut water was performed by four trained panelists (three females and one male of 22–25 years old) with the methodology adapted from Assa *et al.* (2013). The panelists were trained prior to the experimental session, where they rated the intensity of each sensory attribute on a five-point scale. Sourness scores were determined based on a citric acid solution (v/v) where 4 = strongly sour or 0.5 % citric acid, 3 = moderately sour or 0.25 % citric acid, 2 = slightly sour or 0.1 % citric acid, and 1 = no sour or plain water. In addition, sweetness scores

were determined based on sucrose solution (w/v) where 4 = strongly sweet or 15 % sucrose, 3 = moderately sweet or 7.5 % sucrose, 2 = slightly sweet or 1 % sucrose, and 1 = no sweet or plain water. The panelists were directed to rinse their mouths after each sample tasting To preserve the flavor, right after the coconut water was extracted from the fruit, a sample of it was poured into a non-odorous bottle and evaluated immediately. Each sample consisted of three cups labeled with a randomized 3-digit code to ensure an unbiased assessment before being given to each panelist.

4. Statistical analysis

The experiment was conducted in a completely randomized design with a non-equal number of replications. Four levels (1-4) of sweetness were tested with 31, 94, 108, and 61 replications, respectively. Additionally, four levels (1-4) of sourness were tested with 80, 128, 64, and 22 replications, respectively. The data were analyzed for one-way variance using the ANOVA method, and pairwise comparisons of the means were conducted using Tukey's test with SPSS Statistics version 23 (SPSS Inc., Madrid, Spain). Stepwise discriminant analysis (SDA) and Pearson's correlation analysis were conducted to assess the significance of the relationship between the physiological and sensory properties using SPSS. A violin plot analysis was performed using R software (version 4.2.1).

The classification model of coconut water sweetness was analyzed using SSC, TA, SSC/TA, FT , and BrimA as independent variables and sweetness of the coconut water as the dependent variable. This analysis was performed using discriminant analysis (DA) with a stepwise method (IBM SPSS Statistics for Macintosh, version 28.0, IBM Corp., Armonk, NY). The sweetness of coconut water was ranked within the sweet and non-sweet groups from lowest to highest scores. The samples were then alternately divided into calibration and validation groups in a 3:1 ratio to ensure a similar distribution of sweetness in both groups. The calibration group data was used to generate the predictive model, which was then applied to the validation group data to test the model accuracy in classifying the sweetness groups of coconut water.

Results

1. The variation of coconut quality parameters

The SSC of the coconut water samples ranged from 5.4 to 9.2 %, with an average of 7.3 %, while the TA content ranged from 0.02 to 0.11 %, with an average of 0.04 %. FT was in 2.3–10.3 mm range, with the average of 7.3 %. Sensory evaluation revealed that there were variations in perceived sweetness and sourness among samples (Figure 2), possessing different SSC and TA among groups categorized according to sensory intensities. For sweetness, the SSC ranged from 5.4 to 8.0 % in the 'not sweet' group and from 6.0 to 9.2 % in the 'slightly sweet,' 'moderately sweet,' and 'very sweet' groups. For sourness, the titratable acidity (TA) values ranged from 0.016 to 0.106 % in the 'not sour' group, from 0.018 to 0.067 % in the 'slightly sour' group, from 0.022 to 0.07 % in the 'moderately sour' group, and from 0.022 to 0.098 % in the 'very sour' group.

However, the SSC and TA values did not appear to be strong indicators to distinguish sample groups of different sensory intensities. For the sweet taste, although the SSC of the

'not sweet' and 'slightly sweet' groups were significantly different, those of the 'moderately sweet' and 'very sweet' groups were not (Figure 2A). In contrast, the SSC/TA and BrimA were significantly different among all four groups of sweet taste (Figure 2B–C). For the sour taste, the TA, SSC/TA and BrimA of the 'not sour' and'slightly sour' groups were not significantly different, but those of the 'moderately sour' and the 'very sour 'groups were (Figure 2E–G). As for the flesh thickness, no significant difference was observed among 'slightly sweet', 'moderately sweet' and 'very sweet' groups, as well as among 'not sour', 'slightly sour' and 'moderately sour' groups (Figure 2D and 2H).

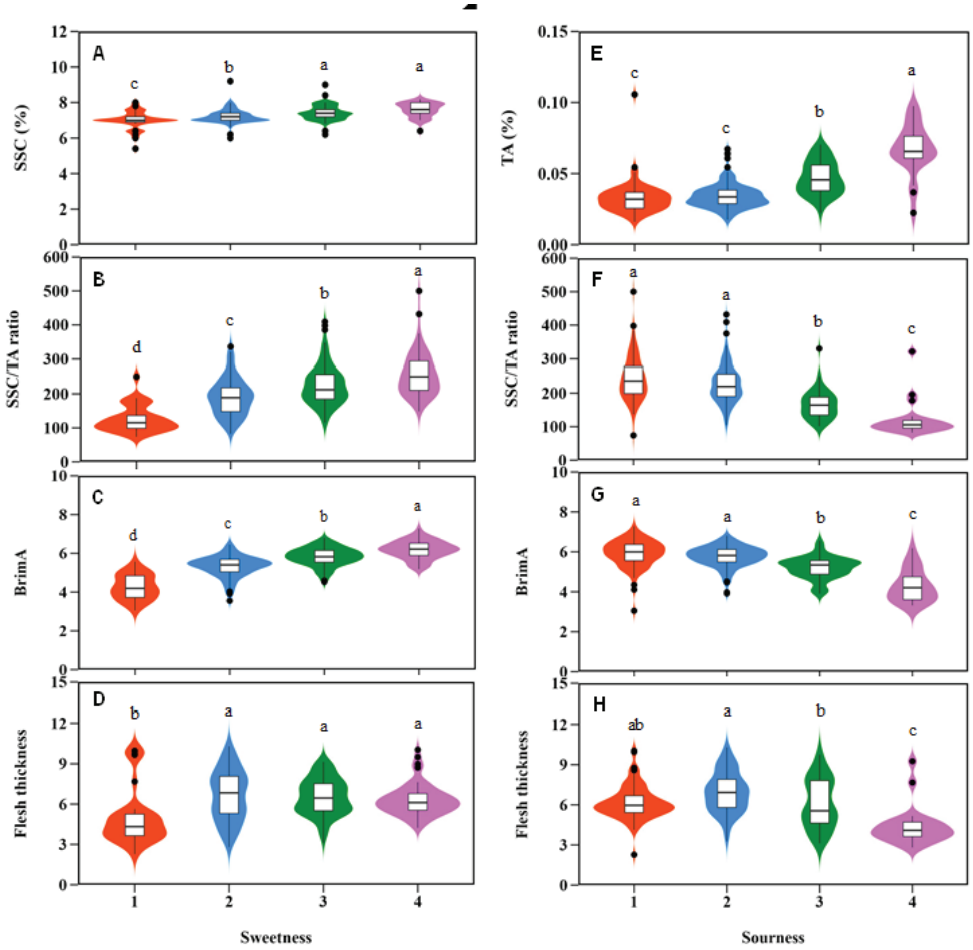

Figure 2 Summary of statistics for soluble solids contents (SSC), titratable acidity (TA), and SSC/TA ratio in coconut water, and coconut flesh thickness (FT) in relation to different intensities of perceived sweetness (A–D) and sourness (E–H). For both sweetness and sourness, four sensory intensities were categorized: 1 = 'not sweet' or 'not sour', 2 = 'slightly sweet' or slightly sour', 3 = 'moderately sweet' or 'moderately sour', and 4 = 'very sweet' or 'very sour'.

2. Relevance of each quality parameter to sensory quality

To develop the best index for assessing sweetness in coconut water, the correlation between relevant parameters and sweetness was investigated (Table 1). It was shown that sweetness exhibited a strong positive correlation with BrimA (r = 0.70) compared to SSC/TA (r = 0.54) or SSC (r = 0.41), while displaying a negative correlation with TA

(r = -0.51). Sourness, on the other hand, displayed a significant positive correlation with TA (r = 0.59). In addition, FT showed a significant negative correlation with SSC and TA with r = -0.44 and -0.60, respectively. This indicated that an increase in FT coincided with a decrease in both SSC and TA. However, the correlation between FT and sweetness, as well as sourness, were relatively weak (r = 0.12, and -0.20, respectively).

Table 1 Pearson correlation coefficients among quality parameters and sensory properties of coconut water of young aromatic coconut samples.

	SSC	TA	BrimA	SSC/TA	FT	Sweetness	Sourness
SSC	1						
TA	0.13	1					
BrimA	0.68	-0.63**	1				
SSC/TA	0.09	-0.88**	0.72**	1			
FT	-0.44	-0.60**	0.10**	0.42**	1		
Sweetness	0.41	-0.51**	0.70**	0.54**	0.12	1	
Sourness	-0.05	0.59**	-0.47**	-0.54**	-0.20	-0.58**	1

* Correlation is significant at the 0.05 level (2-tailed). ** Correlation is significant at the 0.01 level (2-tailed).

3. Classification of coconut water sweetness using discriminant analysis

To confirm the significance of BrimA in distinguishing coconut water sweetness levels, stepwise discriminant analysis (SDA) was conducted. SDA, a multivariate technique, develops discriminant functions from multiple variables to maximize differences between sweetness categories while minimizing variation within each category (Cruz-Castillo *et al*., 1994). For this study, SDA was conducted utilizing SSC, TA, SSC/TA, BrimA, and FT to create a model that categorizes coconut water into four distinct sweetness levels. The effectiveness of the model was assessed based on classification accuracy, defined as the percentage of correctly classified coconut water samples. The contributions of each independent variable to the classification were evaluated using their discriminant functions and assessed through standardized coefficients. From the preliminary results, the highest accuracy for classifying sweetness levels into four groups was 60%, with difficulty in differentiating fruit between groups 1 and 2 and between groups 3 and 4 was evident. Therefore, we reanalyzed the data, this time classifying the sweetness into two l evels: 'not sweet' (comprising the previous groups 1 and 2) and 'sweet' (comprising the previous groups 3 and 4).

From the new sweetness level separation model, for the calibration set, the overall accuracy for classifying sweetness levels into two groups was 79.2 %. For the ‘not sweet’ group, 67 % of the samples were correctly predicted and for the ‘sweet’ group, 88.2 % of the samples were correctly predicted (Table 2). The variable that contributed most to the classification was BrimA (standardized canonical discriminant function coefficient of 1.297), followed by TA (standardized canonical discriminant function coefficients of 0.436)

(Table 2 and data not shown). For the validation set, samples of the 'not sweet' group were correctly predicted at 61 %, and samples of the 'sweet' group were correctly predicted at 78 %, with an overall accuracy of 70.78 % (Table 3).

Table 2 Classification accuracy of the coconut water sweetness used to develop the canonical discriminant model.

(n=221)

	Actual group	Predicted group		Classification accuracy (%)	Significant variables
		Not sweet	Sweet		
Count	Not sweet	63	31	79.2	BrimA, TA
	Sweet	15	112		
%	Not sweet	67	33		
	Sweet	11.8	88.2		

Table 3 Classification accuracy when the discriminant model was applied to the validation data set of 73 coconut.

(n=221)

	Actual group	Predicted group		Classification accuracy (%)
		Not sweet	Sweet	
Count	Not sweet	19	12	70.78
	Sweet	9	33	
%	Not sweet	61	39	
	Sweet	21	78	

Discussion

Typically, soluble solids content (SSC) and flesh thickness (FT) are reported to be correlated with the flavor of coconut water (Jaroonchon et al., 2017). However, this correlation is usually established across different maturity stages, which may not serve as suitable indices for fruits at the same maturity but varied in quality (Jaroonchon *et al*., 2017). In our study, we assessed the quality of coconut water at the same maturity stage to identify the best flavor index parameter.

SSC exhibited a moderate correlation with sweetness in young aromatic coconut water. This can be explained by the composition of SSC in coconut water, which primarily includes sugars along with small amounts of organic acids, fat, protein, vitamins, and minerals (Jackson *et al*., 2004; Tan *et al*., 2014). Of these contents, organic acids have a higher capacity to dissociate and can elicit stronger sour taste responses (Da Conceicao Neta *et al*., 2007). Consequently, even a small amount of acid can significantly impact the sour taste.

In this study, BrimA showed a stronger correlation with the sweetness of coconut water, as indicated by a higher degree of correlation and a greater contribution to the

sweetness grouping analyzed by DA. The BrimA index (SSC – k × TA) is based on the principle that sugars and acids have contrasting effects on taste, and the tongue detects sugars and acids with different sensitivities. BrimA essentially combines these taste elements in a linear, additive manner, with the k coefficient accounting for the tongue's varying sensitivity to acid and SSC levels (Jordan *et al*., 2001).

Moreover, some reports suggest that BrimA is superior to the SSC/TA ratio in determining sweetness. However, the constant k may vary from 2 to 10, depending on the fruit species or cultivar due to their differences in acid and sugar ratios. For instance, values range from 2 for pomegranates (Fawole and Opara, 2013a, b) to 4 for oranges (Obenland *et al*., 2009) and 5 for citrus and grapes (Jordan *et al*., 2001). In this study, the constant k for coconut water was determined to be 35, which is significantly higher than previously reported for other fruits. This may be due to the lower acid content in aromatic coconut compared to other fruits, such as apple: 0.9–28.4% (Pissard *et al*., 2021), tangerine: 0.12–0.62% (Funsueb *et al*., 2023), and pitaya: 0.09–0.47% (da Silva Ferreira *et al*., 2023). However, to confirm this hypothesis, further studies on other low-acid fruits are required. In addition, this study was conducted as a single trial with 290 fruits. Therefore, further investigation using different production years is necessary to assess the effectiveness of the BrimA index for young aromatic coconuts.

Conclusion

The sensory test on young aromatic coconut water confirmed that sweetness was well correlated with BrimA, the combined index of SSC and TA. In addition, a sweetness discriminant model was presented with an overall classification accuracy of 70.78 %

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