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Development of TCS3200 Color Sensor Based on Arduino Uno and Its Application in Determining Borax Levels in Food

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Abstract

A color scanner application using the TCS3200 sensor, Arduino Uno microcomputer with IDE Software Program, a black box container, and a 12x2 matrix display has been designed, built, and tested. This sensor is employed to measure the level of borax in food items such as meatballs, tofu, and noodles in Banda Aceh. The obtained results are then compared with the measurement results of the Standard Ultraviolet-Visible Spectrophotometry (UV-Vis) method. Samples were prepared using centrifuge technique and the filtrate was collected. Subsequently, optical samples were prepared using dried filter paper with curcumin and scanned with the TCS3200 color sensor. Sample collection was carried out at Lamnyong Market, Lamdingin Market, Seutui Market, Suzuya Mall, and Ulee Kareng Market. Sample identification was performed using qualitative analysis, namely the flame test, and quantitative analysis using the TCS3200 color sensor based on Arduino Uno. The results of the quantitative analysis obtained from the TCS3200 color sensor compared with the ultraviolet-visible spectrophotometry (UV-Vis) method as the standard method indicate that the samples of meatballs, tofu, and noodles do not contain the harmful preservative borax. The positive control for borax using the TCS3200 color sensor is 56.8 ppm, while using the UV-Vis spectrophotometer it is 57.6 ppm. The t-test results from both methods show consistency between the TCS3200 color sensor measurement method and UV-Vis spectrophotometer.

Keywords: Borax, meatballs, tofu, flame test, TCS3200 color sensor

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Abstrak (Indonesian)

Telah dirancang, dibuat, dan diuji sebuah aplikasi pemindai warna meggunakan sensor TCS3200, mikrokomputer Arduino Uno dengan Software Program IDE, wadah kotak hitam serta display matrix 12x2. Sensor ini digunakan untuk mengukur kadar boraks dalam makanan di Banda Aceh berupa bakso, tahu, dan mie. Hasil yang diperoleh kemudian dibandingkan dengan pengukuran metode Standar Spektrofotometer Ultraviolet-Visible (UV-Vis). Sampel dipreparasi menggunakan teknik *sentrifuge* dan diambil filtrat, selanjutnya disiapkan sampel optis menggunakan kertas saring yang telah dikeringkan dengan kurkumin dan dipindai dengan sensor warna TCS3200. Teknik pengambilan sampel dilakukan di Pasar Lamyong, Pasar Lamdingin, Pasar Seutui, Suzuya Mall, dan Pasar Ulee Kareng. Sampel diidentifikasi menggunakan analisis kualitatif yaitu uji nyala api dan analisis kuantitatif yaitu sensor warna TCS3200 berbasis Arduino Uno. Hasil analisis kuantitatif yang diperoleh sensor warna TCS3200 dibandingkan dengan metode spektrofotometri ultraviolet visibel (UV-Vis) sebagai metode standar menunjukkan bahwa sampel bakso, tahu dan mie tidak mengandung bahan pengawet berbahaya yaitu boraks. Kontrol positif boraks menggunakan sensor warna TCS3200 adalah 56,8 ppm dan menggunakan spektrofotometer UV-Vis adalah 57,6 ppm. Hasil pengukuran uji *t* dari kedua metode ini menunjukkan bahwa terdapat keselarasan antara metode pengukuran sensor warna TCS3200 dengan spektrofotometri UV-Vis.

Kata Kunci: Boraks, bakso, tahu, uji nyala api, sensor warna TCS3200

INTRODUCTION

The addition of food additives can improve the quality and characteristics of food. Food additives are typically used in the manufacturing, processing, and storage of food. Some food additives have the potential to pose risks to human health, and these food additives are strictly prohibited by certain national regulations. Unfortunately, some sellers still add illegal food additives such as borax to increase their income [1].

Borax is a colorless, transparent crystal or white crystalline powder in solid form, easily soluble in water. Borax is widely used in the food industry as a preservative and additive to enhance taste and texture. However, borax is highly toxic, known as a carcinogen, and can cause cumulative damage to the stomach, kidneys, liver, lungs, and human brain [2,3]. There are various methods for detecting borax, including UV-Vis spectrophotometry [4], Fourier Transform Infrared (FT-IR) spectrophotometry [5], and X-Ray Diffraction (XRD) [5]. These methods entail relatively high costs and time consumption. Testing using spectrophotometry requires knowledge and skills, making it accessible only to specific individuals. Therefore, to assist the public in distinguishing and selecting safe food, there is a need to develop a cheaper, portable borax detection tool that can be used at high concentrations, namely through sensor methods [6].

A sensor is a device that detects something sample with a transducer that converts electrical energy into chemical quantities [7]. The sensor used is TCS3200 equipped with Arduino Uno. The TCS3200 color sensor is a converter programmed to change colors into frequencies, consisting of a configuration of silicon photodiodes and a current-to-frequency converter in a single monolithic CMOS IC. The TCS3200 sensor is capable of measuring the Red-Green-Blue (RGB) components of the surface of an illuminated object. The TCS3200 sensor illuminates or is illuminated by 2 white Light Emitting Diodes (LEDs), and the RGB light from the object's surface is converted into a frequency proportional to the RGB light reflected from the object's surface [8]. In this study, the sensor detects color degradation of tissue paper treated with a reagent, enhancing its sensitivity specifically for Borax analysis. The reagent used is curcumin, which can cause a color change from yellow to red due to the formation of the complex $[B(C_{21}H_{19}O_6)_2]Cl$ [9].

The color intensity contributed by the presence of borax is converted through the pin output of the sensor into a square signal whose frequency depends on its concentration. This varying frequency square signal is then processed using a microcontroller on the Arduino Uno. In this processing, four filters are utilized, namely green, blue, red, and no filter. The filter settings are adjusted by providing low and high logic in the Arduino IDE program, following the research reported. In this case, the no filter is not included because the three parameters are sufficient to represent the degradation of borax color in the sample [10].

MATERIALS AND METHODS

Materials

The materials used are UV-Vis spectrophotometer (Thermo Scientific), TCS 3200 (ICTAOS/AMS), and Arduino Uno (Wavgat). Food samples (meatballs, tofu, and noodles) were obtained from Lamyong Market, Lamdingin Market, Setui Market, Suzuya Mall, and Ulee Kareng Market in Banda Aceh. H_2SO_4 (E.merck), CH_3OH (E.merck), CH_3COOH (E.merck), C_2H_5OH (E.merck), NaOH (E.merck), curcumin (E.merck), and borax (E.merck) were also used.

Hardware Design

The hardware design begins with the development of a console for the TCS3200 color sensor, followed by connecting the color sensor's output port through jumper cables to the Arduino Uno microcomputer to process frequency data and convert it into 8-bit digital RGB data. There are 256 color digit variations for each RGB color component that can be sorted and distinguished through processing. These color digit variations are displayed on the computer screen and converted to reduce color variations. The color variations are also recorded in .xls (MS Excel) format (**Figure** 1).

Development of TCS3200 sensor console

The TCS3200 sensor console is designed in black to absorb all wavelength colors. The distance between the arrangement of diodes and the color object is 3 cm. The console is arranged in such a way that light from outside cannot enter. The TCS3200 sensor is positioned across the color sample, which is absorbed into the filter paper. Four units of white wavelength LEDs will illuminate the filter paper, and the intensity of light reflecting off the array of diodes will follow the color intensity of the sample.

Software design

The creation of software design begins with a trial of blinking on the Arduino Uno system to determine the response and performance of the microcomputer. The software used is the Arduino IDE with available open-source libraries - in the C programming language. The program library is modified to enable the required

color filter, Arduino Uno pin, required display format, and data storage mode (**Figure** 2).

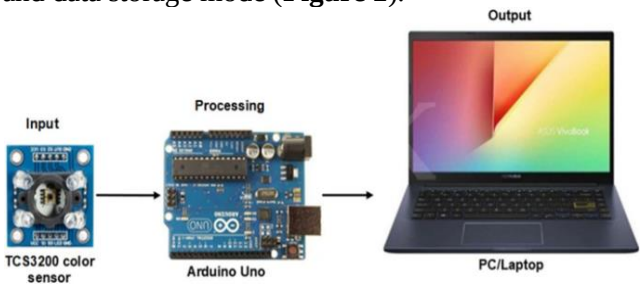

Figure 1. Schematic Diagram of Hardware Design

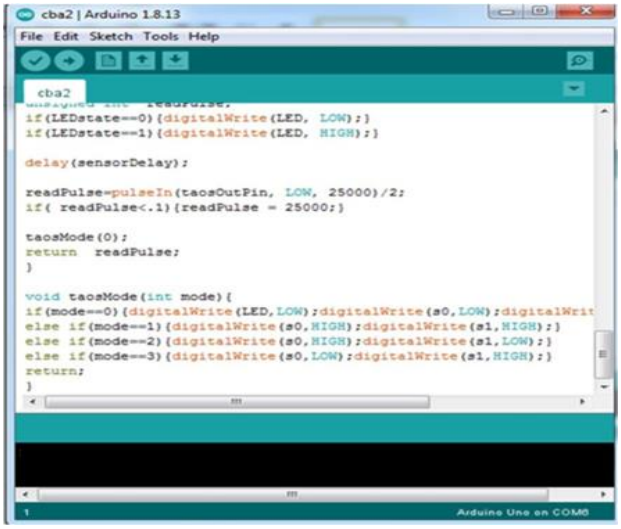

Figure 2. Display of the main menu of the Arduino IDE Software

Qualitative flame test

The meatball sample is weighed at 5 g and placed into a porcelain cup. Next, 10 drops of H_2SO_4 (sulfuric acid) are added, followed by the addition of 2 mL of C_2H_5OH (ethyl alcohol), and then ignited. If a green flame appears, it indicates the presence of boron compounds such as metal borate or ethyl borate [11].

Analysis of borax using TCS3200 color sensor calibration curve construction for borax

A stock solution of borax was prepared by weighing 50 mg of borax powder and adding it to 100 mL of H_2O, resulting in a concentration of 500 µg/mL. Subsequently, the stock solution was diluted to concentrations of 50, 100, 150, 200, 250, 300, 350, 400, 450, and 500 µg/mL for TCS3200; and 5, 10, 20, 30, 60, and 80 µg/mL for UV-Vis spectrophotometer by adding H_2O. Next, 0.5 mL of borax solution from each prepared concentration was placed in a porcelain dish and 0.5 mL of 10% NaOH solution was added. The mixture was heated on a water

Determination of borax levels using TCS3200 color sensor

The standard borax curve was obtained by measuring the RGB values of the standard borax solution using the TCS3200 sensor. The concentration of borax used ranged from 50 to 500 mg/L, which was previously reacted with a reagent. Samples of meatballs, tofu, and noodles weighing 5 g each were taken and mixed with 20 mL of water. They were then blended until smooth and filtered using filter paper. The filtrate was collected and dipped into filter paper that had been dried with a curcumin solution. Subsequently, each sample was analyzed for borax content using the TCS3200 color sensor [9]. Measurements were conducted three times, and the concentrations were averaged. Afterward, the RGB values were converted into color indices, namely Hue, Intensity, and Saturation (HIS), using the following equation.

$$\text{Red } (I_R) = \frac{R}{R+G+B} \quad (1)$$

$$\text{Green } (I_G) = \frac{G}{R+G+B} \quad (2)$$

$$\text{Blue } (I_B) = \frac{B}{R+G+B} \quad (3)$$

The HIS color model is designed to resemble human vision perception, while the RGB values resemble the image of the display system [10]. The calculated HIS values are then plotted as the dependent variable (y-axis) against variations in borax concentration (x-axis).

The determination of borax levels using UV-Vis spectrophotometer

0.5 mL of borax isolated from the meatball sample was pipetted and then added to 0.5 mL of 10% NaOH solution. The mixture was heated on a water bath until it dried. The heating process continued in an oven at a temperature of 1000 ± 5℃ for 5 minutes. Subsequently, 1.5 mL of 0.125% curcumin solution was added and heated while stirring for approximately 3 minutes. After cooling, 1.5 mL of H_2SO_4 and CH_3COOH (1:1) were added while stirring until there was no yellow color observed either in the crucible or on the stirrer. The mixture was left to stand for ± 8 minutes. A small amount of C_2H_5OH was then added, followed by filtration using filter paper. The filtrate was collected and observed for absorbance at the λmax using a UV-Vis spectrophotometer [12].

Validation of the TCS3200 color sensor and UV-Vis Spectrophotometer method

The validation methods include accuracy, precision, sensitivity, and linearity, which are

performed based on recommendations from the previous report [10].

Comparison of methods using two-way t-test

The results of the samples between the TCS3200 color sensor and the UV-Vis spectrophotometry method were compared [10]. Furthermore, a two-way t-test was conducted to observe the significance between the newly studied TCS3200 color sensor method and the reference method using UV-Vis spectroscopy by calculating the t-values for each method and subsequently comparing them with the theoretical t-value.

RESULTS AND DISCUSSION

Qualitative analysis

The qualitative analysis of borax in samples was conducted using the flame test method on each sample of meatballs, tofu, and noodles taken from various areas in Banda Aceh, such as Lamyong Market, Lamdingin Market, Setui Market, Suzuya Mall, and Ulee Kareng Market. This qualitative analysis was carried out to identify whether the meatball, tofu and noodle samples contained borax or not by changing the green color which was marked as positive for borax [16]. The qualitative analysis measurements were performed with three repetitions to assess the accuracy of the obtained data. The flame test was conducted by weighing each sample at 5 g, then grinding each sample and adding 10 drops of concentrated H_2SO_4 and 2 mL of C_2H_5OH before ignition, and observing the results. The test results for each sample of meatballs, tofu, and noodles obtained from various areas in Banda Aceh can be seen in **Table** 1 and the flame test can be seen in **Figure** 3

Table 1. Flame Test

No	Sample	Flame test	Result		
			I	II	III
1	Positive control	Green flame	+	+	+
2	Meatball Lamdingin market	Bright Reddish Yellow	-	-	-
3	Meatball Setui market Suzuya	Bright Reddish Yellow	-	-	-
4	Meatball Suzuya	Bright Reddish Yellow	-	-	-
5	Tofu Lamnyong market	Bright Reddish Yellow	-	-	-
6	Tofu Lamdingin market	Bright Reddish Yellow	-	-	-
7	Tofu Setui maret	Bright Reddish Yellow	-	-	-
8	Tofu Ule Kareng market	Bright Reddish Yellow	-	-	-
9	Noodle Lamnyong market	Bright Reddish Yellow	-	-	-
10	Noodle Lamdingin market	Bright Reddish Yellow	-	-	-
11	Noodle Setui market	Bright Reddish Yellow	-	-	-
12	Noodle Ule Kareng market	Bright Reddish Yellow	-	-	-

Description: (+) contains borax, (-) does not contain borax

Figure 3. Results of the qualitative flame test. (A) positive control, (B) meatball sample, (C) tofu sample, (D) wet noodle sample

Quantative Analysis

Color Sensor

Figure 3. Results of the qualitative flame test. (A) positive control, (B) meatball sample, (C) tofu sample, (D) wet noodle sample. The determination of the standard borax curve is done by creating a series of standard solutions, namely 50, 100, 150, 200, 250, 300, 350, 400, 450, and 500 ppm. Subsequently, the RGB values are measured in each of these standard solutions using the TCS3200 color sensor. The standard borax curve for each R, G, and B value can be seen in **Figure** 4.

The standard curve for the Red (R) curve has a regression equation and an R-squared value of y =

0.0005x + 0.462, R^2 = 0.9698. For Green (G), the equation is y = -0.0003x + 0.3007, R^2 = 0.7867, and for Blue (B), it is y = -0.0002x + 0.2373, R^2 = 0.7085. Measurements are considered good when the R-squared value is greater than 80% ($R^2 \geq 0.80$) [14]. Therefore, the standard Red curve can be used to determine borax concentration as it has an R-squared value of ≥ 0.80 compared to the standard Green (G) and Blue (B) curves.

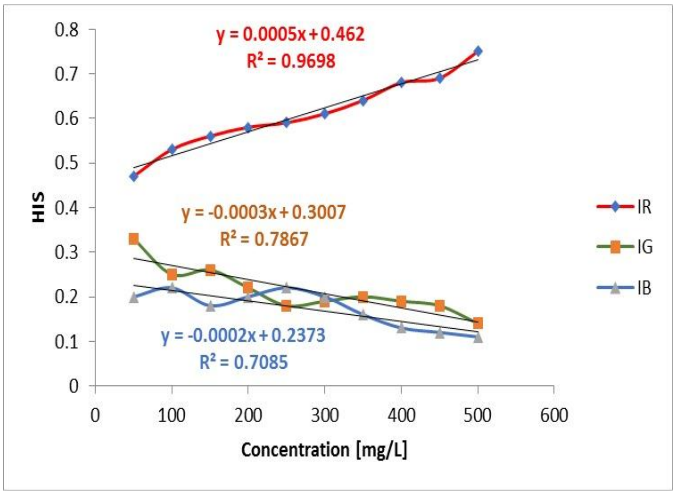

Figure 4. Borax RGB Standard Curve

The determination of borax levels using the TCS3200 color sensor

Quantitative analysis of borax in the samples was carried out using the color sensor test method TCS3200 based on Arduino Uno. Samples of meatballs, tofu, and noodles were collected from Lamyong Market, Lamdingin Market, Setui Market, Suzuya Mall, and Ulee Kareng Market, with three repetitions to assess the accuracy of the obtained data. The sensor test involved weighing each sample at 5 grams, adding 20 mL of distilled water to each sample, and grinding it until smooth. Subsequently, each sample was filtered, and the filtrate was collected. The obtained filtrate from each sample was immersed in filter paper soaked in curcumin solution. If the filter paper changed color to brick red or brownish-red, then the sample was considered positive for containing borax [12,17] . The TCS 3200 color sensor test results can be seen in **Table** 2 and **Figure** 5.

Based on **Table** 2, it can be seen that the RGB values obtained from each sample represent a code to indicate a specific color. The obtained RGB values will then be converted into a color index, namely Hue, Intensity, and Saturation (HIS), or more commonly known as the Lab color model. The HIS color model is designed to resemble human vision perception, while RGB values resemble the perception of the display system [12]. The HIS values obtained will have a similar function to the absorbance values in UV-Vis spectrophotometry. Samples of meatballs, noodles, and tofu with yellow colors do not contain borax, while the positive control with a brick-red (reddish-brown) color with RGB values contains 56.8 mg/L of borax. In a previous study Iwanto [9] stated, when borax was added to meatball and tofu samples at concentrations of 10, 20, 30, 40, 50, 60, 70, 80, 90, and 100%, positive values were obtained, indicating the presence of borax [9]. This means that the TCS3200 color sensor can be used to detect borax. The results obtained with the TCS3200 color sensor will be compared with UV-Vis spectrophotometry to determine if this method yields similar results.

Table 2. Quantitative test of TCS3200 color sensor

Sample	Average RGB value			Result
	R	G	B	
A	87	43	48	Red brick
B	98	82	43	Yellow
C	98	82	23	Yellow
D	99	81	31	Yellow
E	99	78	35	Yellow
F	99	86	31	Yellow
G	97	88	43	Yellow
H	99	93	25	Yellow
I	99	85	42	Yellow
J	98	83	21	Yellow
K	99	83	43	Yellow
L	99	83	34	Yellow

Description:
(A) Positive control, (B) Lamdingin Market meatballs, (C) Seutui Market meatballs, (D) Suzuya Mall meatballs, (E) Lamyong Market tofu, (F) Lamdingin Market tofu, (G) Setui Market tofu, (H) Ule Kareng Market tofu, (I) Lamnyong Market fresh noodles, (J) Lamdingin Market fresh noodles, (K) Setui Market fresh noodles, (L) Ule Kareng Market fresh noodles

A **B** **C** **D**

Description: Brick red (borax positive), yellow (borax negative)

Figure 5. The Results of Quantitative Testing: (A) Positive Control, (B) Meatball Sample, (C) Tofu Sample, (D) Wet Noodle Sample.

Determination of the Maximum Wavelength of Borax

The absorbance values observed at wavelengths between 400 and 600 nm on the UV-Vis spectrophotometer. The wavelength curve in **Figure** 6 indicates that the maximum wavelength is at 550 nm. The measurement results for the maximum wavelength of borax were chosen based on the highest absorbance value.

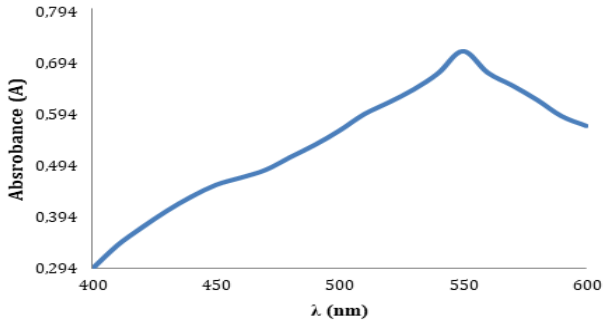

Figure 6. Maximum Wavelength

Standard curve of borax with UV-vis spectrophotometer

The determination of the borax standard curve is carried out by creating a series of standard solutions, namely 5, 10, 20, 30, 60, and 80 ppm. Subsequently, their absorbance is measured at the maximum wavelength of 550 nm. The standard borax curve can be seen in **Figure** 7, and the regression equation for the curve is y = 0.0272x + 0.1686 with an R^2 value of 0.9979.

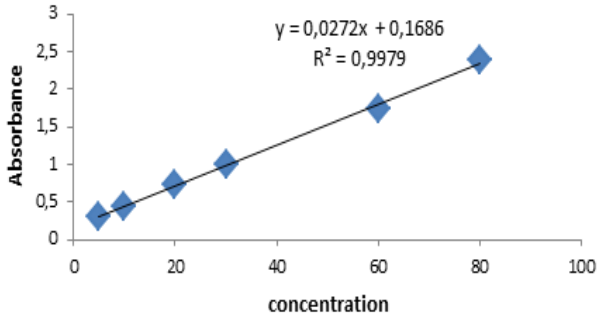

Figure 7. Borax Standard Curve

The determination of borax levels using UV-Vis spectrophotometer

The prepared sample was measured for absorbance five times with UV-Vis at a wavelength of 550 nm. The calculation to determine the borax content in the sample was performed by substituting the absorbance values of the sample into the regression equation on the standard curve and the concentration value of the positive control food sample was 57.6 mg/L can be seen in **Table** 3.

Table 3. Precision values of TCS3200 and UV-Vis

Sample	Absorbance					Average	Concentration (ppm)
	1	2	3	4	5		
Positive control	1.726	1.726	1.729	1.745	1.750	1.7352	57.6

Method validation accuracy

The determination of accuracy is based on the recovery values, indicating the proximity of the solution values to the actual concentrations. In the calculations, borax concentration data with the TCS3200 color sensor are used: 300, 350, and 450 ppm, while for UV-Vis, the concentrations are 5, 30, and 80 ppm. Based on the calculation results, the percentage recovery values for the TCS3200 color sensor and UV-Vis can be seen in **Table** 4.

Table 4. Accuracy values of TCS3200 and UV-Vis

TCS3200		UV-Vis	
µ (ppm)	%Recovery (%)	µ (ppm)	%Recovery (R)
300	98.67	5	99.8
350	101.71	30	102
450	101.33	80	102

Harvey [15] the accuracy value of a method in the range of 90% to 107% shows that the method has good accuracy. Based on **Table** 4, the percentage accuracy calculation still shows an allowable error range of 90% to 107% [15]. Therefore, it can be concluded that both methods used have high accuracy.

Precision

The precision calculation of data on the TCS3200 color sensor is obtained from the calculation results of the standard curve with borax concentrations of 300, 350, and 450 ppm, while for UV-Vis, the concentrations are 5, 30, and 80 ppm. Based on the calculation results, the coefficient of variation values for the TCS3200 color sensor and UV-Vis can be seen in **Table** 5.

Table 5. Precision values of TCS3200 and UV-Vis

TCS3200		UV-Vis	
µ (ppm)	Coefficient of variation (KV) (%)	µ (ppm)	Coefficient of variation (KV) (%)
300	0	5	0.04
350	0	30	0.0053
450	0	80	10.0089

Based on **Table** 5, the precision calculation has a value below 2%. A method is considered accurate if it has a coefficient of variation less than 2% [15]. Therefore, it can be concluded that both methods used have good precision

Linearity

The linearity value is obtained from the R^2 value of the standard curve linear regression equation. Based on calculations from the standard curve data, the

linearity value for the TCS3200 color sensor (R^2) is 0.9698, with the regression equation y = 0.0005x + 0.462, and for UV-Vis, where the R^2 is 0.9979, with the regression equation y = 0.0272x + 0.1686.

Sensitivity

Sensitivity is the ability of a sensor to detect the smallest amount that can differentiate a specific analyte from other compounds present in the sample. The sensitivity value is indicated by the slope of the standard curve. Based on the linear regression equation of the standard curve, the TCS3200 color sensor obtained a slope value of 0.0005 ppm with the regression equation y = 0.0005x + 0.462, and the UV-Vis sensor obtained a slope of 0.0272 ppm with the regression equation y = 0.0272x + 0.1686.

Linearity

The linearity value is obtained from the R^2 value of the standard curve linear regression equation. Based on calculations from the standard curve data, the linearity value for the TCS3200 color sensor (R^2) is 0.9698, with the regression equation y = 0.0005x + 0.462, and for UV-Vis, Where the R^2 is 0.9979, with the regression equation y = 0.0272x + 0.1686.

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Comparison of methods using Two-Way T-Test

As for the comparison between the concentration values of the samples using the TCS3200 colour sensor and UV-Vis, it can be seen in **Table** 6.

Table 6. Comparison of TCS3200 and UV-Vis Spectrophotometer Measurements $t(n_1+n_2-2; \alpha) = 8.95\%$

Sample	TCS3200 Concentration (ppm)	UV-Vis Concentration (ppm)	t-statistics	t-table (8.95 %)
Positive control	56.8	57.6	0.66	2.31

Based on the results of measurements from two instruments, it can be seen that the difference in the levels of borax obtained using both instruments is not too significant, with a measurement difference of 0.8 ppm. Based on the two-way t-test calculation above, with a 95% confidence interval and 8 degrees of freedom (df), the critical t-table is 2.31, and the t-is 0.66, which is less than t-tabel (0.66 < 2.31). The two-way t-test is conducted to determine whether there is a significant difference in the means of each data set by comparing the averages [18,19,20]. The conclusion from the t-test calculation is that the TCS3200 colour sensor measurement method is as effective as the UV-Vis Spectrophotometer measurement method.

CONCLUSION

Based on the research results obtained, it can be concluded that the qualitative and quantitative tests on samples of meatballs, tofu, and noodles taken from several markets in Banda Aceh do not contain borax. The positive control measurement using the TCS3200 color sensor is 56.8 mg/L, and the positive control measurement using UV-Vis Spectrophotometer is 57.6 mg/L. The t-test results indicate no significant difference between the measurement method using the TCS3200 color sensor and UV-Vis Spectrophotometry.

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