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Research Article

COLOR MEASUREMENT CAPABILITY OF SMARTPHONES: ANALYSIS OF CHOCOLATE COLOR

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Abstract Color measurement of foods can be made with many techniques, both sensory and instrumental. With the developing technology, fast and low-cost innovative techniques are getting more attention. In this study, color analysis made through smart phone application compared with the colorimetric method. In this context, the color differences of chocolates with various cocoa solids ratios were calculated. Taking advantage of the accessibility and user friendliness of smartphones, images were taken from the sample surface in a regular illuminated home/office environment. Photos taken from the phone gallery were measured with the Color Grab (Loomatix) application. Correlations of L*a*b* color values obtained in CIE Lab space system were calculated. These values were also used to calculate the Total Color Difference (ΔE) and Whiteness Index (WI). As a result, it has been observed that the color of chocolate, which is considered as a food sample in the study, can be measured with a smart phone application, which is a faster and less costly method. It is predicted that smart phone application can be used as a very practical tool in the measurement of food quality due to its updateability, ability to storage and shareability of measurement information on smartphones.

Keywords: Food quality, Smartphone, Chocolate, Color analysis, Consumer

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Introduction

Color is a perceptual phenomenon that depends on the observer and the conditions under which the color is observed. This phenomenon depends on the properties of light, which can be measured in terms of intensity and wavelength. The concept of color emerges when light reaches the retina of the human eye at different wavelengths. The perception of color by the eye varies due to the light striking objects and partially reflecting them. This situation is defined as hue or color. The color of matter becomes visible only when light from a bright object or source illuminates or hits the surface (1).

The color of food is a key indicator of its quality, influencing how we assess freshness, ripeness, and safety. Bright, vibrant colors often signal freshness, on the other hand dull or faded colors or changes in color may create negative perception. Briefly, color is one of the most important sensory aspects of food products. As well as indicating its likely freshness and flavour, it can also influence consumer choice and enjoyment of a product. Thus, measurement of the color of food products play a crucial in role for food quality and safety.

Color determination can be done by visual inspection or by using color measuring devices (colorimeters). Despite the differences in lighting, human control is quite successful, but in this case, color determination is subjective since it varies from observer to observer. Color standards are used as reference materials to make a more objective color analysis. Their use in this way is slow and requires special training of observers. For this reason, the use of colorimeters has become widespread (2). Thus, more accurate, effective and repeatable analyzes have become possible (3). These tools are essential for applications requiring consistent and precise color analysis. However, for casual users, small businesses, or non-critical tasks, a cost-effective and accessible alternative must be offered.

Smartphones, with their sophisticated cameras and processing power, are emerging as a viable option for basic color measurement. With the help of specialized apps and accessories, smartphones can approximate color analysis for non-critical tasks.

Currently, smartphones function as portable microcomputers, capable of performing complex tasks while remaining lightweight, mobile, and suitable for real-time monitoring. According to statistics, there are currently over 7.2 billion smartphones worldwide and it is estimated to exceed 8 billion in 2029. This high penetration rate, coupled with a vast user base, makes smartphones increasingly accessible tools.

Equipped with advanced technical features—such as high-speed processors, digital cameras, batteries, high-resolution displays, and intuitive user interfaces—smartphones are well-suited for various types of measurements. Wireless data transfer technologies, including Wi-Fi, Bluetooth, and cellular services, enable real-time viewing of results and seamless data sharing. Recent studies have demonstrated that smartphones, when integrated with appropriate accessories, can serve as portable laboratory tools for applications like food analysis (4-12).

Moreover, verification and quality assessment of food products can be made from photographs obtained via smartphones (13). In our group, smartphones had been previously used for colorimetric paper-based sensors (14), and their capability of being low-cost spectrophotometer alternative were investigated (15). Smartphones worked great for measuring color of solutions or paper zones.

The aim of this study is to determine whether food color analysis via a smartphone application is an alternative to conventional methods.

Within the scope of the study, the measurability of color, which is a quality and/or safety criterion for food products, was examined with a smartphone. In this context, the color of chocolate samples containing different cocoa solids was measured with a smartphone. The results obtained with smartphone were compared with the results of the colorimeter, and their performance was evaluated.

Material and methods

Material

Chocolate samples produced under 10 different brand names were purchased from a local market in Ankara and stored at room temperature. In total, 36 chocolate samples, weighing between 60-80 grams, were studied and the samples were coded and grouped according to the brand. The complete list of chocolate products and their cocoa mass content were given in Table 1. The cocoa mass content values in Table 1 refer to the amount of cocoa mass declared on the label by the manufacturer.

Color measurement

Portable Colorimeter: Color analysis of chocolate samples was performed with a colorimeter (Model CR400, Konica Minolta, Japan). For each sample, color measured from 5 different points and every measurement was performed twice. Color values of the samples were recorded in CIE Lab color system.

Smartphone: Color measurement via smartphone was made using the Color Grab (Loomatix © 2021 Version 3.9.2) application, which can run on the Android operating system and is accessible from the application store. A Samsung SM-A51 5F model smartphone was used to capture images. The sample images were taken under stabilized camera features according to the variables in Table 2.

Image acquisition and capture

The photographing procedure was carried out between 12:00 and 15:00 in a closed environment with variable daylight to meet the conditions of being simple, versatile and low cost. The samples were placed on a certain brand-model A4 paper to ensure that the background color was standard and sustainable. To prevent color differences that different light angles could create in the samples, measurements were carried out by positioning the samples differently on the A4 paper. The results were obtained by taking the average of these measurements. Photographs were taken from a distance of 30-50 cm, in 4 different positions, and images were obtained in 4 different positions for each sample (Figure 1). For color analysis, L*, a* and b* values were obtained via Color Grab application in the CIE Lab system by browsing from the phone's photo gallery and taking measurements from 5 different points of the chocolate sample image.

Color value calculations

Total color difference (ΔE): The total color difference is the linear distance in color space between the two set of co-ordinates and defined by the Equation 1. Total color difference value of the samples was calculated by the taking the A4 paper as our reference point. In equation 1, L_0*, a_0* and b_0* values refer to the average L*, a* and b* values of A4 paper under each sample.

$$\Delta E = \sqrt{(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2} \quad (1)$$

$$\Delta L = L^*_1 - L_0^*$$

$$\Delta a = a^*_1 - a_0^*$$

$$\Delta b = b^*_1 - b_0^*$$

Whiteness index (WI): WI is the condition in which the color of an object appears different depending on the light source. Although substances appear to be the same color when viewed under the same light source, they may appear to be different colors from each other under different light sources. In addition to the CIE L*a*b* system provided by the colorimeter; it can be used to define the character of color quality (chocolate surface color). It is an important quality measurement parameter for measuring the color of chocolate, which changes depending on the change in temperature conditions or inappropriate storage conditions after the cooling phase of the chocolate. It is calculated using Equation 2 (16-17).

$$WI = 100 - \sqrt{((100-L)^2 + a^2 + b^2)} \quad (2)$$

Results and Discussion

Comparison of measured color values

The L*, a*, b* data measured with the colorimeter are given in Table 3. Among the same group of chocolate samples, the lowest L* values were observed in the chocolate samples coded U6, N5, E4, T2, V2, M2, B5, O3, P2 and G1; the highest L* values were observed in the white chocolate samples coded U1, N1, M1, B1 and O1. L* is the brightness-lightness component and its values vary between 0-100.

"0" gives information about darkness and "100" about lightness. Within the scope of the obtained data, it was observed that the L* values of the chocolate samples specified as "bitter chocolate" and with a cocoa dry matter ratio higher than 35% were at lower values (close to 0). It was observed that the L* values of the chocolate samples specified as "white chocolate" in the label information, and which did not contain a cocoa mass were at higher values (close to 100). The average color ranges of all measured samples were measured between 23.35 and 83.72 for L* values.

In the CIE Lab system, the a* value is the component that shows the color change from green (-a) to red (+a) and varies between (-120) and (+120). According to the obtained data, no similarity was observed among the a* values of the samples. It was observed that the average color values of the a* values of all measured samples were between -5.09 and 10.30.

In the CIE Lab system, the b* value is the component that shows the color change from blue (-b) to yellow (+b) and varies between (-120) and (+120). When the b* values were compared according to the obtained data, it was seen that all of them consisted of positive values, showed a similarity to the L* values and were inversely proportional to the cocoa mass content as expected. The average color values of the b* values of all measured samples were measured between 1.91 and 27.82.

These results show that L* values have a wider distribution, and the chocolate sample colors are generally in reddish-yellow color tones. In the white chocolate sample samples (U1, N1, M1, B1 and O1), the a* values are negative and the b* values are positive, and the b* values are measured higher than the other sample values. These results confirm that the white chocolate samples have greenish-yellow color tones (the change of the a* color parameter from negative to positive indicates that the color changes from green to red).

L*, a*, b* data measured with a smartphone application are given in Table 4. In a similar manner, the lowest L* values were observed in U7, N4, E3, T2, V2, M2, B5, O3, P2 and G1 coded chocolate samples; the highest L* values were observed in U1, N1, M1, B1 and O1 coded white chocolate samples. It was observed that the average color ranges of all measured samples were between 25.2 and 88 for L* values.

When the a* values of the samples were examined, it was observed that there was no closeness or similarity between the samples in terms of cocoa dry matter, and it was seen that the average a* values of the samples were measured between -3.3 and 18.1. When b* values were examined, it was seen that they were inversely proportional to cocoa dry matter, as in L* values. The b* values of the samples were measured between -5 and 32.2.

Total color difference

In order to calculate the total color difference for each chocolate sample, the L*, a*, b* values of the A4 white paper measured with the colorimeter and smartphone application were calculated as L_0*, a_0*, b_0* in Equation 1, and the values given in Table 5 were obtained. In an effort to make a better visual evaluation, the data in Table 5 has been converted into a graph (Figure 1). As can be seen from the figure, there is a close similarity between the Total Color Difference value of the samples.

Whiteness index (WI) values

Calculated Whiteness index (WI) values of the samples were listed in Table 4 and they were visualized in Figure 2 for better comparison. As with the Total Color Difference values, there is a close similarity between the values of colorimeter and smartphone.

Last of all, collected data were analyzed and smartphone data were compared with the colorimeter data. In this context, colorimeter data was accepted or recognised as standart. The coefficient of determination (R^2) and absolute average deviation (AAD) were determined, and these values were used to compare smartphone with colorimeter. The AAD is calculated by Equation 3, where $y_{i,col}$ and $y_{i,phone}$ denote the colorimetric and smartphone data, respectively, and p is the number of sample.

$$AAD = \left\{ \left[\sum_{i=1}^{p} \left(\left| y_{i,col} - y_{i,phone} \right| / y_{i,col} \right) \right] / p \right\} \times 100 \quad (3)$$

R^2 and AAD values for Total Color Difference were found to be as 0.99 and 18.98%, respectively. For the Whiteness Index, the R^2 were determined as 0.99 and the AAD value was calculated as 13.67%. Although the R^2 values found were acceptable, it was observed that the calculated AAD values were above 10%, which shows that the method has room for improvement.

Conclusion

In this study, samples of chocolate, a widely consumed food product, were analyzed to measure the usability of smartphone applications in daily life. The effectiveness of this new method was questioned by comparing the measurement data obtained from the colorimeter and smartphone applications of various chocolate samples containing different amounts of cocoa solids.

Smartphones, which are easy-to-use, portable and fast devices, are increasingly preferred in the field because they do not require expensive equipment or high levels of expertise. For this purpose, it is quite practical to use a smartphone with a processor and detector function. Smartphones are available everywhere and the calculated numerical values can be easily shared over long distances thanks to internet access. Smartphones, which do not require any cost and are owned by almost everyone today, have the potential to perform routine tests performed by trained personnel using laboratory instrumentation quickly and on-site.

Many advanced smartphone-based devices have been identified, showing applications in the food safety sector, as well as in medicine, the environment and industry. The real question is perhaps when these smartphones will start to be widely seen on farms, restaurants and markets. Because this will mean a greater awareness of what we eat.

This study has shown that smartphones can be used as an effective tool for color analysis in foods and can store information about color differences in foods. Considering the prevalence of smartphones, it is an exciting result that consumers can quickly access information about the appearance of foods regardless of time or place. Future research can be devoted to the accessibility of applications that will provide access to color information about foods using smartphones and the development of these applications.

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Table 1. Cocoa mass content of chocolate products and their groups

GROUP	Sample Code	Cocoa Dry Matter Ratio
U	U1	White chocolate
	U2	29%
	U3	30%
	U4	52%
	U5	53%
	U6	60%
	U7	80%
N	N1	White chocolate
	N2	29%
	N3	55%
	N4	60%
	N5	82%
E	E1	32%
	E2	45%
	E3	54%
	E4	70%
M	M1	White chocolate
	M2	33%
B	B1	White chocolate
	B2	30%
	B3	31%
	B4	36%
	B5	60%
	B6	85%
O	O1	White chocolate
	O2	34%
	O3	61%
V	V1	30%
	V2	57%
T	T1	30%
	T2	60%
P	P1	37%
	P2	57%
G	G1	52%
	G2	72%
	G3	90%

Table 2. Smartphone camera settings

Image size	3000 x 4000
Zoom	-
Flash mode	off
White balance	Fluorescent
Operation mode	Manual
Aperture	f /2,0
Shutter Speed	1/50 s
Recording Type	JPEG
Focal Length	4.60 mm
Resolution	72 dpi

Table 3 Average L*, a* and b* values of the samples obtained via Portable Colorimeter

SAMPLES	Portable Colorimeter		
	L^*	a^*	b^*
U1	83,00(± 0,0)	-3,8(± 0,0)	27,11(± 0,2)
U2	36,04(± 0,0)	9,72(± 0,0)	11,19(± 0,0)
U3	35,26(± 0,4)	10,01(± 0,0)	11,38(± 0,0)
U4	27,85(± 0,1)	5,19(± 0,1)	4,19(± 0,0)
U5	41,22(± 1,5)	4,12(± 0,2)	7,14(± 0,2)
U6	25,28(± 0,0)	3,76(± 0,0)	2,89(± 0,0)
U7	26,60(± 0,0)	3,33(± 0,0)	2,75(± 0,0)
N1	77,50(± 0,7)	-1,00(± 0,0)	27,80(± 0,4)
N2	33,89(± 0,2)	8,90(± 0,0)	9,49(± 0,1)
N3	27,00(± 0,0)	4,98(± 0,0)	3,93(± 0,1)
N4	26,57(± 0,1)	4,15(± 0,1)	3,21(± 0,0)
N5	24,97(± 0,2)	2,90(± 0,2)	1,91(± 0,1)
E1	35,06(± 0,1)	8,77(± 0,0)	9,88(± 0,0)
E2	28,40(± 0,0)	5,94(± 0,1)	4,92(± 0,1)
E3	26,46(± 0,1)	4,09(± 0,1)	3,03(± 0,0)
E4	25,78(± 0,1)	3,94(± 0,0)	3,00(± 0,0)
M1	83,72(± 0,4)	-5,09(± 0,1)	27,82(± 0,0)
M2	39,01(± 0,0)	10,30(± 0,0)	13,00(± 0,0)
B1	80,50(± 0,7)	-2,00(± 0,0)	24,00(± 0,0)
B2	36,43(± 0,0)	9,36(± 0,0)	12,10(± 0,0)
B3	36,60(± 0,0)	9,56(± 0,0)	12,76(± 0,0)
B4	32,02(± 0,0)	8,88(± 0,0)	9,69(± 0,0)
B5	23,35(± 0,0)	3,11(± 0,0)	2,90(± 0,0)
B6	25,95(± 0,1)	4,51(± 0,0)	3,53(± 0,0)
O1	81,49(± 0,0)	-2,54(± 0,0)	23,84(± 0,0)
O2	36,39(± 0,1)	8,52(± 0,6)	11,46(± 0,0)
O3	27,12(± 0,0)	3,33(± 0,1)	3,13(± 0,0)
V1	35,35(± 0,9)	9,55(± 0,0)	11,45(± 0,0)
V2	25,79(± 0,0)	4,39(± 0,0)	3,86(± 0,0)
T1	37,10(± 0,1)	9,49(± 0,1)	11,89(± 0,0)
T2	26,25(± 0,1)	2,12(± 0,0)	1,95(± 0,0)
P1	34,41(± 0,0)	9,27(± 0,0)	10,66(± 0,0)
P2	28,00(± 0,3)	5,74(± 0,2)	5,03(± 0,1)
G1	28,47(± 0,5)	6,79(± 0,1)	5,46(± 0,0)
G2	29,13(± 0,2)	4,83(± 0,0)	3,85(± 0,0)
G3	35,45(± 2,1)	4,42(± 0,0)	5,69(± 0,6)

Table 4 Average L*, a* and b* values of the samples obtained via smartphone and mobile app

Samples	Smartphone		
	L*	a*	b*
U1	84,0(± 5,1)	-3,3(± 2,0)	31,8(± 4,9)
U2	43,7(± 6,4)	16,3(± 3,2)	20,8(± 3,9)
U3	46,2(± 8,0)	16,3(± 3,1)	20,5(± 3,4)
U4	36,1(± 3,9)	9,2(± 3,1)	8,5(± 4,6)
U5	34,9(± 4,1)	8,4(± 2,8)	8,1(± 3,5)
U6	32,0(± 6,8)	2,4(± 1,6)	5,5(± 4,0)
U7	28,9(± 6,1)	2,0(± 1,9)	6,9(± 3,0)
N1	83,2(± 8,1)	4,4(± 1,3)	22,8(± 2,4)
N2	42,3(± 7,7)	14,2(± 3,5)	10,2(± 3,1)
N3	32,3(± 3,4)	9,0(± 2,6)	4,2(± 1,3)
N4	27,3(± 4,5)	7,8(± 2,9)	2,2(± 2,0)
N5	28,5(± 4,5)	4,7(± 1,6)	0,0(± 2,5)
E1	43,7(± 5,9)	18,1(± 2,8)	11,4(± 2,6)
E2	31,5(± 2,0)	13,1(± 2,0)	3,5(± 1,9)
E3	29,7(± 2,0)	8,2(± 2,0)	-0,1(± 2,1)
E4	30,3(± 2,0)	7,1(± 2,0)	-0,8(± 2,1)
M1	85,9(± 3,3)	1,9(± 1,0)	25,1(± 2,7)
M2	42,6(± 2,9)	14,1(± 1,7)	15,9(± 1,9)
B1	85,8(± 3,0)	-2,4(± 0,7)	32,2(± 1,9)
B2	39,5(± 2,8)	15,0(± 1,3)	27,0(± 1,8)
B3	38,9(± 2,6)	12,0(± 2,3)	26,0(± 2,3)
B4	33,7(± 3,0)	12,1(± 2,1)	20,3(± 2,1)
B5	25,2(± 2,4)	2,7(± 1,2)	7,2(± 1,7)
B6	25,3(± 3,3)	3,4(± 1,6)	10,2(± 1,7)
O1	88,0(± 2,3)	1,1(± 1,2)	31,0(± 2,6)
O2	42,8(± 1,7)	17,3(± 0,6)	22,1(± 1,6)
O3	27,8(± 2,7)	4,5(± 2,0)	6,7(± 0,9)
V1	42,4(± 3,6)	13,6(± 1,9)	11,4(± 1,3)
V2	33,4(± 3,5)	5,4(± 1,0)	2,2(± 1,3)
T1	42,8(± 2,7)	13,6(± 2,2)	7,3(± 3,9)
T2	33,2(± 3,0)	1,3(± 1,4)	-5,0(± 1,8)
P1	40,7(± 1,5)	15,6(± 0,7)	15,0(± 1,2)
P2	36,1(± 1,0)	8,0(± 1,2)	4,5(± 0,8)
G1	33,3(± 1,3)	7,9(± 2,2)	5,0(± 2,0)
G2	36,8(± 2,3)	2,3(± 1,4)	2,0(± 1,1)
G3	42,6(± 2,8)	2,4(± 1,3)	3,6(± 0,9)

Table 5. Total Color Difference and whiteness index (WI) values of the samples

Samples	Colorimeter	Smartphone	Colorimeter	Smartphone
	TOTAL COLOR DIFFERENCE (ΔE)		WHITENESS INDEX (WI)	
U1	87,4(± 0,0)	90,0(± 5,1)	67,8(± 0,1)	64,0(± 4,9)
U2	39,0(± 0,0)	51,3(± 6,9)	34,3(± 0,0)	37,5(± 5,0)
U3	38,4(± 0,3)	53,4(± 7,7)	33,5(± 0,4)	39,9(± 6,8)
U4	28,6(± 0,1)	38,6(± 3,7)	27,5(± 0,1)	34,7(± 4,1)
U5	42,0(± 1,5)	37,1(± 4,3)	40,6(± 1,5)	33,8(± 4,0)
U6	25,7(± 0,0)	32,9(± 6,3)	25,1(± 0,0)	31,6(± 6,9)
U7	26,9(± 0,0)	30,0(± 6,0)	26,5(± 0,0)	28,4(± 5,9)
N1	82,3(± 0,5)	86,5(± 8,2)	64,3(± 0,7)	70,5(± 4,6)
N2	36,3(± 0,2)	46,0(± 7,7)	32,6(± 0,1)	39,5(± 7,1)
N3	27,7(± 0,0)	33,9(± 3,1)	26,7(± 0,0)	31,5(± 3,5)
N4	27,1(± 0,1)	28,7(± 4,1)	26,4(± 0,2)	26,8(± 4,6)
N5	25,2(± 0,2)	29,0(± 4,3)	24,9(± 0,2)	28,3(± 4,6)
E1	37,5(± 0,1)	48,7(± 6,5)	33,7(± 0,1)	39,5(± 4,7)
E2	29,4(± 0,0)	34,5(± 5,6)	28,0(± 0,0)	30,0(± 6,1)
E3	26,9(± 0,1)	30,9(± 4,2)	26,3(± 0,1)	29,1(± 4,4)
E4	26,3(± 0,1)	31,3(± 3,6)	25,6(± 0,1)	29,8(± 3,8)
M1	88,4(± 0,4)	89,5(± 2,8)	67,4(± 0,2)	71,1(± 3,5)
M2	42,4(± 0,0)	47,7(± 2,8)	36,8(± 0,0)	38,8(± 2,9)
B1	84,0(± 0,7)	91,7(± 2,4)	69,0(± 0,4)	64,6(± 2,7)
B2	39,5(± 0,0)	50,2(± 2,1)	34,6(± 0,0)	32,0(± 2,8)
B3	39,9(± 0,0)	48,4(± 2,6)	34,6(± 0,0)	32,4(± 2,6)
B4	34,6(± 0,0)	41,2(± 2,9)	30,8(± 0,0)	29,5(± 2,9)
B5	23,7(± 0,0)	26,5(± 2,1)	23,2(± 0,0)	24,8(± 2,4)
B6	26,6(± 0,1)	27,6(± 2,5)	25,7(± 0,1)	24,5(± 3,4)
O1	84,9(± 0,0)	91,8(± 1,6)	70,0(± 0,0)	64,6(± 3,1)
O2	39,1(± 0,2)	50,8(± 1,5)	34,8(± 0,0)	36,4(± 1,7)
O3	27,5(± 0,0)	30,2(± 2,4)	27,0(± 0,0)	28,7(± 2,8)
V1	38,8(± 0,8)	46,0(± 2,8)	34,1(± 0,8)	39,7(± 3,9)
V2	26,4(± 0,1)	34,0(± 3,4)	25,6(± 0,1)	33,2(± 3,5)
T1	40,1(± 0,0)	45,6(± 3,1)	35,3(± 0,1)	40,5(± 2,5)
T2	26,4(± 0,1)	33,7(± 3,0)	26,2(± 0,1)	33,0(± 3,0)
P1	37,2(± 0,0)	45,4(± 1,5)	32,9(± 0,0)	36,8(± 1,4)
P2	29,0(± 0,2)	37,8(± 1,1)	27,6(± 0,3)	36,1(± 1,0)
G1	29,8(± 0,5)	35,3(± 1,5)	27,9(± 0,5)	31,6(± 1,4)
G2	29,8(± 0,2)	38,5(± 2,3)	28,9(± 0,2)	37,9(± 2,3)
G3	36,2(± 2,2)	45,1(± 2,8)	35,0(± 2,1)	44,6(± 2,8)

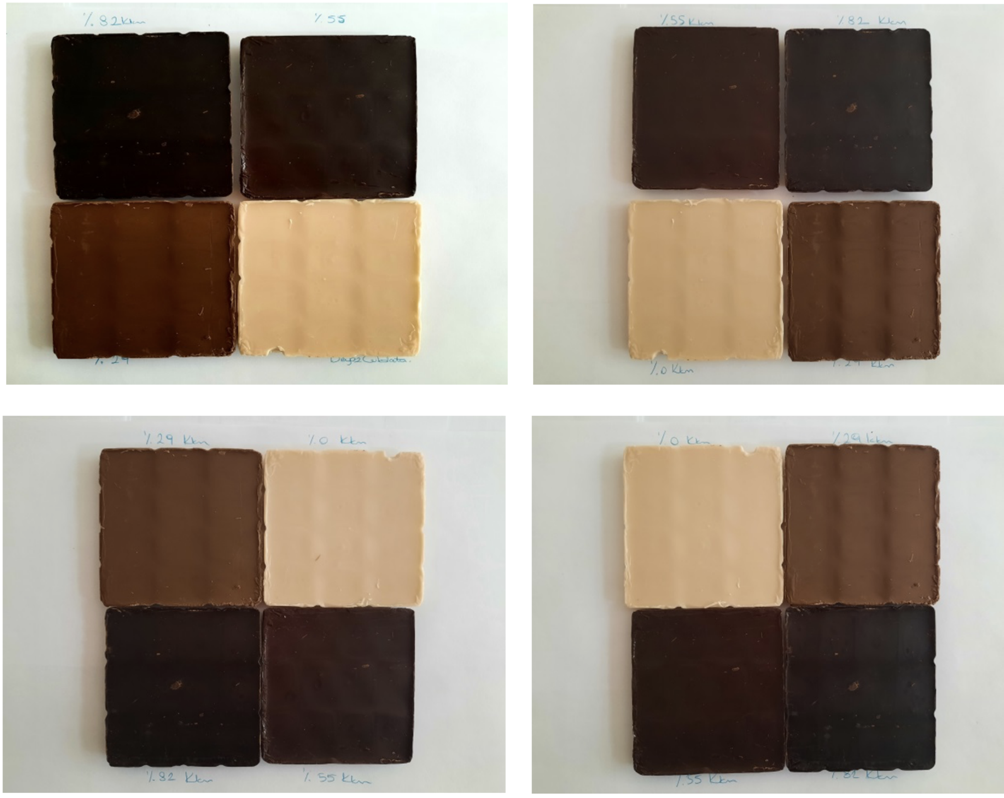

Figure 1. Images of chocolate samples in different locations captured with a smartphone camera

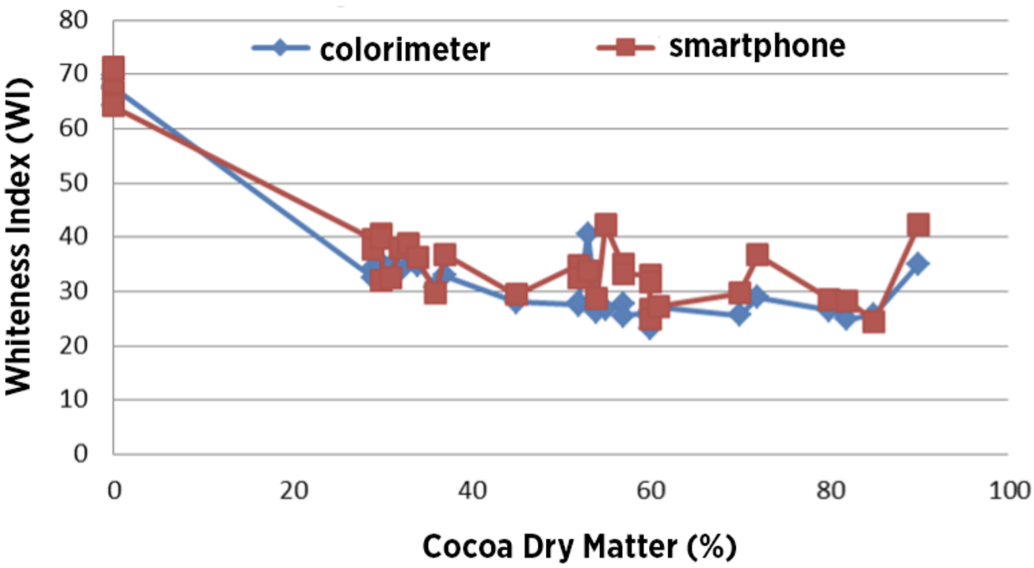

Figure 2. Whiteness index of the samples (blue: portable colorimeter, red: smartphone)