RELATIONSHIP BETWEEN TOTAL SOLID CONTENT AND RED, GREEN AND BLUE COLOUR INTENSITY OF STRAWBERRY (*Fragaria* x *ananassa* Duch.) FRUITS

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ABSTRACT

The relationship between total solid contents and red, green, blue (RGB) colour intensity of full spectrum images of strawberry fruits were examined to develop an efficient, non destructive, cost effective and economical method to determine correct maturity stage of strawberry fruits for harvesting. The RGB colour intensity of the full spectrum images of strawberry fruits of cv. Chandler, RGB colour ratio and their respective total solid content (Brix value) at three different colour development stages; fully red coloured (FRC), three-quarter coloured (TQC) and half coloured (HC) were analyzed. Total solid contents of the strawberry fruits were significantly difference among the three colour developmental stages of fruits. The highest average total solid contents (7.7 ^{0}Brix) was found in the fully red coloured strawberry fruits while the lowest total solid content (5.3 ^{0}Brix) was found in the half coloured fruits. Total solid content of three-quarter coloured fruits was 6.1 ^{0}Brix. The sum of red, green and blue colour (R+G+B) intensities and the ratio of $((G+B-R)/(R+B+G))^2$ were strongly correlated (R^2=0.95 and 0.89 respectively) with the total solid content of strawberry fruits. This two indices could be used to decide the correct maturity stage of the strawberry fruits. With reducing the values of these indices, increase the TSS of fruits. consequently, the lowest values of indices indicates the highest total solid contents in fruits .

Keywords**:** *Fruit colour developmental stages, Full spectrum colour images, RGB colour intensity, Strawberry, Total solid content*

INTRODUCTION

Strawberries are non-climacteric fruits and must be picked at the fully ripe stage to achieve best eating quality as ripening does not continue normally following detachment (McGlasson, 1985; Rosen and Kader, 1989). Monitoring ripeness of some fruit are difficult by using destructive chemical analysis (Downey *et al.,* 2007), chemometric analysis (Gishen *et al.,* 2005) or complex sensory analysis (Le Moigne *et al.,* 2008). Appearance (red colour intensity and distribution, fruit shape, freedom from defects and decay), firmness and flavour (determined by amounts of sugars, organic acids, phenolics and characteristic aroma volatiles) are the main factors considered in determining the quality of strawberry fruits (Kader, 1991). As strawberry fruits ripen, an increase in anthocynin content is accompanied by decrease in firmness and chlorophyll content. The accumulation of anthocynin coincides with the induction of the activities of phenylalanine ammonia-lyase

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and uridine diphosphate glucose; flavonoid 03-glucosyltransferase enzymes (Given *et al*., 1988). Other compositional changes with ripening include increase in soluble solids, total sugars, total ascorbic acids, pH and water soluble pectin; and decrease in acidity, total phenols, protopectin, cellulose and activities of polyphenol oxidase and peroxidise (Sprad and Morris, 1981).

Quality sensing is need for most agricultural products at different stages of production. The portable sensors of fruits ripening directly applied at field levels to predict the best harvesting period (Tuccio *et al*., 2010). Bray (2009) explained that many constituents of quality including that those contribute to taste, aroma and antioxidant potential can be quantified by measuring reflectance of the visible regions (400 – 780 nm). Borhan *et al*., (2004) evaluated the image features from colour (red, green and blue) and multispectral bands (550, 710 and 810 nm) in predicting chlorophyll and nitrate contents of potato leaves grown in the greenhouse and they found that the average prediction accuracies varied from 90.5% to 92.3% from normalized colour and multispectral band image features. Annamalai *et al*., (2004) investigated a machine vision system utilizing colour vision as mean to identify the harvesting maturity of citrus fruit and to estimate yield information of the citrus grown in real time. According to Peng and Lu (2007), multispectral imaging is used to detect pigment concentration and soluble solid (sugar) in fruits. Hyper spectral imaging technology was used for measuring fruit maturity, firmness and soluble solid content (Elmasry *et al.,* 2007).

Near infrared tomography and terahertz imaging are used in non destructive evaluation of non food products and medical items (Gibson *et al.,* 2005; Pickwell and Wallace ,2006; Kemsley *et al.,* 2008). Another Brix sensing technique by measuring electric properties of watermelon are correlated with soluble solid content (Nelson *et al.,* 2007). But these modern technologies are more expensive to be use at small scale cultivations.

Therefore, standardized and possibly cheaper and faster non destructive, simple methods for determining total soluble solid content of the strawberry is used to be developed. The purpose of this paper is to present an efficient cost effective and non destructive method to determine the correct fruit maturity of strawberry by analyzing the relation of RGB colour intensity with total soluble solid content of fruits.

MATERIALS AND METHODS

Agronomic practices

Strawberry cv. Chandler was grown open field, at the Agricultural Research Station of Rahangala at Boralanda in Sri Lanka in 2012. Planting space is 40 x 30 cm. Compost was applied at the rate of 10 t/ha on three days before planting. As basal dressing, 80 kg of urea, 160 kg of triple super phosphate (TSP) and 40 kg of muriate of potash (MOP) were applied per ha. Application of urea at the rate of 80 kg/ha and MOP at the rate of 40 kg/ha were done at two and four months after planting respectively. At 6 months after planting, urea, TSP and MOP were applied consecutively at the rate of 60, 80 and 40 kg/ha. Pest and disease management and other cultural practices were done according to the recommendation of the Department of Agriculture, Sri Lanka.

Colour assessment

Strawberry fruits were harvested at three different stages of fruit colour development; fully red coloured (FCR), three-quarter coloured (TQC) and half coloured (HC). Infrared filter of FineFix AV 100 digital camera was removed to obtain full spectrum

colour images including RGB as well as near infra red spectra. Digital photographs of each colour development stages of fruits were taken with flash having an image size of 4000 x 3000 (12 mega pixels). The average percentage of Red, Green and Blue (RGB) colour intensity of the images were analyzed using the ANALYSING DIGITAL IMAGE version II software. Rectangular spatial tool that measures average colour intensity of the image was used to measure the RGB colour of the original image without enhancing or masking. The average RGB intensities of 10 fruits were recorded from 10 plots.

Total soluble solid

Total soluble solid contents of strawberry fruits were measured using hand held refractometer, having a built-in automatic temperature compensation.

Statistical analysis and calculation of RGB ratio

Data were subjected to statistical analysis using AssiStat version 7.6 beta (2012) software. The following indices were calculated using the percentages of RGB intensity.

Average red colour intensity =R

Average green colour intensity =G

Average blue colour intensity =B

Maximum red colour intensity $=R_{mx}$

Maximum green colour intensity $=G_{mx}$

Maximum blue colour intensity $=B_{mx}$

Minimum red colour intensity $=R_{mi}$

Minimum green colour intensity $=G_{mi}$

Minimum blue colour intensity $=B_{mi}$

RGB intensity ratio(I) =R+G+B

Red intensity ratio (RIR) =R/I

Green intensity ratio(GIR) =G/I

Blue intensity ratio (BIR) =B/I

RG intensity ratio =(R+G)/(R+G+B)

RB intensity ratio =(R+B)/(R+G+B)

BG intensity ratio =(B+G)/(R+G+B)

Difference colour index (DCI) $=((G+B-R)/(R+B+G))^2$

RESULTS AND DISCUSSION

Strawberries are graded according to fruit colour development and minimum of 2/3 of the fruit surface with red or pink colour is required for harvesting (Given *et al*., 1988; Kader, 1999). Sistrunk and Morris (1985) concluded that strawberry clones which display red colour and which contain a good balance of acidity and sugar are usually rated high in flavour quality. In addition, maturity stage at harvest and postharvest handling procedures affect quality of strawberry fruits. In strawberry, sweetness is normally measured on a Brix scale and marketing standards stipulate that sufficiently ripe fruit must exhibit more than 7 ^{0}Brix values (Kader, 1999). Total solid contents (TSS) of the strawberry fruits were significantly difference among the three colour developmental stage of fruits. TSS of Fully red coloured (FRC) fruits was 7.7 ^{0}Brix value, three-quarter coloured (TQC) fruits was 6.1 ^{0}Brix value and half cloured (HC) fruits was 5.3 ^{0}Brix value (Table 01).

Full spectrum colour images include visible as well as near infrared (NIR) range spectra.

Table 01: Average colour intensities sand total solid contents of three different colour group of strawberry fruits

Fruit Colour Development stage	Average total solid contents** (^{0}Brix)	Average Red Colour Intensity**	Avearge Green Colour Intensity**	Avearage Blue Colour Intensity**
Full Red Colour (FRC)	7.7^a	0.47^b	0.21^c	0.27^b
Three-Quarter Coloured (TQC)	6.1^b	0.64^a	0.31^b	0.28^b
Half Clour (HC)	5.3^c	0.65^a	0.57^a	0.45^a
CV%	11.53	11.18	22.44	20.89

***Significant at the level of 1% probability level*
Means followed by the same letters in superscripts are not significantly different at p=0.01

Consequently, NIR also included to the pixel values of RGB in this full spectrum images. Carlini *et al.,* (2002) used visible and NIR spectra to analyze soluble solids in cherry and apricot. Examining the ratio of reflected infrared to red wavelengths is an excellent measure of vegetation health. This is normalized difference vegetation index (NDVI). Healthy plants have a high NDVI value because of their high reflectance of infrared light, and relatively low reflectance of red light (Moore and Holden, 2003). In this experiment, the lowest red, green and blue colour intensities were found in FRC fruits (0.47, 0.21 and 0.27 colour intensities respectively). There was not found statistically significant difference in the average red colour intensities (0.64 and 0.65 colour intensities respectively) in TQC and HC fruits. In addition, there was not observed statistically difference of the average green colour intensities (0.57 and 0.31 colour intensities respectively) in HC and TQC fruits (Table 01). Average red (R^2=0.92) and green(R^2=0.82) colour intensities were reduced when increasing TSS of strawberry fruits. Average blue colour intensities were also reduced when raising TSS but there was not seen strong correlation (R^2=0.6) than red and green colour (Figure 01).

Values of the maximum red of FRC and TQC fruits (246 and 253 colour intensities

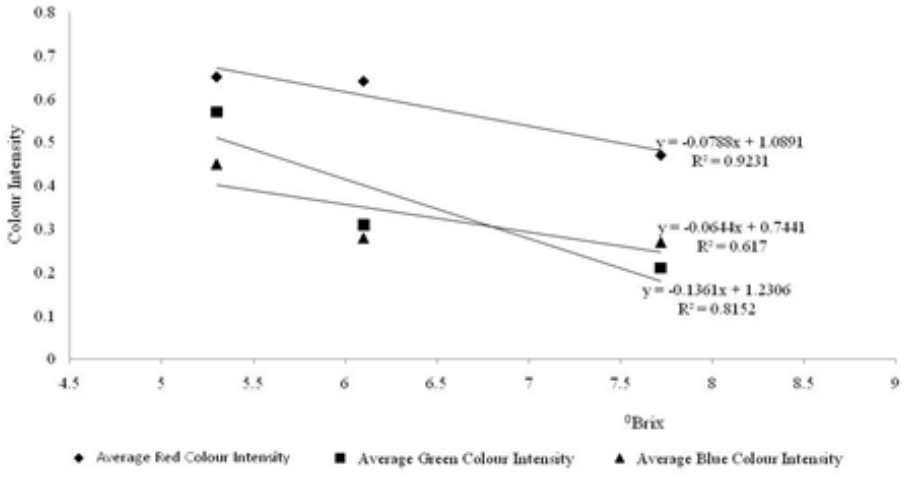

Figure 01: Average colour intensities vs. total solid contents of strawberry fruits.

respectively) were higher than HC (233 colour intensity). Additionally, maximum blue channel values of FCR (228 colour intensity) were also higher than both TQC and HC fruits (189,179 colour intensities respectively) (Table 02). When consider the maximum blue colour intensity (R^2=0.98) it was increased with TSS. However, poor correlation were found among maximum red (R^2=0.26) and green (R^2=0.07) clour intensities with TSS (Figure 02). Minimum green colour intensities were significantly difference among FCR, TQC and HC (5.3, 21.2 and 65.3 colour intensities respectively) (Table 03). Minimum red, green and blue colour intensities were reduced with increasing TSS (R^2 = 0.98, 0.80 and 0.66 respectively) (Figure 03).

RGB colour intensities of full spectrum images of strawberry fruits could be used to

Table 02: Maximum colour intensities of three colour group of strawberry fruits

Fruit Colour Development stage	Maximum Red Colour**	Maximun Green Colour*	Maximum Blue Colour**
Full Red Colour (FRC)	246[a]	202.1[ab]	228[a]
Three-Quarter Coloured (TQC)	252[a]	188.1[b]	189[b]
Half Clour (HC)	233[b]	213.7[a]	179[b]
CV%	3.99	8.95	8.58

***Significant at the level of 1% probability level*
**Significant at the level of 5% probability level*
Means followed by the same letters in superscripts are not significantly different at p=0.01 and p=0.05

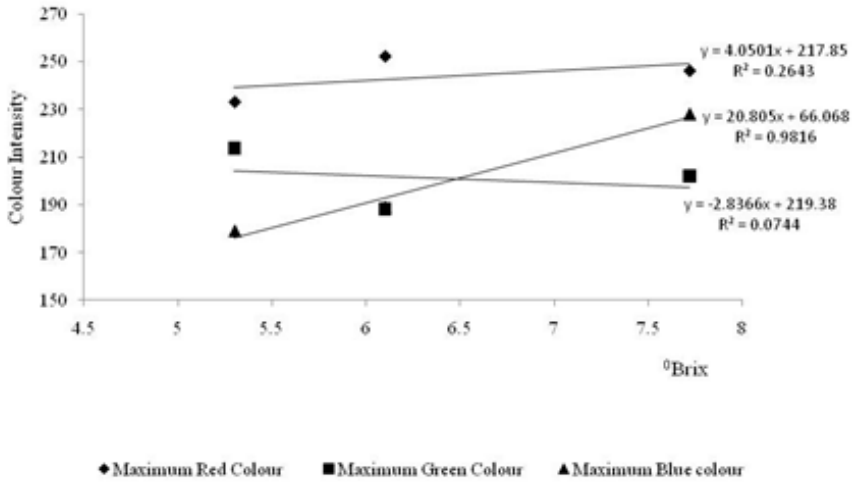

Figure 02: Maximum colour intensities vs. total solid contents of strawberry fruits.

Table 03: Minimum colour intensities of three colour group of strawberry fruits.

Fruit Colour Development stage	Minimum Red Colour**	Minimum Green Co-lour**	Minimum Blue Colour**
Full Red Colour (FRC)	44.6[b]	5.3[c]	12.8[b]
Three-Quarter Coloured (TQC)	77.7[a]	21.2[b]	14.9[b]
Half Clour (HC)	85.3[a]	65.3[a]	34.1[a]
CV%	40.23	45.67	52.19

***Significant at the level of 1% probability level*
Means followed by the same letters in superscripts are not significantly different at p=0.01

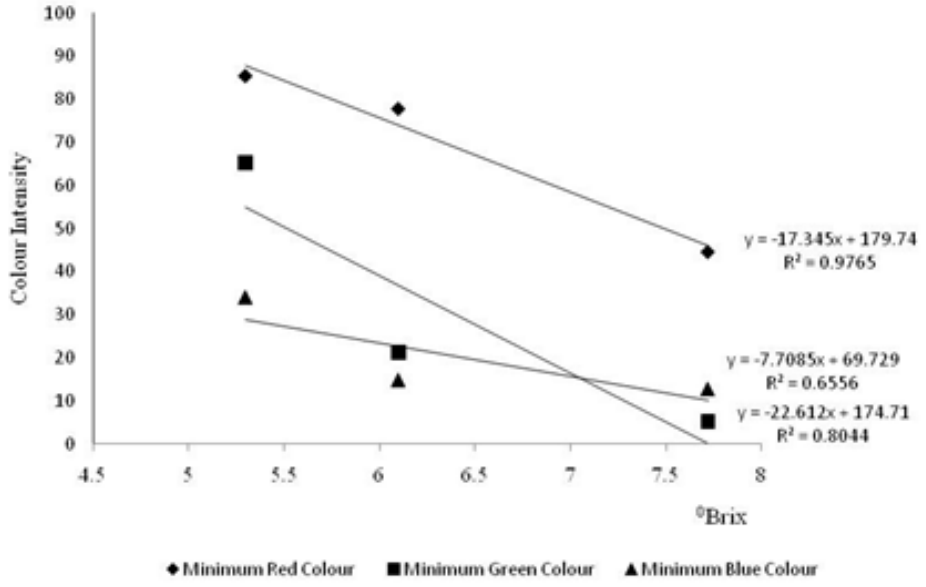

Figure 03: Minimum colour intensities vs. total solid contents of strawberry fruits.

identify the correct maturity stage due to it had strong correlation (R^2=0.95) between RGB intensities and TSS (Figure 04). The lowest RGB intensity and G/I ratio were found in FRC fruits (0.95 and 0.23 values respectively) while the highest in HC fruits (1.23 and 0.34 values respectively). The ratio of R/I and B/I could not be used to determine the correct maturity stage due to the highest R/I ratio (0.53) and the lowest B/I ratio (0.22) were found in TQC. Consequently, there was not seen a peculiarity pattern with TSS (Table 04). The highest $((G+B-R)/I)^2$ ratio was seen in HC fruits (0.046) while the lowest ratio in FRC (0.004) and it was correlated strongly (R^2 = 0.89) with TSS . In addition, the highest (R+G)/I ratio was found in TQC (0.78 value) and lowest in FRC (0.71 vlaue). The lowest (R+B)/I ratio was observed in HC fruits (0.62 vlaue) while the highest in both FRC (0.78 vlaue) and TQC (0.79 value). When consider the (B+G)/I ratio, the highest ratio was found in HC (0.60 value) and the lowest in TQC (0.47 value). Both (R+G)/I and R/I ratio were poorly correlated (R^2 = 0.35 and 0.35 rspectively) with TSS (Figure 04 and Table 05). Kalt *et al.,* (1993) reported that white strawberries become red during the storage without sufficient change in

sugar. Therefore, RGB colour intensity based total solid content determination method can be used at harvesting time of strawberry fruit due to it include visible as well as NIR spectra.

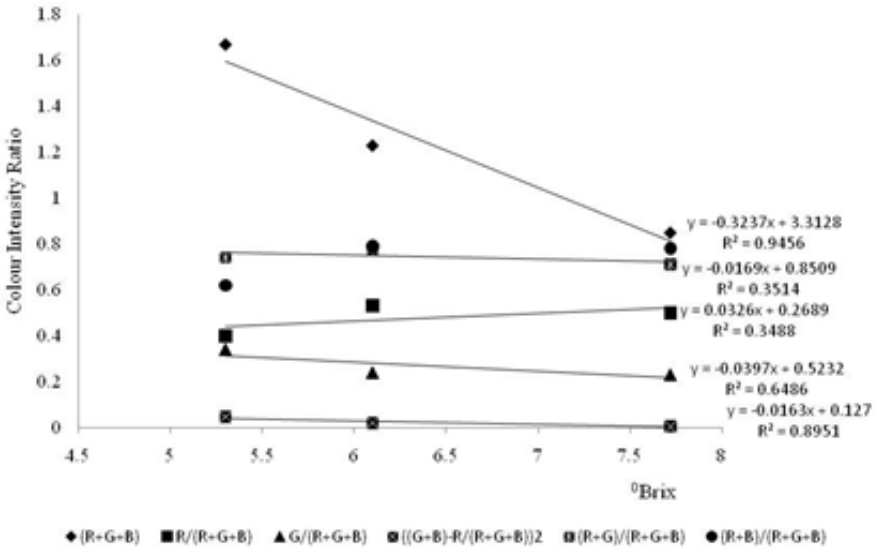

Figure 04: Colour intensity ratio vs. total solid contents of strawberry fruits.

Table 04: RGB colour intensity and colour ratio of three colour group of strawberry fruits.

Fruit Colour Development stage	(R+G+B)**	R/(R+G+B)**	G/(R+G+B)**	B/(R+G+B)**
Full Red Colour (FRC)	0.95^{c}	0.50^{b}	0.23^{c}	0.29^{a}
Three-Quarter Coloured (TQC)	1.23^{b}	0.53^{a}	0.24^{b}	0.22^{c}
Half Clour (HC)	1.67^{a}	0.40^{c}	0.34^{a}	0.26^{b}
CV%	15.81	7.93	9.69	6.12

***Significant at the level of 1% probability level*
Means followed by the same letters in superscripts are not significantly different at p=0.01

Table 05: RGB colour ratio of three colour group of strawberry fruits.

Fruit Colour Development stage	((G+B)-R / (R+G+B))^{2**}	(R+G) / (R+G+B)**	(R+B) / (R+G+B)**	(B+G) / (R+G+B)**
Full Red Colour (FRC)	0.004^{a}	0.71^{c}	0.78^{a}	0.50^{b}
Three-Quarter Coloured (TQC)	0.020^{b}	0.78^{a}	0.79^{a}	0.47^{c}
Half Clour (HC)	0.046^{c}	0.74^{b}	0.62^{b}	0.60^{a}
CV%	85.04	2.11	11.58	7.19

***Significant at the level of 1% probability level*
Means followed by the same letters in superscripts are not significantly different at p=0.01

CONCLUSIONS

TSS among the FRC, TQC and HC strawberry fruits were found significantly different. The highest TSS was seen in FRC (7.7 ^{0}Brix) and the lowest was seen in HC (5.3 ^{0}Brix). The values of the minimum green colour intensity, RGB intensity and $((G+B-R)/I)^2$ ratio were reduced with TSS of fruits. In addition, these indices could be used to determine the TSS of strawberry fruits successfully.

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