

Destructive and Non-destructive Quality Measurements of Strawberry (*Fragaria* × *ananassa* cv. Tristar) Cultivated using Soilless Culture in Tropical Greenhouse

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ABSTRACT

The quality parameters were investigated in strawberry fruit using soilless cultivation under the tropical greenhouse production. The soilless strawberry production using substrate and NFT system was compared with soil cultivation and they were cultivated using standard nutrient solution with an electrical conductivity 2 mS cm⁻¹ for all. Objectives of the studies were to investigate characterize the quality of soilless cultivated strawberries under tropical greenhouse and to identify the comparison between the color skin of strawberry that measurements using chromameter and digital image processing. The quality parameters, consist of fresh weight, size, texture of skin, soluble solids, total acidity, ascorbic acid, and anthocyanin values, were determined destructively using standard method. The color skin of strawberry fruit were determined non-destructively using the chromameter and digital image processing, then result between these measurement values were compared statistically. Based on results, the strawberry fruit grown in soilless cultivation systems under tropical greenhouse had bigger and better fresh weight, size and crop yield (in NFT soilless cultivation only) compared to soil cultivation in physical quality, and nutrition quality had higher values of soluble solids, ascorbic acid, L* and a*, while total acidity and anthocyanin fruit values were higher in soil cultivation. On the other hand, the comparisons of values the color skin of strawberry that measured between chromameter with digital image processing was relatively different, through different color specification and conversion method with moderate accuracy. Further research could be considered to improve this image processing method with low cost of the instrument and the ease of use.

Keywords: color, destructive quality, non-destructive quality, soilless culture, strawberry

1. INTRODUCTION

Strawberry (*Fragaria* × *ananassa*) is one of the most popular fruits because of its shape, taste and the presence of antioxidant compounds, and have relevant biological activity in human health [1]. In the last few decades, agronomic research has prioritized the attainment of high productivity, improved resistance to diseases and pests, transportability and extended shelf life of the fruit [2]. Climate conditions such as tropical condition could have enormous influences on the product quality of fresh fruits. Heavy rainfalls can damage the crop and infestation by disease is caused by high humidity and rainfall, and the consumption of pesticides increases [3]. They do not only affect the

physiological processes and lead to differences in appearance of fruit products, but also the internal quality such as sugars, acids, and flavor substances as well as vitamins and secondary plant compounds [4]. Controlled environment technology, such as cultivation under greenhouse, becomes an alternative to reduce these impacts and also provide better facilities than open-field cultivation [5,6]. Strawberry demand and availability in the market have widely increased, making this fruit a target of biofortification efforts [7].

According to previous experiments on local strawberry fruits in Ketep, Magelang, Central Java, several quality parameters such as sweet taste, fresh in aroma, skin color and texture of their skin were chosen by consumer in Yogyakarta area [8]. However, local

strawberry production is still not suitable with consumer preferences that mentioned above, then previous experiment applied using salt stress treatments to improve their quality of strawberry for consumer preference using soil production [9,10] and soilless culture [11,12]. Cultural system in strawberry production can directly affected fruit quality such as applications of salt stress in soilless cultivation of strawberry could be improved taste, texture, firmness and aroma [13], but temperature and high solar radiation during cultivation could be affected their taste and content of ascorbic acid [14].

The assessment of the quality of strawberries such as sweetness, acidity and flavour, but also the development of red or scarlet color is one of the most important characteristics affecting strawberry fruit quality, as well as contributing to a consumer's first impression [15]. The physical appearance and color of food have correlations with physical, chemical, and sensory qualities like firmness, pH, sugar, acid, taste, and aroma [16,17]. Some studies suggest that the skin color of the fruit can be expressed in color space [18]. The determination of color can be carried out by human visual inspection or by using a color measuring instrument, but sometimes human visual inspection has deficiencies such inconsistent, time-consuming, and subjective [19]. Color measurement instruments, such as chromameter, can determine skin color changes, but the procurement is inaccessible due to the cost and maintenance was expensive. The alternative way to assesses the color quality of fresh fruit was using digital image processing which can determine color change continuously, real-time, fast, have a good documentation system, and less expensive [16,20].

In this study, strawberry fruits were cultivated both, in soil and soilless culture in the lower sea-level conditions compared with the previous experiments [9,11] and using tropical greenhouse. The aims of this study were to characterize the quality of strawberries cultivated under tropical greenhouse using both nondestructive and destructive analysis and to identify the quality of skin color parameters of strawberry fresh fruit using non-destructive approach.

2. MATERIALS AND METHOD

2.1. Plant Materials

Strawberry (*Fragaria × ananassa* cv. Tristar) plants were cultivated under tropical greenhouse in Cangkringan Village, Sleman District, Special Region of Yogyakarta, Indonesia at latitude 7°39'58" S and longitude 110°27'42" W with an altitude of 389 m above the sea level with climatic conditions of air temperature range between 22-32°C and average relative humidity 60-90% yearly. The greenhouse was conducted in a 4.1 m in height and 38 m² of covered area with a modified

standard peak type with the structure was constructed of steel and roofed polyethylene using the mesh 50 net that attached to the greenhouse sides to prevent the entry of birds, and insects. Strawberry fresh fruit samples were grown in three different cultivation systems, soil culture, substrate soilless culture and nutrient film technique (NFT) soilless culture.

Harvested fruits samples were harvested at 2/3rd maturity till full maturity stage range based on [21] were used, then they were wrapped with 0.7 mm plastic polyethylene, then inserted in the bag with insulated form to keep ambient temperature conditions (25°-30°) and transported to Faculty of Agricultural Technology Gadjah Mada University in Yogyakarta for analysis within 1-2 hours. The number of 25 fruits in each sample was measure with triple replications.

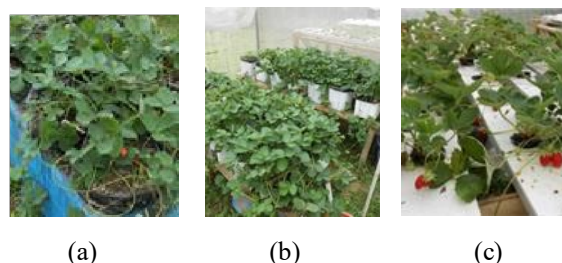


Figure 1. Strawberry fruit production with 2 mScm⁻¹ nutrient solution) (a) Soil culture as a control (b) Substrate soilless culture (c) Nutrient film technique (NFT) soilless culture.

2.2. Soilless cultivation of strawberry fruit production

Strawberry production in soilless culture was compared with soil culture as control based on [13]. Fig. 1 above shows the strawberry fruit production under different cultivation production. The soilless culture consisted substrate media with combination of perlite and vermiculite (1:1) using 10 L plastic boxes which was added semi automatically 100 mL once a day and Nutrient Film Technique System (NFT system) was used intermittent semi automatically on-off system for replenishment the nutrient solution. Electric Conductivity (EC) of the nutrient solution was 2 mScm⁻¹, and they were applied for soilless culture and soil culture as a control of strawberry plants. The electrical conductivity of nutrient solution was determined using a digital TDS & EC meter (Choiceown, TWQ-006A, Taiwan). The commercial AB mixture as a standard solution was used as nutrient solution, with sodium chloride concentration 0.02%; potassium concentration of 205.05 mgL⁻¹; phosphorus concentration of 48.6 mgL⁻¹; sulphur concentration of 181.19 mgL⁻¹ and magnesium concentration of 253.78 mgL⁻¹.

2.3. Destructive quality analysis of strawberry fruit.

Destructive quality evaluation of fresh strawberry fruit were based on their physical and nutritional characteristics. For physical evaluation, fresh weight was measured using a balance (T and D, Co. Ltd, Osaka, Japan), firmness (N) of fruit was measured with a penetrometer (Extech FHT200 FHT 200, Taiwan), fruit size was determined using vernier caliper, then determination of crop yield of fresh fruits were weighed throughout the crop cycle and expressed in g.plant⁻¹. For nutritional characteristics such as total soluble solids (TSS) expressed as °Brix, were measured with a hand refractometer (ABBE, Atago, Japan) calibrated against sucrose. Titratable acidity was determined by titration with 0.1 N NaOH method as described by [22] and expressed as mg.g⁻¹ citric acid. Ascorbic acid was determined by titration with 0.01 N iodine according to the method by [22] and expressed as mg.g⁻¹ ascorbic acid. Anthocyanin content was determined using a modified pH differential method described by [23] and expressed as ppm. Spectrophotometer UV/Visible (Jenway, 6305, UK) was used to measure the absorbance of anthocyanin at 520 and 700 nm in buffers at pH 1.0 and 4.5.

2.4. Non-destructive quality analysis of strawberry fruit

Analysed for external skin color was measured using a chromameter (Konica Minolta CR 400, Japan) and digital image processing (Nikon, S3300, Japan). Strawberry color measurement was replicated six times for each sample. The color values measured using chromameter was noted as L*a*b* color space, while color values measured using digital image processing noted as RGB color space. The chromameter was calibrated using Konica Minolta standard white calibration plate CR-A43.

Image acquisition of strawberry fresh fruit samples was done inside a cardboard box with nonglossy black walls to minimize the light and reflection from the box (Fig. 2.a-b) was used based on [24]. The RGB images were captured using an image processing system consisting of a charge-coupled device (CCD) with a focal length of 3.5 mm. The CCD image sensors digital cameras have very low noise and good uniformity [25]. The image was taken in 4 megapixels (2272 x 1704) resolution. The camera was located vertically at a distance of 11 cm from the samples. The field view of the camera was 14 × 10.5 cm². Images were taken under LED 2.2 Watt (Luby L-7619-A) lamp that placed in the interior cardboard box walls at around 45° angle from the camera lens axis [20]. Each LED lamp has 27 light-emitting diodes (LEDs). White LED lights are used as the light source because of its long life, durability and

low maintenance cost [25]. In order to calibrate the digital image processing system, the digital image of 5 color charts which consist of red, green, blue, white, and black color (Fig. 1.c) was taken. The R, G, and B color values of each color chart were measured using a Matrix Laboratory program (Mathworks, ver. Matlab R2014b) software.

The red (R), green (G) and blue (B) color values were obtained by extracting color of the strawberry digital image using a Matlab software. Beforehand, the images through the pre-processing image steps, such as cropping image and thresholding. The strawberry fresh skin fruit color mean values were extracted and calculated for each R, G, and B color space. The RGB color values were converted into L*a*b* color values by Matlab software using the 'rgb2lab' function included in the Matlab image processing toolbox [26]. The L*a*b* color values that obtain from chromameter and digital image processing, were calculated as °hue and chroma as in specific formula. °Hue was expressed on a 360° grid, where 0° = bluish – red; 90° = yellow; 180° = green; and 270° = blue then calculated hue as color intensity ($\arctan(b/a)$) [27]. Chroma is a measure of intensity or saturation or as actual color $[a^2 + b^2]^{0.5}$ [28].

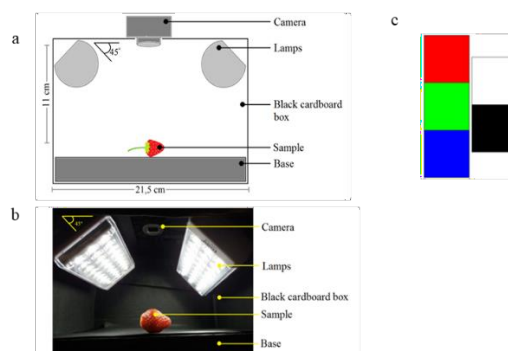


Figure 2. Image acquisition system in black box (a-b) and Color chart (c).

2.5 Statistical analysis

The mean of quality parameter values of strawberry was calculated performed with SPSS version 21.0 (IBM.corp). Analysis of variance (ANOVA) was used to evaluate differences in the quality parameters of strawberry among the culture practices and the L*a*b*-converted mean values from image processing were compared to L*a*b* of chromameter, then followed by Tukey's least squares means test for multiple comparisons, with a 0.05 significant level. Root mean square error (RMSE) with 0.05 significant level was also used to compare the data between chromameter and image processing

3. RESULTS AND DISCUSSION

3.1 Destructive analysis of strawberry fruit quality

Results of destructive analysis of physical quality of strawberry fresh fruits grown under tropical greenhouse are shown in Tab. 1 below. This table show the three different cultivation system (soil culture as a control, substrate soilless cultivation, and NFT soilless cultivation) were used to produce the strawberry fruit.

Table 1. Physical characteristics of strawberry fruit quality under different cultivation system in tropical greenhouse. Data were average with standard deviation from 25 samples of strawberry fruit

Physical characteristics	Cultivation System		
	Soil system (control)	Substrate soilless culture	NFT soilless culture
Fresh weight (g)	3.69 ± 0.97a	5.54 ± 0.48b	6.70 ± 1.34bc
Length (cm)	1.85 ± 0.33a	2.19 ± 0.55ab	2.31 ± 0.21b
Diameter (cm)	2.31 ± 0.16a	2.94 ± 0.94b	3.30 ± 0.29b
Texture of skin (N)	1.49 ± 0.18a	1.42 ± 0.39a	1.39 ± 0.16a
Crop yield (g.plant ⁻¹)	1.89 ± 0.15a	1.80 ± 0.12a	3.94 ± 0.28b

Different letters in the same row indicate significant differences at the 5% level by Tukey test.

Table 2. Nutritional characteristics of strawberry fruit quality under different cultivation system in tropical greenhouse. Data were average with standard deviation from 25 samples of strawberry fruit

Nutritional characteristics	Cultivation System		
	Soil system (control)	Substrate soilless culture	NFT soilless culture
Total Soluble Solid (°Brix)	8.96 ± 1.19a	8.57 ± 1.72a	10.84 ± 1.34b
Total acidity (mg.g ⁻¹)	5.37 ± 0.56a	3.76 ± 1.11a	4.98 ± 0.24a
Ascorbic acid (mg.g ⁻¹)	3.01 ± 0.54a	5.40 ± 0.36b	3.92 ± 0.36b
Anthocyanin (ppm)	28.01 ± 7.21a	25.45 ± 6.48a	26.17 ± 7.87a

Different letters in the same row indicate significant differences at the 5% level by Tukey test.

The strawberry fruit grown in soilless cultivation systems under tropical greenhouse had bigger and better fresh weight, size and crop yield (in NFT soilless cultivation only) compared to soil cultivation, but similar result for texture of strawberry skin. Soilless culture using substrate and NFT systems had good drainage system in the root area, where combination of

perlite and vermiculite could be increased exchange of air and water ventilation ,aeration capacity, and also increased capability to absorb water and nutrition [6, 29]. These conditions could be improved their physical quality of the fruit strawberry that cultivated in the soilless system in the tab.1 mentioned above. On the other hand, soil cultivation will be lower aeration capacity due to increased percentage of soil pore that caused by inserted water, it could be disturbed capability of roots to absorb water and nutrition especially phosphor and potassium [30]. Furthermore, yield crop quantity and quality of strawberry fruit using soilless culture was depend on their media, concentration of nutrient solution and root with an air environment condition on plant cultivation [4, 31].

Table 2 shown data of the nutritional characteristics of strawberry fruit quality under different three cultivation system in tropical greenhouse that mentioned above. Total soluble solid as indicator for sweetness of strawberry fruit were similar for soil and substrate soilless cultivation, but NFT soilless cultivation was higher value on total soluble solid content. Total acidity and anthocyanin content of the strawberry fruit that produced from different cultivation were not significantly different. On the other hand, ascorbic acid or vitamin C content of the fruit that produced from soilless culture, both of them substrate and NFT soilless culture, were significantly different compared with that content of ascorbic acid in soil culture of strawberry fruit.

Total soluble solids of strawberry fresh fruit for NFT soilless had highest value and similar result with the analyzed strawberry fruits presented of 6.33 – 10.86 °Brix of total soluble solids from [32]. It can be supposed that NFT soilless culture system had higher aeration capacity for oxygen level that can be trigger of transported nutrition and also higher sugar hydrolysis activity by invertase enzyme [21,25]. Values for total acidity were lower in fruits grown in both soilless cultivation system compared to fruits grown in soil. The strawberry grown in NFT has greater value of total acidity than strawberry grown in substrate. However, the total acidity of strawberry fruits was not significantly different statistically ($P < 0.05$). These results are in agreement with the findings from [4], that reported total acidity values of strawberry grown in soilless were lower compared to those found in soil system. Both soilless systems, substrate and NFT, showed higher values for fruits ascorbic acid than soil system, and this results also demonstrated by [33] in Tomato, who found that fruits produced in a soilless system, especially NFT, were richer in ascorbic acid than the soil grown fruits Other factors influencing in ascorbic acid synthesis are genotypic variation, maturity at harvest, harvesting method, and postharvest handling [34]. Mean values for anthocyanin content shown not significant differences among strawberry cultivation

systems, it can be supposed that organic matter with the same EC was relatively similar concentration of the phenolic compound such as anthocyanin [6]. Strawberry fruit production using soilless cultivation in the greenhouse could be increased phytochemical concentration and fruit nutrition [35], although, it was cultivated under the lower altitude from the strawberry fruit optimum condition that previously applied [9,11].

3.2. Non-destructive quality of strawberry fruit skin colors

Image acquisition in the black box for strawberry color skin measurement of digital image processing was shown in Fig. 3.a. Thus, images were treated in preprocessing image steps that shown in Fig. 3.b-g.

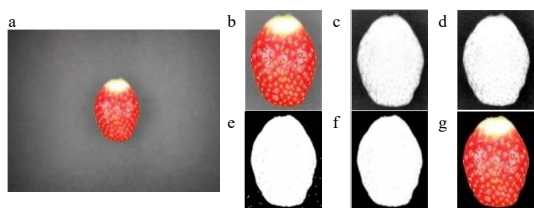


Figure 3. The acquisition and pre-processing image using Matlab: a = cropping image; b = grayscale image; c = Adjust intensity image; d = binary image; e = removed noise image; f = filled image

The image cropping process was done to reduce the unused background of the image (Figure 3.b), then image cropping was converted to grayscale (Figure 3.c). Furthermore, adjusted image intensity of the grayscale image to improve image contrast (Figure 3.d) and the image converted to a binary scale to obtain the borders of the strawberry object in the image (Figure 3.e). The image obtained was often distorted, so that small objects or noise from the binary image was removed for more accurate image processing (Figure 3.f), then the final step was filled the strawberry object holes on the image (Figure 3.g) so that only the color of the strawberry fruit was extracted.

The comparison of color skin measurement of strawberry fruit using chromameter and digital image processing for three different cultivation system of strawberry fruit was shown in Tab.3 below. The mean values of L^* , a^* , b^* , hue, and chroma of the chromameter from the skin strawberry fruit that produced from soil system and substrate soilless culture was similar, but relatively different with NFT soilless culture for L^* , a^* and hue. This indicate that, NFT soilless culture could be produced some skin fruit strawberry with relatively had lightness and more reddish. Furthermore, these range of mean values from characteristics of the skin strawberry fruit were similar with [18]. On the other hand, mean value of the L^* , a^* , hue, and chroma from chromameter was significantly different compared with these characteristics that

measured using digital image processing, but they still in the range of color categories red-purple (0°) until yellow (90°) [2]. Although, b^* and chroma values were relatively similar between chromameter and digital image processing measurement. Accuracy of the image processing measurements compare with chromameter were higher than 95% for measure b^* , 80% for chroma, and 65.9% for all color characteristics, respectively.

Differences in color values can occur due to differences in measurement equipment specifications and color space conversion methods performed through direct conversion [16]. The level of accuracy measurement using digital image processing is not as good as the chromameter, but the ease of use and low cost of the color measurement instrument can be considered [36]. Further research is important to improved accuracy of the digital image processing to measure strawberry fruit skin through increasing capability of equipment specification and compatibility of conversion method to produce higher accuracy with the low-cost operation and easy to use.

4. CONCLUSIONS

- 1) a). The strawberry fruit grown in soilless cultivation systems under tropical greenhouse had bigger and better fresh weight, size and crop yield (in NFT soilless cultivation only) compared to soil cultivation in physical quality.
- b). Nutrition quality of strawberry fruit from soilless cultivation had higher values of soluble solids, ascorbic acid, L^* (lightness) and a^* (redness), but total acidity and anthocyanin fruit values were higher in soil cultivation.
- 2) The comparisons of values the color skin of strawberry that measured between chromameter with digital image processing was relatively different with moderate accuracy.

AUTHORS' CONTRIBUTIONS

Mohammad Affan Fajar Falah made contributions for the idea of the research, responsibility of conducting the research, supervised for the collected and analysed, and responsible for manuscripts. Nadia Ulfiyati made contributions for collecting and analysed the data for non-destructive quality. Bagas Waras made contributions for collection the data on cultivation and greenhouse system. Vivi Afrianti made contributions for collecting and analysed the data for destructive quality. Mirwan Ushada made contributions for analysed the non-destructive data and manuscript.

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Table 3. Comparison of skin color characteristics of strawberry fruit quality under different cultivation system in tropical greenhouse using Chromameter (Chro) and Image Processing (IP). Data were average with standard deviation from 25 samples of strawberry fruit

Skin color characteristics	Cultivation System					
	Soil system (control)		Substrate soilless culture		NFT soilless culture	
	Chro	IP	Chro	IP	Chro	IP
L*	39.95 ±	58.55 ±	39.49 ±	58.59 ±	43.77 ±	55.79 ±
	1.99a1	0.79b2	3.25a1	1.67a2	2.33ac1	1.17b2
a*	26.64 ±	10.82 ±	29.67 ±	12.34 ±	32.97 ±	17.68 ±
	3.11a1	2.53b2	4.73a1	5.93b2	3.30ac1	3.80b2
b*	25.36 ±	25.78 ±	24.51 ±	23.48 ±	26.24 ±	28.25 ±
	2.19a1	1.96a1	4.04a1	3.32a1	4.05a1	2.70a1
Hue	38.78 ±	67.89 ±	37.36 ±	66.84 ±	39.68 ±	61.66 ±
	3.51a1	5.04b2	4.98a1	8.82b2	3.09a1	4.60b2
Chroma	42.07 ±	33.53 ±	35.98 ±	30.69 ±	37.84 ±	38.60 ±
	2.36a1	2.86b2	5.21b1	4.35b1	2.78b1	5.92ab1