



Production of indicator labels for smart packaging to monitor the quality of bell peppers (*Capsicum annuum* var. *grossum*)

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Abstract

Bell pepper (*Capsicum annuum* var. *grossum*) is available in several types and colors, commonly classified into green, yellow, and red varieties. Red bell peppers represent fully ripened fruit and contain higher levels of vitamin C than other types. However, they are highly perishable. One approach to minimizing quality deterioration is the use of smart packaging. This study aimed to develop a smart packaging indicator that enables consumers to assess the freshness of red bell peppers without damaging the product. The research was conducted in two stages: (1) preparation of the color indicator solution, which was soaked for 24 hours, and (2) application of the indicator to smart packaging. The results showed that bromophenol blue with a 24-hour soaking time produced the best indicator for smart packaging labeling. The applied indicator exhibited visually detectable color changes from yellow to purple. A yellow color indicated fresh red bell peppers, while a shift to yellow-green signaled reduced freshness. A purple color showed that the fruit had begun to rot. These color changes corresponded to variations in several quality parameters, including total acidity, vitamin C, total dissolved solids, and hardness, which are commonly used to evaluate fruit freshness. Overall, the developed indicator demonstrates good potential for use in smart packaging applications.

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1. Introduction

Bell Peppers generally originate from Latin America and were later cultivated in Indonesia. Although pepper consumption in Indonesia remains relatively low, peppers are a horticultural crop with high commercial value and strong potential as an export commodity (1). Peppers also contain high nutritional value, including vitamin C, vitamin A, folic acid, oleoresin, capsaicin, carotenoids, bioflavonoids, antioxidants, essential oils, and flavonoids (2). However, bell peppers are perishable horticultural products, as indicated by weight loss, texture changes, and reduced firmness (3). Their deterioration can also be accelerated by consumer handling practices, such as squeezing the peppers to assess their quality.

One way to minimize damage to peppers is through the use of smart packaging. Smart packaging utilizes two types of indicators: external and internal indicators (4). External indicators are placed on the outside of the packaging, while internal indicators are positioned inside the packaging, either in the headspace or on the lid (5). Common color indicators used in smart packaging include bromothymol blue, phenol red, bromophenol blue, and methyl red (6–8). These indicator solutions are acid–base indicators that generally function in quantitative analysis. Each indicator has a specific pH range and exhibits distinct color changes under acidic or basic conditions (7).

Research on smart packaging has been widely conducted. For example, Riyanto applied smart packaging to detect the freshness of kurisi fish fillets (6); Octavia developed smart labels to detect *Staphylococcus aureus* contamination in meat (9); and Hurriyah developed bromophenol blue and bromothymol blue indicators in smart labels to detect the ripeness of red dragon fruit (*Hylocereus polyrhizus*) (7). Based on these studies, the present research was carried out to develop a freshness indicator for red bell peppers using bromothymol blue, phenol red, bromophenol blue, and methyl red as smart packaging elements. This innovation aims to provide information and facilitate consumers, students, and the food industry in understanding and implementing smart packaging technologies.

2. Materials and Methods

2.1. Materials and Tools

The tools and materials used in this study included dropper pipettes, measuring cups, blender, hair dryer, analytical balance, beakers, stirring rods, knives, volumetric flasks, refrigerator, penetrometer, hand refractometer, colorimeter, and burettes. The materials used in this study were red bell peppers, bromothymol blue, phenol red, bromophenol blue, methyl red, NaOH solution, styrofoam, Whatman No. 1 filter paper, distilled water, phenolphthalein solution, plastic wrap, aluminum foil, starch indicator, 0.1 N iodine, tissue and labeling materials.

2.2. Methods

2.2.1. Stage one

Preliminary research was carried out to determine the most suitable indicator solution that produces visible color changes observable to the naked eye. The indicator solutions tested in this stage were bromophenol blue, bromothymol blue, phenol red, and methyl red.

2.2.1.1. Fabrication of Indicator Label

Whatman No. 1 paper, cut into 2 × 4 cm strips, was soaked in bromothymol blue, phenol red, bromophenol blue, and methyl red solutions for 24 hours at room temperature and covered with aluminum foil. The indicator labels were then dried using a hair dryer for 10 minutes.

2.2.2. Stage two

2.2.2.1. Bell Peppers Storage

The peppers were placed on a styrofoam tray and covered with plastic wrap. Indicator paper was attached to the inner surface of the plastic wrap covering the tray. The samples were then stored in a refrigerator at 10°C. Total soluble solids (TSS), total acidity, fruit firmness, and the color index of the indicator paper on the pepper packaging were measured daily for 21 days (10).

2.2.2.2. Vitamin C

The vitamin C content in the sample was determined using the iodometric titration method. A total of 5 grams of the sample was dissolved in 25 mL of distilled water and then filtered. From the filtrate, 25 mL was taken and 4–5 drops of starch indicator were added. The solution was then titrated with 0.1 N iodine solution. The titration endpoint was

indicated by a blue color change. The vitamin C content was calculated using the formula provided by (11):

$$\text{Vitamin C} = \frac{\text{ml Iod} \times 0.88 \times \text{FP}}{(\text{B} \times 1000)} \times 100\% \quad (1)$$

ml Iod = Volume of iod used during titration

Fp = Dilution or dilution factor

B = Sample mass (g)

2.2.2.3. Total Soluble Solid (12)

Total soluble solids (TSS) were measured using a hand refractometer. The samples were first homogenized using a blender. The refractometer prism was then cleaned with sterile distilled water. Afterward, 1–2 drops of the sample solution were placed onto the prism surface. The TDS value of the sample was expressed in degrees Brix (13).

2.2.2.4. Total Acid (14)

Total acidity was measured using the titration method by dissolving 5 grams of the sample in 100 mL of distilled water. Then, 25 mL of the filtrate was taken, and 2–3 drops of phenolphthalein indicator were added. The solution was titrated with 0.1 N NaOH until a pink endpoint was reached. Total acidity was calculated using the formula described by (14):

$$\text{Total Acid} = \frac{\text{ml NaOH} \times N \times Fp \times Mr \text{ NaOH}}{\text{weight of sample}} \times 100\% \quad (2)$$

Information:

MI NaOH = Volume of NaOH used during titration

N = Normality of NaOH (0.1 N)

Fp = Dilution or dilution factor

Mr NaOH = Molar mass of NaOH

2.2.2.5. Fruit Firmness (15)

Fruit hardness was measured using a penetrometer. The fruit sample was placed on the instrument's sample table, and the probe was adjusted until its tip touched the fruit surface while the scale needle indicated zero. A 10-gram load was then added to the base of the needle, and the penetration time was set to approximately 10 seconds. The penetrometer needle lock and the scale needle adjuster were pressed slowly until they touched the needle, after which the needle lock was released to allow the probe to penetrate the fruit. The value obtained represents the penetration depth of the penetrometer needle within ± 10 seconds (16).

2.2.2.6. Color Analyses of Indicator Label

Color measurements of the smart indicator labels were analyzed using a colorimeter (AMT-506). Color quantification was performed by placing the colorimeter sensor directly on the smart indicator label. The device displayed the L^* , a^* , and b^* values on the screen.

To determine the overall color change of the indicator label during storage, the hue value (h°) was calculated. using the following formula (17):

$$^{\circ}\text{Hue} = \tan \left(\frac{\bar{x} b^*}{\bar{x} a^*} \right) \times 180 / \text{PI}() \quad (3)$$

Information:

$\bar{x} b^*$: Average b^* value

$\bar{x} a^*$: Average a^* value

180 : *Degrees Archtangent*

PI () : $\pi = 3,14$

3. Results and Discussion

Preliminary research was carried out to identify the most suitable indicator solution for developing smart packaging indicator labels for bell peppers. The indicator solutions tested included methyl red, bromophenol blue, bromothymol blue, and phenol red. The selection of the indicator solution was based on qualitative observations of color changes in the indicator labels immobilized on Whatman paper as the quality of the bell peppers declined during storage. The following section presents the results of the indicator label observations during bell pepper storage.

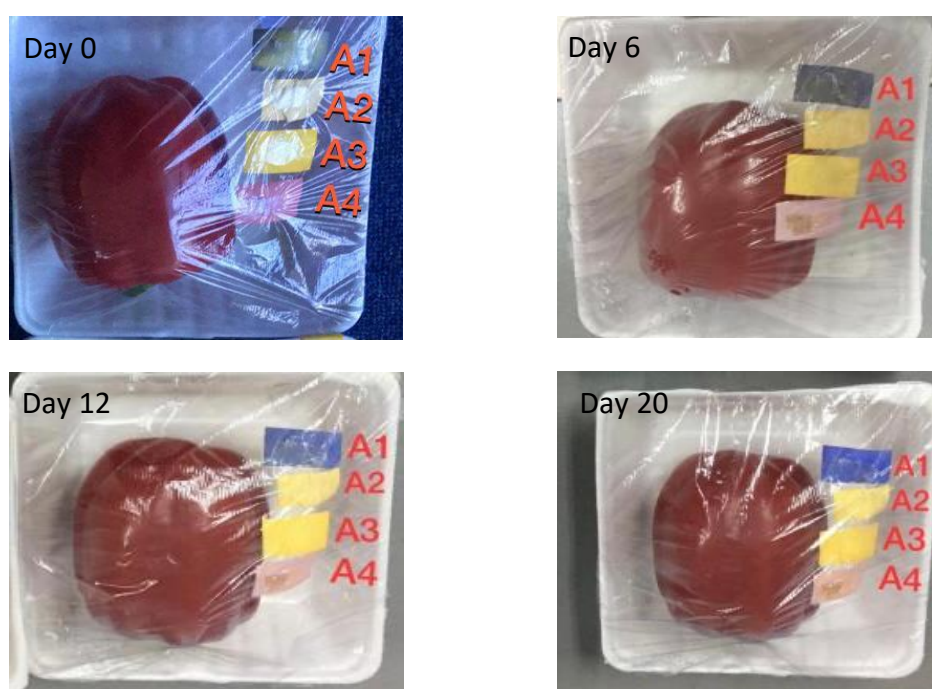


Figure 1. Color hanges of indicator labels, A1; Bromophenol Blue, A2; Bromothymol Blue, A3; Phenol Red, A4; Methyl Red.

Based on the observed color changes of the indicator labels in Figure 1, the solution selected as the freshness indicator for bell peppers was bromophenol blue. This indicator demonstrated high sensitivity, as evidenced by its distinct color changes and its pH transition range, which closely corresponds to the pH range of red bell peppers.

3.1. Total Acid

Fruits generally contain organic acids, for example, citrus fruits contain citric acid, apples contain malic acid, and peppers contain ascorbic acid. The total acid content in fruits typically increases during the stages of formation, growth, and early storage. However, during the ripening phase, the total acid content gradually decreases as sugar levels increase, leading to a sweeter taste (18).

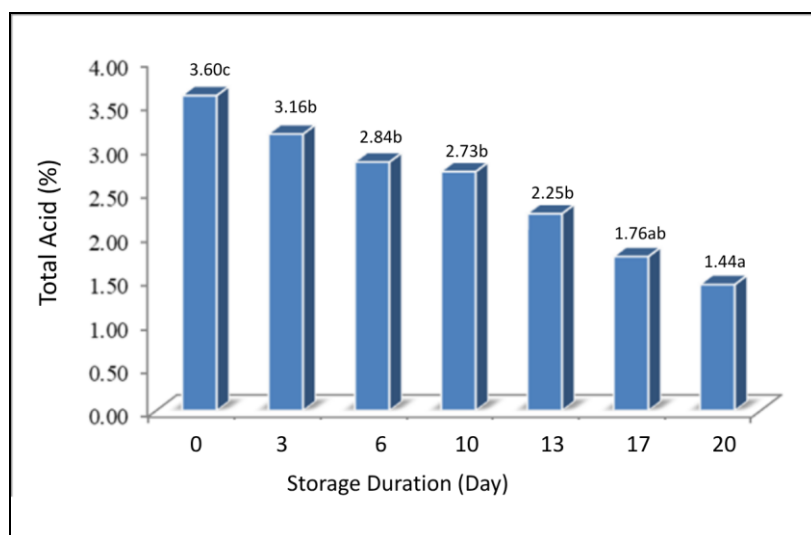


Figure 2. The effect of storage duration on total acid of bell peppers; values followed by different letters indicate significantly different results ($p < 0.05$).

According to statistical analysis, the total acidity of bell peppers from day 0 to day 20 showed a significant difference. As presented in Figure 2, total acidity decreased progressively during storage, from an average of 3.60% on day 0 to 1.44% on day 20. This decline in total acidity may be attributed to the conversion of organic acids into sugars during respiration. A decrease in total acid content generally indicates that the ripening process is progressing well (19). Additionally, total acidity is closely related to pH, where a reduction in total acidity corresponds to an increase in pH, and vice versa (20).

3.2. Vitamin C

Vitamin C plays an important role in the body because it functions as an antioxidant and possesses medicinal properties. Biochemically, vitamin C is involved in oxygenation, biosynthesis, and carnitine production, acts as a reductive cofactor for hydroxylation during collagen formation, and enhances iron absorption and metabolism (21). Additionally, the vitamin C content in bell peppers is much higher than in oranges. Every 100 g of red bell peppers contains approximately 190 mg of vitamin C (22).

According to statistical data on vitamin C levels in bell peppers from day 0 to day 20, there were significant differences throughout the storage period. Figure 3 shows a daily decrease in vitamin C, from 4.61% on day 0 to 1.72% on day 20. The decline in vitamin C content during storage may be attributed to the oxidation of L-ascorbic acid to dehydroascorbic acid. In addition, cell wall damage and overripening can further contribute to the reduction in vitamin C (23). However, the decrease in vitamin C levels observed in this

study tends to be relatively low, likely because low storage temperatures inhibit metabolic activity, thereby slowing the degradation of vitamin C in bell peppers.

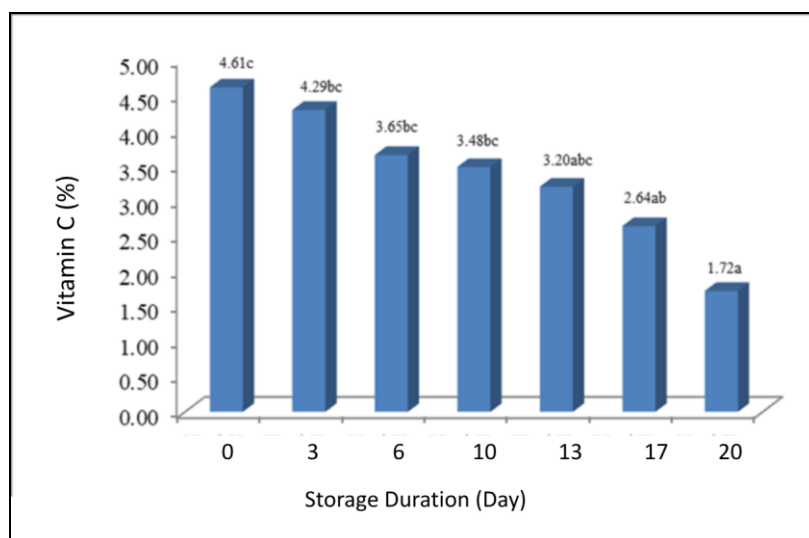


Figure 3. The effect of storage duration on vitamin C of bell peppers; values followed by different letters indicate significantly different results ($p<0.05$).

3.3. Total Soluble Solids

Total soluble solids (TSS) refer to the dissolved solids present in a sample, either in the form of ions or compounds. The TDS value can be used as an indicator of fruit ripeness. TDS is commonly measured using a refractometer, an instrument that determines the refractive index (RI) of a solution and converts it into a percentage of total dissolved solids (10).

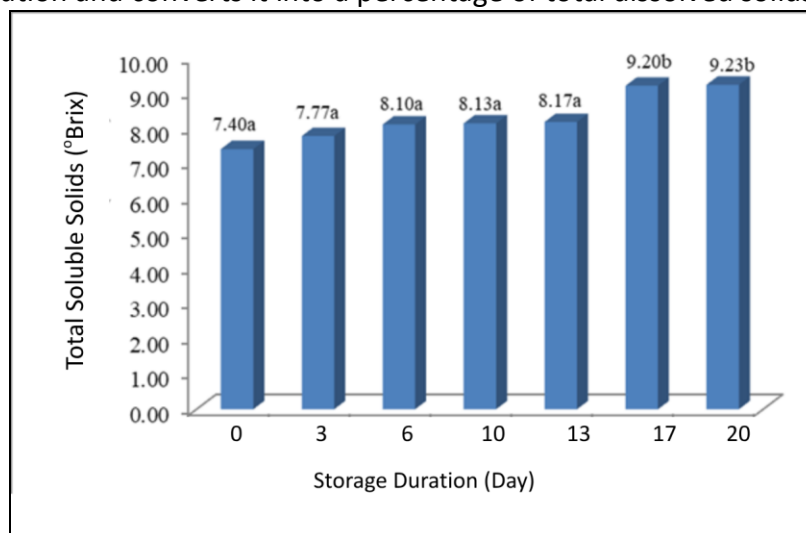


Figure 4. The effect of storage duration on total soluble solids of bell peppers; values followed by different letters indicate significantly different results ($p<0.05$).

According to statistical data showed in Figure 4, the Total soluble solids (TSS) of bell peppers from day 0 to day 13 showed no significant difference, whereas day 13 differed significantly from day 17 and day 20. Based on these results, the TDS of packaged bell peppers increased during storage, from 7.4 %Brix on day 0 to 12.23 %Brix on day 20. This

increase may be attributed to the hydrolysis of carbohydrates into glucose and fructose during the ripening process. The riper the fruit becomes, the higher its total dissolved solids content. In addition, fruits with higher acidity tend to have lower TSS values, while higher sugar content contributes to increased TSS levels (24).

3.4. Firmness

Fruit hardness can be used as an indicator of fruit freshness. High fruit hardness typically indicates that the internal cell pressure is still well maintained and that the fruit's cellular tissues have not yet experienced structural damage (25).

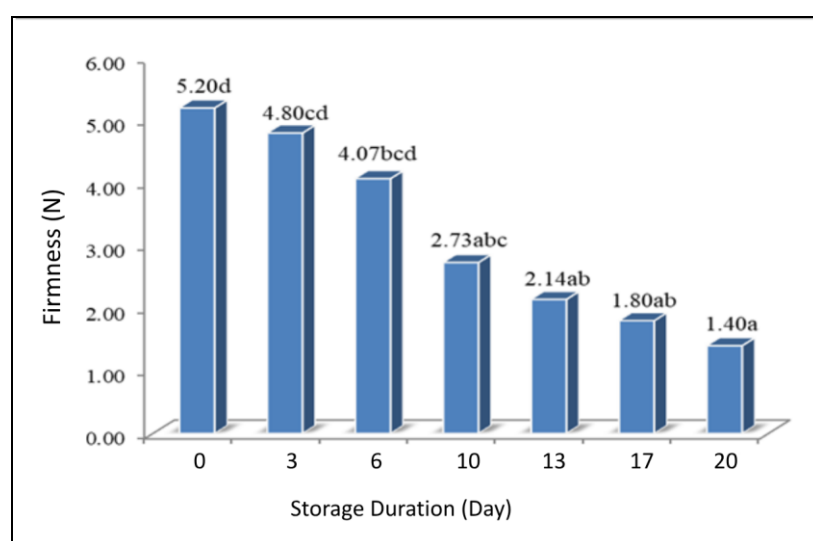


Figure 5. The effect of storage duration on firmness of bell pepper; values followed by different letters indicate significantly different results ($p < 0.05$).

According to statistical data on the hardness of bell peppers from day 0 to day 20, the results showed significant differences. Figure 5 indicates a progressive decline in fruit hardness during storage, from 5.2 N on day 0 to 1.40 N on day 20. The decrease in hardness may be attributed to a high respiration rate, which accelerates metabolic processes in the fruit, including the degradation of water-insoluble pectin (protopectin) into water-soluble pectin. This conversion reduces the cohesive strength between cell walls, weakening the structural integrity of the tissue and ultimately lowering the hardness of the bell peppers (26).

3.5. Measurement of the indicator label

The indicator label used in this study, bromophenol blue, is an acid–base indicator commonly applied in smart packaging. This indicator exhibits a color change from greenish-yellow at a pH of around 3.0 to purplish-blue at a pH of approximately 4.6 (7).

Based on Figure 6, the indicator label changed color as the quality of the red peppers declined due to the gradual biosynthesis of volatile acids in the packaging during the ripening process (27). Figure 6 shows that from day 0 to day 10, the indicator color changed from yellow to greenish-yellow, accompanied by a decrease in hue value from 86.68 to 32.00. From day 10 to day 21, the color further changed from greenish-yellow to purple.

Between day 10 and day 13, the hue value continued to decrease from 32.00 to –86.21, and from day 13 to day 21, it increased slightly from –86.21 to –23.34.

These color changes are caused by the release of volatile acids, such as acetic acid, from red bell peppers during storage, which interact directly with the indicator (28). A yellow indicator color signifies that the peppers are fresh and still have a firm texture. A shift to greenish-yellow indicates reduced freshness, characterized by decreasing firmness and the beginning of softening. Meanwhile, a purple indicator color shows that the packaged peppers have begun to decay, marked by a very soft texture and the onset of fluid release.

These changes in indicator color are consistent with the chemical changes occurring in the fruit during storage, including an increase in pH, a decrease in total acidity, a reduction in vitamin C content, an increase in total dissolved solids, a decrease in firmness, and a decrease in moisture content (29).

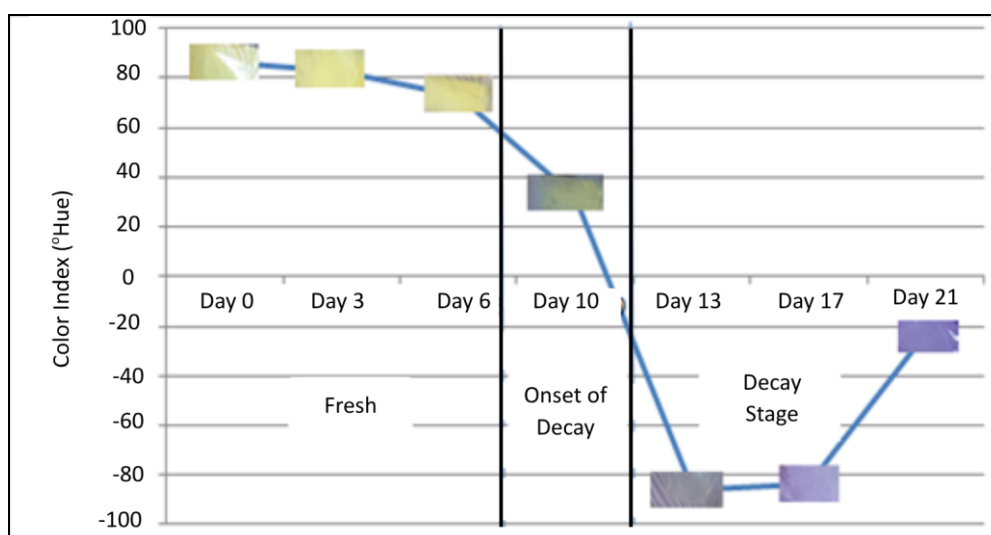


Figure 6. Color change profile of bell pepper freshness indicators based on hue values.

4. Conclusions

The color indicator that has been applied to the package changes color from yellow to purple which can be seen with the naked eye. The yellow color on the indicator reflects the freshness of the red peppers. Meanwhile, the change in the color of the indicator to a yellow-green color indicates that the fruit is less fresh, which is indicated by a decrease in hardness and a change in color to purple, indicating that the fruit has started to rot. The change in indicator color is directly proportional to changes in several parameters, namely total acid, vitamin C, moisture content, pH, total dissolved solids, hardness and organoleptic tests which usually serve to characterize fruit freshness. In general, this indicator can be used as smart packaging.

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Author Contributions

S.L. conceived and designed the experiments; S.L. performed the experiments; S.L. analyzed the data; S.L. wrote the paper; S.L. monitored the planning and execution of the study

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Data Availability Statement

Available data are presented in the manuscript.

Conflicts of Interest

The author declares no conflict of interest.

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