A needle-punched nonwoven experiment using cotton and polyester scraps to wrap preserved fruit

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ABSTRACT

This study investigates the use of cotton and polyester scraps to produce nonwoven fabrics via the needle-punching method in order to create packaging to preserve fruit. Firstly, the fiber properties were investigated. The needle-punching approach was then used to produce nonwovens, which underwent testing to determine their properties. The nonwovens were then used to create open-ended bags of two fabric types: perforated and non-perforated. These bags were used to wrap three different fruit types: Kimju guava, pear, and tomato. A color meter spectrophotometer was used to obtain the systematic color values for the fruits using C.I.E. LAB (L*a*b*). The color values were obtained and used to compare color change (ΔE). The testing results for the effective length of the cotton and polyester fibers showed respective values of 20 mm and 33.7 mm, while the cotton fiber resolution was 3.42 denier. Three nonwoven fabrics were produced for analysis: cotton fibers, poly-cotton blends, and polyester fibers. Their respective weights per unit area were 82 g/m², 96 g/m², and 90 g/m². It could be determined that the polyester nonwovens provided the most suitable physical properties, including thickness of 1.49 mm and air permeability of 160 cm³/s/cm². The force required to rear the fabric in the longitudinal direction was 29.44 N, while in the transverse direction it was 24.532 N. The longitudinal and transverse breaks measured 236.844 and 220.448 mm, respectively. It was not possible to obtain results for the puncture test because the nonwoven fabric was too thin and weak. Testing of the fruit preservation qualities of the nonwoven protective wrappings over a ten-day duration revealed that perforated cotton was best for Kimju guava and tomato preservation, with the recorded color change (ΔE) indicating the superiority of this nonwoven fabric over the alternatives.

1. Introduction

The Thai economy is heavily reliant upon agriculture, with many different agricultural techniques practiced across the country depending upon the local climate and topographical conditions. As a consequence, many projects have been implemented to support occupational skills development for agricultural workers, and to improve the efficiency and quality of the agricultural sector as a whole. These improvements are necessary in the transportation and distribution of agricultural products. For example, various types of fruit including apple, pear, persimmon, peach, durian, kiwi, guava, and tomato must undergo complex and lengthy transit processes which can result in damage to the skin of the fruit, or to the interior pulp, often as a result of insect activity, and resulting in the destruction of the crop. In this study, therefore, the differences between ripe and climacteric, or overripe, fruit is tested, with Kimju guava, pear, and tomato all undergoing investigation. The intention is to make use of textiles to address the issue of damage to fruit products. Cotton chips have organized features, while cotton fibers primarily comprise carbon, oxygen, and hydrogen.

Guava (Psidium guajava L.) is an important economic crop in Thailand, with exports reaching USD 5.03 million in 2020 [1, 2]. A majority of these guava exports are to other ASEAN nations, such as Singapore, Malaysia, and Myanmar, and to Qatar and the UAE in the Middle East [2]. It is essential to handle guava correctly to ensure its quality is maintained, and its shelf-life extended. Excessive handling during the harvesting and distribution processes can damage the fruit, resulting in water loss, peel browning, and increased susceptibility to disease [3, 4]. The pear (Pyrus communis L.) is popular because of its distinctive yet delicate aroma, its crisp texture and sweet flavor [5]. In the absence of packaging, however, the shelf-life is short, at just 7–10
days at room temperature (25–30 °C) [6]. The pear is also prone to rot, can suffer physical damage when handled, and can lose nutrients and moisture when stored. They are usually harvested in August, when temperatures are high, and this presents challenges in transportation and also for storage over extended periods of time. The pear also ripens very quickly, which further contributes to the short shelf-life, and presents difficulties in transportation and handling [7]. Meanwhile, the tomato (Lycopersicon esculentum) serves as a source of minerals and vitamins for the human diet, but cannot be stored for long periods. This perishability causes farmers to lose a significant proportion of their crop every year [8], so the role of packaging is crucial to support the distribution of products such as the Kimju guava, pear, and tomato.

Composite materials for a variety of applications can easily be produced from nonwoven webs, which offer excellent strength, light weight, and superior flexibility in comparison to traditional materials [9]. Nonwovens provide the important inherent quality of excellent z-directional properties, thereby reducing the potential for delamination. Muller and Krohjilowski (1999) examined the production of composites making use of flax fibers and biodegradable melt-blown polymers (PVA, PLA, and PEA) as the principal components [10]. Natural fiber-based composites involving biodegradable melt-blown textiles as a binder, present similar characteristics to conventional polypropylene-based composites. While composites based on flax fiber provide greater strength, the properties of the fiber tend to make the material more brittle. Natural fibers have been investigated to determine whether they might serve to enhance the impact strength of fiber-reinforced composites [11]. They can also be produced at lower cost than alternatives since they use renewable resources such as wood pulp or cotton linters. The thermoplastic qualities of cellulose acetate (CA) are ideal to support its use as a binder fiber for thermal calendaring when nonwovens are produced from cotton and from CA mixes. High quality nonwovens can be produced from these blends which offer the additional advantage of biodegradability when they are no longer functional [9, 10, 11, 12]. Furthermore, plasticized CA fibers present good thermal bonding capability as well as suitable tensile properties, so these materials make highly promising candidates for potential applications [13, 14].

The textile industry has taken increasing interest in natural products which offer potential due to their biological activity, biocompatibility, and reduced toxicity. There is a growing market textiles which provide biological qualities including UV protection, antibacterial or insecticidal properties, or simply greater comfort and a more pleasant odor [15]. Natural fibers are also increasingly popular as a means of producing ‘green goods’. They are biodegradable, can easily be recycled, and are not expensive to produce. Their specific weight is low, and their thermal and acoustic qualities are advantageous. They offer high hygroscopicity, and tend not to accumulate electrostatic charges on their surface. However, many natural fibers, both fabrics and nonwovens, can become biodegradable under humid conditions or high temperatures. In the construction and automotive sectors, it has been shown that microorganisms are responsible for the destructing of natural fiber-based finishing or insulation materials, so it is essential that steps are taken to prevent such biodeterioration [15].

Microorganisms attack natural fibers by breaking down one of the key components, cellulose. As a consequence, the material is weakened and often begins to emit unpleasant odors, thus impairing the microbiological purity of the air. One further problem with biodeterioration is that materials used in the automotive, construction, or paper sectors which contain natural fibers can be adversely affected. In a warm and humid climate, fungi or mildew can damage the cellulose which is the main component of natural fibers [16].

The microbiological degradation of textiles made from natural fibers can present a problem for both the fibers which serve as the raw materials, and also the finished products, which can include textiles such as hemp, jute, linen, cotton, ramie, sisal, and manila. Other types of mixed or synthetic textiles can also be adversely affected, such as paper, leather, polypropylene, polyamide, polyacrylonitrile, polyester, and polyethylene. The production of nonwoven fabrics often makes use of the spun-bonding method, since it allows the creation of textiles at lower cost and with no need for intermediate steps. It is no longer necessary to cut the continuous filaments into short strands, and the steps of packing, transport, and storage are also eliminated. The needle-punch bonding method, which is a mechanical bonding approach, offers a common means of bonding materials for a range of purposes, such as drainage or filtration [17, 18, 19].

The aim of this study is to develop a textile product for the purpose of preserving fruit, employing waste scraps of cotton fiber and polyester fiber through the use of a needle-punched nonwoven fabric manufacturing process. The wrapping created will ensure the freshness of the fruit and protect the fruit from damage by bruising, thus maintaining fruit quality. The use of waste materials for this purpose will also serve to add value to textile products when fruit wrapping materials are produced.

2. Materials and methods

This study comprised seven steps, as shown in Figure 1.

- Determine the fineness and length of 100% cotton fibers and 100% polyester fibers.
- Produce nonwoven fabrics from 100 percent cotton, cotton combined with 50:50 polyester, and 100 percent polyester using needle punching.
- Nonwoven fabrics were evaluated for their thickness, unit weight, air permeability, tensile strength, and puncture strength.
- Designed, cut, and sewn, these fruit wrappers are made from three different types of nonwoven fabrics and are categorized as standard fruit wrappers or perforated fruit wrappers for improved ventilation.
- Wrap three different types of fruits - Kimju guava, pear, and tomato - in five different nonwoven materials.
- Utilize a spectrophotometer to evaluate the fruit quality and compare the color values (ΔE).
- Summarize and analyze results.

Figure 1. Schematic diagram of the research procedure.
2.1. Fineness and length of 100% cotton and 100% polyester fibers

2.1.1. Cotton and polyester properties

The fiber resolution test based on the ASTM D1448 standard requires fiber samples of 5 g in weight. The samples are placed inside the fiber tube of the cotton fineness meter, before sealing the lid. The fibers are compressed into 1-inch-long cylinders with a 1-inch diameter, whereupon the valve is opened to allow air to pass through. The airflow rate was measured in terms of micrometers per inch, while the mean values for five samples of 100% cotton fiber were collected, and compared to the resolution, as shown in Table 1. The fiber properties are shown in Table 2.

2.1.2. Cotton and polyester length

The tests are based upon ASTM D5332 for cotton fibers and ASTM D5103 for synthetic fibers. The first test requires 20 strands to be removed from each sample using tweezers. The fibers are then straightened and placed on a smooth black velvet floor. The distance from the margins of one end to the other is then measured in millimeters using a ruler. The mean values for the 20 samples were then calculated.

2.2. Production of needle-punched nonwovens

Nonwovens can be produced by the following devices using the needle-punched method as shown in Figure 2. The first is the Felt Carder Code 337A, which has a front roller with a width of 70 cm, and produces connected nonwovens using a laboratory needle. The second is the Loom Model 237 which operates through an up-and-down motion which presses the sheet 100 times per minute, a fabric-pulling roller moving at 5 ft/min, and a number 40 needle and pinboard. This needle is relatively small (a smaller needle number indicates a larger needle; large needles include formed-barb needles, triangle needles, and needle panels comprising up to 1,000 needles).

Fabric details can be given as follows: 100 g of 100% cotton; 100 g of 100% polyester; 50 g cotton and 50 g polyester in a 50:50 blend. Nonwovens are 140 × 35 cm in size. Cotton fiber resolution is 3.36 micronaire, with fiber length of 20 mm; polyester fiber resolution is 1.19 denier, with fiber length of 37.7 mm. Fibers with tensile strength of 6.33 g/denier, elongation rate of 24.1%, and kink of 9.2 per centimeter were transferred to the fiber carding machine, as shown in Figure 3(a). Then, Figure 3(b) show the material exiting the roller; the Felt Carder Code 337A has a roller of 70 cm width at the front, which folds the fiber sheet into three sections ready for entry to the carding machine. The fiber sheet is then carded for a second time, to provide better fiber alignment, and uniform sheet thickness with no unwanted fiber clusters. Next is the needle punching process shown in Figure 3(c), the fiber enters the needle-punching machine. The flap head stitched to the conductive fabric so that it can enter the needle-punching machine, followed by the wadding and conductive fabric. These parts can then be stitched together and subsequently attached to the machine belt. The production of nonwovens via the needle-punching method using a metal rod at the end of the cloth hook to draw the sheets of webbing to the front of the machine, which can be seen in Figure 3(d), whereupon the roller is positioned over the fiber guide cloth. Finally, the power can be turned on, the cloth is turned over, and the process repeated. The nonwovens created via needle-punching are of size 140 × 35 cm, but for practical purposes the size is 120 × 30 cm because the side of the fabric lacks a needle-punched section. The head sides of the fabric are attached to sewn-together guide fabric and are highly stretched.

Table 1. The fiber resolution in microcar.

| Micronaire value | Resolution          |
|------------------|---------------------|
| Below 3.0        | Very high resolution|
| 3.0-3.9          | Fine                |
| 4.0-4.9          | Moderate            |
| 5.0-5.9          | Rough               |
| More than 6.0    | Very rough          |

Table 2. The fiber properties.

| Properties of fibers | Cotton fibers | Polyester fibers |
|----------------------|---------------|------------------|
| Effective length     | 20 mm         | 33.7 mm          |
| Finesseness          | 3.42 Denier   | 1.62 Denier      |
| Tenacity             | 0.38 N/tex    | 0.62 N/tex       |
| Elongation           | 5.58%         | 26.07%           |

2.3. Evaluation of the characteristics of nonwoven fabrics

2.3.1. Test of nonwovens

To measure the weight per unit area, the test is based upon the ASTM D 3776-96 standard. A fabric cutter is used to cut five pieces of fabric, each with an area of 100 cm². These pieces are then weighed, with the reading recorded in grams to four decimal places. This value can then be converted as necessary using Eq. (1) and Eq. (2) as shown below. The weights of nonwovens are shown in Table 3.

\[ A = B \times 100 \]  \hspace{1cm}  (1)

\[ C = A/33.906 \]  \hspace{1cm}  (2)

where \( A \) = fabric weight in g/m², \( B \) = fabric weight in g/100 cm², \( C \) = fabric weight in oz/yd².

2.3.2. Test of fabric thickness

On the basis of the ASTM D1777-96 standard, the first stage of the testing process involves measuring the sample fabric thickness using a thickness tester. The wrinkle-free nonwovens are placed on the lower pad of the tester, and the gravity weight is released. The thickness of the fabric can then be determined in ten different places on the material, taking the measurement for 6 s in each case. This allows creased or wrinkled areas to be avoided. The average thickness can then be calculated from the ten measurement readings. The findings are presented in Table 4.

![Figure 2](image128x67 to 468x174)  

Figure 2. Needle punching machines for laboratory use (a) nonwoven needle machine; (b) needle panel, and (c) needle-punched attachment method.
2.3.3. Test of air permeability

Air permeability testing makes use of the M021 tester. Initially, smooth and wrinkle-free fabric samples are cut in line with the ASTM D737 standard. It is important that when the test samples are handled, they do not come into contact with any kind of oil or grease. The samples are then positioned for testing at a specific point, whereby the fabric is attached between the air-permeable channels. When the air valve is opened, this allows the air to pass through the glass tube, so that the air pressure upon the fabric can be determined. The results are recorded, and the mean calculated.

2.3.4. Test of nonwoven tensile strength

In accordance with the ASTM D 5034-95 standard, the test involves the preparation of ten nonwoven samples measuring 10 × 20 cm by cutting along the length and width of ten pieces of fabric. The distance between upper and lower holders is then set to 75 mm before the specimen is dragged at a rate of 300 mm/min. The machine stops automatically when the specimen breaks, allowing the researcher to obtain the

![Figure 3. Needle-punching is used to shape the nonwovens.](image)

| Table 3. Fabric weight class [20]. |
|------------------------------------|
| Fabric weight class | Fabric weights (oz/yd²) | Fabric weights (g/m²) |
|---------------------|--------------------------|------------------------|
| Very light weight   | Less than 1              | Less than 35           |
| Light weight        | 2.0–3.0                  | 70–100                 |
| Medium weight       | 5.0–7.5                  | 170–240                |
| Heavy weight        | 9.5–12.0                 | 300–375                |
| Very heavy weight   | More than 15.0           | More than 475          |

| Table 4. Thickness level of the fabric [20]. |
|---------------------------------------------|
| Thickness level | Thickness (mm) | Thickness (inches) |
|-----------------|----------------|--------------------|
| Thin level      | Less than 0.23 | More than 0.0080    |
| Medium thickness level | 0.23–0.46 | 0.00900–0.0180 |
| Very thick level | More than 0.47 | More than 0.019     |
reading of the required force in pounds. The extent of the stretching prior to breaking is measured in millimeters.

2.3.5. Test of bursting strength

The bursting strength is evaluated using the ASTM D 3786-01 test standard. The test involves the use of a rubber diaphragm plate which expands under exposure to fluid pressure. When the fabric is stretched to its breaking point, the diaphragm fluid pressure is rapidly decreased, causing the diaphragm to collapse. The resistance of the fabric to penetrating pressure is equal to the internal fluid pressure which causes the diaphragm to expand. It is measured in kilopascals, or pounds per square inch, which can also be expressed as kg/cm².

2.4. Design and production of fruit wrapping

2.4.1. Design of the fruit wrapping cloth

The design of the fruit wrap sought to minimize shock while permitting the appropriate airflow. The basis of the design is a mesh foam capable of covering most common fruit types. In this case, Kimju guava, pear, and tomato are the mature fruits selected, while the design of the wrapping should be suitable to cover a range of fruit sizes. The same basic technique is applied for the wrapping, whereby the side surface is covered, and an opening is provided at the top and bottom to allow ventilation. Closing the wrapping would cause heat to be retained, thus overheating the fruit. It is important that the packaging is suitable for the size of the fruit. Kimju guava has a typical diameter of 5–12 cm while the pear is usually smaller at 5–10 cm in diameter. The tomato is smaller still at 3–10 cm in diameter.

2.4.2. Preparation and design of the fabric

The design of the nonwoven fabric fruit wrapper takes the form of a cylindrical sleeve to wrap around the surface of the fruit while providing ventilation at the top and bottom. The size is designed in accordance with the typical size of the fruit type. For the study purposes, the size selected is in line with the typical size expected for a medium-sized fruit specimen of each type. The fabric could therefore be used for multiple trials with readily available fruit samples. Upon determination of the size, the nonwovens are then sewn together as shown in the provided images. All three fabric types are tested with all three fruit types. It is possible to increase the airflow by perforating the fabric. The sample fabrics are therefore further separated into perforated and non-perforated sample types. The tests are carried out using five samples of each fruit type for each of the fabric types. In total 120 fruits were required; the selected samples are commercially available, fresh, and of medium size.

2.5. Fruit quality testing using a spectrophotometer and color value comparison (ΔE)

The experiments are conducted after wrapping the fruit samples in the fabric wrappers. Five samples were used for each combination of fruit type and nonwoven fabric type, including perforated and non-perforated categorizations. Analysis of the fruit color allows an assessment of the fruit quality to be made. The most widely-used color measurement device today is the spectrophotometer making use of the L*, a*, b* system. This is a three-dimensional color system in which the L* axis indicates lightness in comparison to the +L* value. Black can be represented as white through −L*. The (a*) axis represents the color wheel from green (−a*) to red (+a*), while the (b*) axis shows the spectrum from blue (−b*) to yellow (+b*) in line with the ASTM D 1729 test standard for the CIE LAB system (L*, a*, b*) quality measurement approach presented in Figure 4. The colors of the three fruit types were assessed using the CIE LAB Colorimeter (L*, a*, b*). The machine is positioned to allow the head to face the fruit in order to obtain the color value before the fruits are then wrapped in the different types of wrapper: perforated cotton, polyester-cotton blended fabric, perforated polyester cotton blended fabric, polyester, perforated polyester, and commercially available mesh foam. Five samples for each fruit are used, with five color value readings taken accordingly. The fruit colors are recorded in the fruit color recording table, and an average value is determined for each type of fruit. Changes in color values are checked at three day intervals for a period of ten days, while the average color values are recorded every day in order to assess the color difference (ΔE). Finally, the results are used to produce a chart to analyze the test findings.

3. Results and discussion

This study employed cotton and polyester scraps to produce nonwovens which were then wrapped around the fruit samples using an attached needle. The following section explains the relevant properties of the fibers and fabrics, and describes the outcomes of the processes used to preserve the fruit.

3.1. Fineness of cotton fibers

A cotton fineness meter was used on the basis of the ASTM D1448 test standard to assess the fineness of five samples of cotton fibers. The mean was then calculated, with the fiber resolution averaging 3.42 denier. The ASTM D5332 test standard was used to check the length of the cotton fibers using twenty samples of each type. The mean length was 20 mm. An ASTM D5103 test was then performed for polyester fiber length with an expected value of 33.7 mm. The cotton and polyester fibers can be categorized as staple fibers on the basis of the long range from 20 to 460 mm.

3.2. Nonwoven fabric production

The needle-punching method was used to produce nonwovens from cotton and polyester waste. The materials used were 100% cotton fiber,
50:50 cotton and polyester fiber, and 100% polyester fiber. When the adhesion experiment was performed on needle-punched nonwovens as shown in Figure 5, examination with the naked eye indicated that generated nonwovens offered significantly greater thickness than nonwovens. The drawback, however, is that nonwovens have poor tensile strength and can expand under high temperatures. In cases where the fabric weight was lower than the trial resolution and performance concerning the scope, experimental nonwovens could be tested.

### 3.3. Weight of nonwoven fabrics

A number of fabric properties were determined for the nonwovens, including fabric thickness, weight per unit area, air permeability, tensile strength, and penetrating strength. Figure 6 shows the results of the fiber length tests, the weight and thickness of the nonwovens, their air permeability, and their tensile strength. The weight of the nonwovens was measured after first cutting the sample fabric into circles of size 100 cm². Ten samples were prepared in line with the ASTM D 3776-96 standard. The tested samples comprised 100% cotton fiber nonwovens, a blended cotton and polyester nonwoven, and 100% polyester nonwovens. It was reported that the weight per unit area was 82 g/m² for cotton, 96 g/m² for the blend, and 90 g/m² for the polyester, which was less dense than expected. It may be the case that during the cutting of the fiber card, some fibers may have become trapped in the carding machine, pulling the needle and leading to stretched fibers. The outcome would be a reduction in weight per unit area.

### 3.4. Thickness of nonwoven fabrics

A fabric thickness tester was employed to test the thickness of 20 samples of various types in line. The thickness results for the nonwovens were found to be in the range of 1.28–1.49 mm as indicated in Figure 6. These findings indicated that the nonwovens fabric could be classified as highly dense according to the categorizations in Table 2. At the conclusion of the manufacturing process the fibers were carded into sheets, and no further processing was performed. However, when fed through a needle-attached nonwovens machine, the thickness was decreased.

### 3.5. Air permeability of nonwoven fabrics

The ASTM D737 test standard was used to assess air permeability of the nonwovens at the Textile Industry Development Institute. Based on this standard, the best air permeability was recorded for polyester nonwovens at 160 cm³/s/cm². Since polyester also offered the best breathability and ventilation, and did not retain heat, it was an excellent choice for fruit preservation over longer periods of time. The minimum air permeability of 87.95 cm³/s/cm², was recorded for the blended cotton and polyester nonwovens as can be seen in Figure 6. It can be inferred that the ventilation in the blended fabric is inadequate when compared to the 100% polyester sample.

![Figure 6. The chart shows the properties of various types of nonwoven fabrics.](image)

### 3.6. Tensile strength of nonwoven fabrics

Testing of tensile strength was carried out via grab test in accordance with the ASTM D5034-95 test standard. The polyester fiber nonwovens were tested in both longitudinal and vertical directions, and offered superior results compared to 100% cotton or the cotton blend with polyester. The longitudinal test demonstrated tensile strength of 29.44 N while the elongation before breaking was 236.884 mm. The transverse test achieved tensile strength of 24.532 N, and elongation of 220.448 mm. In contrast, cotton nonwovens achieved tensile strength of 1.239–2.098 N and elongation of 68.701–93.688 mm. The performance of the polyester fibers can be explained by the greater strength and fiber length compared to cotton. When the nonwoven fabric is produced via needle-punching, these longer fibers are better able to link together, providing the increased strength compared to other nonwovens, as shown in Figure 7.

![Figure 7. A chart depicting nonwovens' characteristics.](image)
3.8. Design of the fruit wrappers

The fruit wrapper design and cutting can be seen in Figure 8. All three types of nonwovens are used to produce the fruit wrappers in both standard and perforated forms, with the latter allowing for increased ventilation. Those fruits with a size most closely matching the wrapper samples are selected for the fruit wrap test. The nonwovens are then cut to a suitable size, and the fabric is sewn together at the corners using a hemming sewing machine. This results in the creation of a fruit wrapper which opens on both sides like a bag, allowing the whole fruit to be covered. This final wrapper can be seen in Figure 9.

3.9. Fruit wrapping with nonwovens

The experiments were conducted by wrapping the three different types of fruit: Kimju guava, pear, and tomato. A color spectrophotometer was used in accordance with the ASTM D 1729 test standards to assess five samples of each fruit type with each different kind of nonwoven wrapping. The color value standards are well-known internationally and set a clear standard. The changes in color (ΔE) were evaluated by considering the mean values for the color obtained each day. Where a significant color difference is observed, it can be concluded that there has been a significant difference in the fruit quality since the previous measurement was taken. Where the color change is low, this suggests there is a low probability of fruit deterioration during the observation period. If the color difference (ΔE) is lower than 0.7, it cannot be detected by the human eye. The interpretation guidelines for the color values are shown in Table 5 below.

The colorimeter was employed to take color measurements of all samples at three-day intervals, and the mean values for each interval were used to calculate the color difference (ΔE). The findings indicated that the smallest color difference over a ten-day duration for the Kimju

![Figure 8. Design and cutting of the fruit wrapper.](image)

![Figure 9. The final fruit wrapper design.](image)

![Figure 10. The color difference (ΔE) of Kimju guava.](image)

Table 5. Interpretation of color chart analysis.

| The symbol | Meaning | Color comparison (times measured) | Period (days) |
|------------|---------|----------------------------------|---------------|
| ΔE 1       | Using the color values read in the C.I.E. LAB system (L*, a*, b*) to compare the color difference (ΔE) from the formula: $\Delta E = \sqrt{\Delta L^2 + \Delta a^2 + \Delta b^2}$ | 1 and 2       | 1 to 4         |
| ΔE 2       | 1 and 3 |                                  | 1 to 7        |
| ΔE 3       | 1 and 4 |                                  | 1 to 10       |
Tomato – Pear – Kimju guava

...nonwovens were especially effective, producing a much smaller color difference than the other nonwovens in terms of color difference ($\Delta E$). The perforated cotton and polyester blend performed better than the other nonwovens in terms of color difference ($\Delta E$) after ten days than the other nonwoven fabrics which were tested. The perforated cotton and polyester blend performed better than the other nonwovens in terms of color difference ($\Delta E$) over the ten-day test period.

Figure 12 illustrates test results for wrapping the tomato in different nonwovens. All samples’ colors were measured using a colorimeter every three days, and the average of those observations was used to determine the color difference ($\Delta E$). The results indicate that perforated cotton nonwovens were especially effective, producing a much smaller color change than the alternative nonwovens, and also performing better than mesh foam. Meanwhile, when considering transportation over various periods of time, it can be seen from Table 6 that the different fruits and different travel durations require the use of different wrappings. It is therefore the case that a specific fruit, traveling for a specific period of time, will be best served by a specific type of nonwoven fabric wrapping.

4. Conclusions

This research study investigated the use of cotton and polyester scraps to create nonwoven fabrics via the needle-punching technique for the purpose of producing fruit wrapping materials. The properties of the different fibers are first of all tested and analyzed prior to creating the nonwoven fabrics. The nonwoven fabric properties are subsequently also tested. The fabrics were then designed to form a wrapper which could be used to cover and protect three different types of fruit: Kimju guava, pear and tomato. Tests of color change ($\Delta E$) over a ten-day period were used to determine the effectiveness of the different types of nonwoven fabric wrapping in preserving the quality of the fruit samples. The findings suggest that the Kimju guava should best be wrapped in perforated cotton nonwoven fabric since this material showed the smallest color difference ($\Delta E$) at 29.89. Meanwhile, the pear should be wrapped in mesh foam since the smallest color difference ($\Delta E$) was achieved at 1.81. Finally, the tomato should be wrapped in cotton fiber nonwoven fabric, since the smallest color difference ($\Delta E$) was 0.95 with this material.

During the experimental process, it was also observed that there were a number of points which should be addressed in the use of cotton and polyester scraps to create nonwovens for fruit preservation purposes. Firstly, the thickness of the nonwovens should be increased since this would prevent the bruising of the fruit. Secondly, it is important to regulate the temperature. The tests were not conducted in particularly hot or cold conditions, but if fruit is exposed to temperature extremes,
this can result in dehydration, while a very humid atmosphere can lead to the growth of mold which can cause the fruit to rot.

Declarations

Author contribution statement

Sujira Khojitmate: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Montien O-thongkham: Performed the experiments; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Bintasan Kwankhao: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

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Additional information

Data availability statement

The authors do not have permission to share data.

Declaration of interest’s statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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