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Utilization of Eco-Friendly and Microfiber Wrapping Fabrics in Prolonging the Shelf Life of Ripe Banana Fruit

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Abstract
Food packaging plays a crucial role in our lives because it protects foods against contamination sources and preserves their properties throughout their entire shelf life. Banana is one of the rhizomatous plants and is currently being cultivated in many countries around the world. It is the fourth-most important global food crop. Therefore, this research aims to investigate the relationship between different weft materials and the functional properties of the produced packing fabrics. In this paper, the fabrics that are used as an alternative to petroleum packaging products are fabricated as a sustainable solution that aims to extend the shelf life of bananas during storage at room temperature. For this objective, five samples were produced using weave structure (twill 1/3) and five different weft materials (polyester microfiber 300/576, polyester microfiber 300/288, bamboo, raw cotton, and blended bamboo cotton yarn). Additionally, using bleached cotton 50/2 Ne as a warp with a mid-density of 36 warp/cm causes proper porosity. Mechanical, physical, and functional properties such as tensile strength, stiffness, air permeability, and moisture management (MMT) of all the fabric samples were determined; in addition, more performance evaluations were conducted on the produced wrapping fabrics. Fabrics have been wrapped around bananas as packaging bags, and then the experimental parameters on the bananas of the same bunch have been tested to show the packaging efficacy for the longest shelf life. Our finding showed that there is a direct relationship between the production of wrapping fabric (S1) and the decrease in banana weight by a percentage of 65%. The best sample performance for use as a banana wrapping fabric evaluated by radar chart is sample (S1) on its back, manufactured with (25% microfiber 300/576 den: 75% bleached cotton), which can prolong the banana fruit shelf life by 34.2% compared with control sample.
Originality/value: This work was addressed to analyze the impact of using five different weft materials on its performance as the packing fabric to achieve the desired prolong the banana fruit shelf life.

Keywords: Sustainable textiles, Ripe banana packaging, moisture management, Air permeability, Prolonging the Shelf Life, Eco-friendly, Wrapping Fabrics.

1. Introduction

Textile packaging is one of the most technical textiles that can be used in carrying, storing, and protecting industrial, agricultural, and other goods. Eco-friendly packaging is becoming increasingly important in today's society as climate change continues to pose a significant threat to our planet. [1] These eco-friendly packaging solutions can include wrapping fabrics, particularly when the intended product is a fruit that produces specific gases out of its peel as a result of the ripening process. [2] Ethylene gas is a natural plant hormone that helps regulate the ripening process in fruits such as apples, bananas, and avocados. [3] Plastic bags have a lot of environmentally friendly substitutes, like paper bags, jute bags, biodegradable bags, and reusable bags.

Bananas are one of the most widely consumed fruits globally. [4] They are known for their high nutritional value and are a great source of potassium, vitamin C, and dietary fiber. [5] It grows in tropical regions and is cultivated in over 150 countries. Bananas are typically harvested when they are still green and have ripened off the tree. [6] They are then transported to various markets and grocery stores, where they continue to ripen and turn yellow. [7] The ripening process of bananas can be influenced by factors such as temperature and humidity.

A crucial factor in the ripening process of bananas is temperature. [8,9] The ideal temperature range for banana ripening is 13°C to 27°C (55°F to 80°F). [10] The ripening process of bananas will slow down if the

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temperature is too low, and their shelf life will be shortened if the temperature is too high. Furthermore, brown stains on the bananas can occur from an excessively high temperature, which will lower the bananas' quality. [11]

Another important element that influences how quickly bananas ripen and decay is humidity. [12] For proper ripening, bananas need about 85–90% relative humidity. The bananas will dry up, get rough, and lose flavor if the humidity is too low. Conversely, if the humidity is too high, it can cause the bananas to rot and develop mold, which can lead to spoilage. [13] This is why bananas are often stored at cool temperatures to extend their shelf life. Additionally, some retailers use special ripening rooms or ethylene gas to control the ripening process and ensure that bananas reach consumers at their desired level of ripeness. [12]

However, it is important to note that bananas should not be stored in the refrigerator, as it can cause them to turn black and become mushy. Instead, they should be kept at room temperature until they reach the desired level of ripeness. [9] Once ripe, bananas can be eaten. bananas wilt Indicators typically involve changes in color, texture, and firmness. As bananas wilt, their vibrant yellow skin may start to develop brown spots or turn completely brown. The texture of the fruit becomes softer and mushier, and the firmness decreases significantly. Additionally, the aroma of the banana may become stronger as it wilts. It is important to consume bananas before they reach this stage to enjoy their optimal taste and texture. [7]

Banana spoilage can occur when the fruit is exposed to excessive heat or moisture. This can lead to the growth of mold or bacteria, causing the banana to become slimy and develop an unpleasant odor. It is important to avoid placing them near other fruits that release ethylene gas, as this can accelerate the ripening process and increase the likelihood of spoilage. [14]

Reduced O2 and increased CO2 inhibited the action of ethylene, as was previously mentioned in research, delaying the ripening processes of bananas treated with ethylene. [15] That could be carried out by packaging banana fruit. The amount of time that a packaged good remains marketable or of acceptable quality under particular storage circumstances is known as its shelf life. A product's shelf life is determined by the initial quality of the food products, the degree of quality change that is permitted, the state of the environment at the time, the most durable qualities of the packaging materials, and the food products' compatibility with their packaging. [16]

Breathability is one of the fabric's wrapping qualities that has progressively grown in significance. Packaging needs to be made in a way that allows the thermal balance of bananas to be maintained in a variety of environmental circumstances in order to have the longest shelf life. [17] It should do this duty without preventing breathing-induced humidity from evaporating. Moisture management can be defined as the controlled movement of water vapor and liquid water (perspiration) from the surface of the skin or peel to the atmosphere through the textile substrate. [18] By doing this, water drops won't accumulate adjacent to the banana peel. Bananas that are packed in fabrics that swiftly dissipate moisture really help the fruit chill down. Advances in moisture management techniques encompass a range of textile types, including hydrophobic, hydrophilic, hydrophobic-hydrophilic, microfiber, special fiber, waterproof-breathable, spacer fabrics, phase change materials (PCM), and the pinecone effect. [19]

Worldwide, plastic bags are causing irreversible harm to the environment, particularly to agriculture. The use of plastic bags has a negative impact on the environment, affecting the land, water, and air. Fossil fuel is used to make plastic bags, which releases harmful gases that are bad for the planet's many life forms. [20] Not only does it harm the environment, but it also helps to increase the ripeness due to the interaction between polyethylene and ethylene exposure time and a higher concentration of CO2, which generates a huge opportunity for molds and bacteria to grow. [21]

The nature of the textiles as packaging fabrics, which have sufficient porosity, allows bananas to breathe and prevents the growth of bacteria. Bamboo and cotton fibers have great ecologically friendly properties as substitutes for synthetic fiber-based fabrics made from petroleum-based products. [22] A significant portion of the fabric-weaving process involves combining several fiber types with varying blend ratios to cut expenses and alter the generated yarns' characteristics and fabrics. [23] Bamboo is a crucial plant fiber that can help with polymer composite design and advancement. The material exhibits a micro-fibrillary angle of 2–10◦ and 60% cellulose with highly satisfied lignin. It has been shown that this type of fiber has high resilience, stability, and tenacity, and that its thinness and whiteness degree are comparable to those of regular finely bleached viscose. Because of the huge number of micro-gaps and micro-holes packed into the fiber's cross-section, it has significantly more notable moisture absorption and ventilation. [24] Because of their noteworthy antibacterial properties, natural materials like bamboo can tolerate the harsh conditions posed by their environment, including resistance to microbial destruction. [25]

The transportation of liquids in textile materials is a crucial element that influences the functional application of fabrics. Quick drying and wearer physiological comfort are made possible by fabrics that have the ability to quickly drain moisture or maintain a fast liquid flow. Capillary motion moves liquid through fabric pores created in the spaces between threads during textile construction. Liquid moves through fiber bundles with the help of capillary force, which is a result of interface tension and is influenced by the fiber surface area.

Thus, the arrangement and shape of fibers in a textile have a significant impact on capillary action. Fabric interlace is classified into three categories based on its geometry, size, and creation method: yarn-space, which is the space between fabric stitches; fiber-space, which is the space inside yarn; and micro-space, which is the amorphous region inside fiber. Micro- and fiber-space are critical to long-distance liquid movement.

Nevertheless, fiber may not be able to significantly absorb liquid into the fiber body for certain materials. So the fiber space that is affected by fiber alignment plays an important role in hydrophobic polyester fiber wicking. [26]

Despite its lack of environmental authenticity, polyester microfiber contributes significantly to its absorption of humidity. Microfibers are synthetic multifilament yarns with incredibly tiny individual filaments (≤ 1 dtex). The yarn count is expressed in dtex, which is equivalent to a specific weight (grams) in 10,000 meters of yarn. When compared to other fibers, the thickness of the microfiber fiber may be sensed; for instance, it is 60 times thinner than human hair and three times thinner than cotton. Because microfibers are far thinner than normal fibers, significant differences arise in their composition that impact the characteristics of yarns, textiles, and fibers. [27]

According to the latest studies, with their exceptional stability, resistance to multidirectional stresses, and complete protection against microorganisms, the newly developed 3D fabrics made of aramid (upper fabric, face) and modacrylic (lower fabric, back) fibers in a plain weave and twill with higher Polymers 2022, 14, 4952 14 of 15 densities are advised for use as packaging materials for medical sterilization. [28]

This research aims to determine the efficacy of using polyester microfiber, bamboo, cotton, and bamboo blended with cotton as banana packaging. Air permeability, moisture management, and morphological changes of banana fruit during packaging time have an effective role in prolonging banana fruit.

2.Experimental

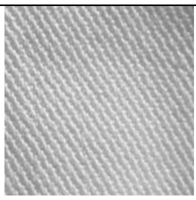
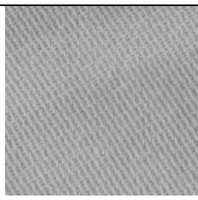
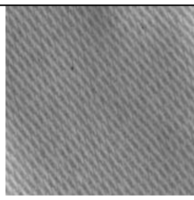
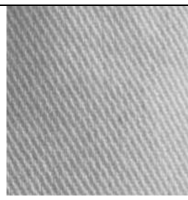
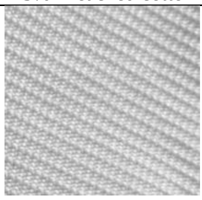
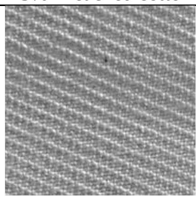
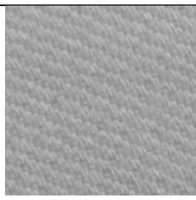
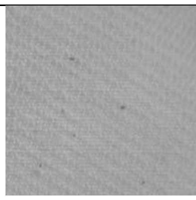
2.1 Materials and Methods

Bleached cotton yarns of 50/2 Ne were used as warps with a density of 36 ends/cm. All samples were woven at the Faculty of Applied Arts, Helwan University, on an electronic dobby loom. In this experiment, polyester microfiber 300/576 denier, polyester microfiber 300/288 denier, bamboo, raw cotton, and 70% bamboo blended with 30% raw cotton were the selected wefts at a density of 40 picks /cm. the weft count equivalent to 16/1 Ne. Consequently, the percentage of weft materials appearing on the face and the back of the fabric is different as shown in Table 1 and Table 2.

Table 1: Specification of produced samples

		Weft			Warp			weight
	Structure	**Materials**	**count**	**density**	**Materials**	**count**	**density**	**g/m^2**
S1	Twill 1/3	100%polyester microfiber	300/576 den	20 picks (2 wefts per 1 pick) 40 wefts	Bleached Cotton	50/2 Ne	36 ends / cm	202
S2		100% polyester microfiber	300/288 den					210
S3		100% Bamboo	16/1 Ne					240
S4		100% Raw cotton						220
S5		70%Bamboo /30% Raw cotton						215

Table 2: Ratio of materials appearance in face and back of samples

	S1	S2	S3	S4	S5
face					
	75% Polyester microfiber300/576 den: 25% Bleached cotton	75% Polyester microfiber300/288 den: 25% Bleached cotton	75% Bamboo: 25% Bleached Cotton	75% Raw cotton: 25% bleached cotton	52.5% Bamboo 22.5 % Raw cotton: 25% Bleached cotton
Back					
	25% Polyester microfiber300/576 den: 75% Bleached cotton	25% Polyester microfiber300/288 den: 75% Bleached cotton	25% Bamboo: 75% Bleached Cotton	25% Raw cotton: 75% bleached cotton	17.5 % Bamboo: 7.5% Raw cotton: 75% Bleached cotton

2.2 Evaluation methodology

Many different tests were carried out on produced samples to evaluate the functional properties. Samples were placed under standard conditions for 24 h in accordance with ASTM D1776/D1776M (2020).[29]

2.2.1. Thickness [mm]

Thickness Gage apparatus is used according to *ASTM standard D 1777-96*, fifteen readings were obtained from various locations on each cloth, the specimen is set on the thickness gauge's anvil, and a weighted presser foot is lowered gradually over the course of five to six seconds to apply full pressure., The thickness of the specimen is determined by measuring the distance from the base to the foot.

2.2.2 Wight [gm/m^2]

The weight in grams of one square meter was gotten according to the stander of *ASTM D3776*. Three round, 10 by 10 cm pieces were cut from various locations on the fabric using a cutting die (Heals of Halifax). At least three samples from each fabric were weighed using an electronic sensitive balance, which has a capacity and sensitivity to weight within 60.1% of the mass of the specimens being examined.

2.2.3 Tensile strength at warp and weft direction [N]

Tensile strength test is carried out according to the specification of *ASTM D5034 -09* "standard test method for breaking strength and elongation of textile fabrics (Grab Test) with a load cell of 5 KN, and 7.5 cm gauge length.

2.2.4 Fabric stiffness [kN/m]

A fabric stiffness tester (circular bend procedure) is used to measure the bending height, flexural rigidity, and bending modulus of fabric according to standard of *ASTM D4032-08*. A bending test is used for measures the severity of the flexing action of a material.

2.2.5 Air permeability [Cm^3/cm^2.sec]

ASTM D737-04 is the standard that is used for air permeability of the fabric. In this experiment, Air vertically is penetrated through a known area of the fabric 20 cm ^{2}, it is important to adjust the pressure difference between the two sides of the fabric to 200 Pa, then the flow rate of air should be determined, and so the air permeability of the fabric. Three readings were taken from different places of each fabric

2.2.6 Moisture management test (MMT)

According to the standard *AATCC 195*. The fabric is tested in a standard testing atmosphere with 70% relative humidity and 20±2ºC temperature properties after the test specimen has been prepared. Moisture management tester MMT is used to detect, quantify, and record the transport behavior of liquid moisture in various orientations and is able to identify six main categories of textiles are mentioned and its grading in Table 3. It is also a tool used to quantify the dynamic liquid transport characteristics of three-dimensional textiles, including knit and woven materials:

- Absorption Rate - Moisture absorbing time of the fabric's inner and outer surfaces.
- One-way Transport Capability - Liquid moisture one-way transfer from the fabric's inner surface to outer surface.
- Spreading/Drying Rate - Speed of liquid moisture spreading on the fabric's inner and outer surfaces. (19)

Table 3: Grading of moisture management test (MMT) indices (AATCC 195). (19)

Grade Index		1	2	3	4	5
Wetting time, WT, s	Top-WT_T	≥120	20–119	5–19	3–5	<3
		No wetting	Slow	Medium	Fast	Very fast
	Bottom-WT_B	≥120	20–119	5–19	3–5	<3
		No wetting	Slow	Medium	Fast	Very fast
Absorption rate, AR, %/s	Top-AR_T	0–9	10–29	30–49	50–100	>100
		Very slow	Slow	Medium	Fast	Very fast
	Bottom-AR_B	0–9	10–29	30–49	50–100	>100
		Very slow	Slow	Medium	Fast	Very fast
Max wetted radius, MWR, mm	Top-MWR_T	0–7	8–12	13–17	18–22	>22
		No wetting	Small	Medium	Large	Very large
	Bottom-MWR_B	0–7	8–12	13–17	18–22	>22
		No wetting	Small	Medium	Large	Very large
Spreading speed, SS, mm/s	Top-SS_T	0–0.9	1–1.9	2–2.9	3–4	>4
		Very slow	Slow	Medium	Fast	Very fast
	Bottom-SS_B	0–0.9	1–1.9	2–2.9	3–4	>4
		Very slow	Slow	Medium	Fast	Very fast
Accumulative one-way transport capability, AOTI, %		<−50	−50 to 99	100–199	200–400	>400
		Poor	Fair	Good	Very good	Excellent
Overall moisture management capacity, OMMC		0–0.19	0.2–0.39	0.4–0.59	0.6–0.8	>0.8
		Poor	Fair	Good	Very good	Excellent

2.2.7 Banana Morphological changes

After wrapping banana fruits inside 10 different fabric samples for 10 days, some color changes appeared on the peel. The readings were taken every 72 hours. By using the image color summarizer software program, descriptive colour statistics for an image are produced. Also, banana weight is measured before and after the experiment. Measuring the weight loss of banana fruit was done by calculating the difference between the maximum and minimum values. One banana used as a control sample (wrapping at a piece of plastic bag).

3. Results and discussion

3.1 Effect of fabric materials on the tensile strength

As is known, the strength of a fabric depends not only on the strength of the constituent yarn but also on the yarn structure, yarn bending behaviour, and fabric structure. All sample parameters are constant except weft material. So, the differences in the same weave depend considerably on the material used in the weft yarn. It was found out that the extensibility of yarns in the weft direction influences the breaking force in the warp direction. Depending on the previous and as shown in Table 4, there are minor differences between the results of the samples tensile strength in the direction of the warp yarn.

Table 4 Results of the tensile strength in both directions

S	*Weft material*	*Warp material*	*Tensile strength in the direction of*	
			Warp / N	*Weft / N*
1	*Polyester microfiber 300⁄576 den*	*Bleached cotton*	*360*	*1860*
2	*Polyester microfiber 300/288 den*		*325*	*1400*
3	*Bamboo*		*322*	*1015*
4	*Raw cotton*		*345*	*473*
5	*70% Bamboo :30% Raw cotton*		*330*	*715*

With graphical representationas shown in Figure 1, it was proved that polyester microfiber yarns of S1 and S2 are the strongest and can withstand the most stress per linear density. Polyester microfiber of 300 /576 has more fibres at the cross section, making sample 1 stronger than sample 2 due to the maximum number of interlacing points, resulting in higher friction between the yarn microfibers weft and consequently also higher tensile strength in the warp direction. Warp and weft cotton yarns have approximately the same tensile strength (345, 473). Raw cotton yarns record a slight rise in tensile strength compared to bleached cotton, which could be explained by the waxy coating process on the weft fibres, which makes them stronger. Bamboo samples show good tensile strength due to the construction of the walls that work as support.

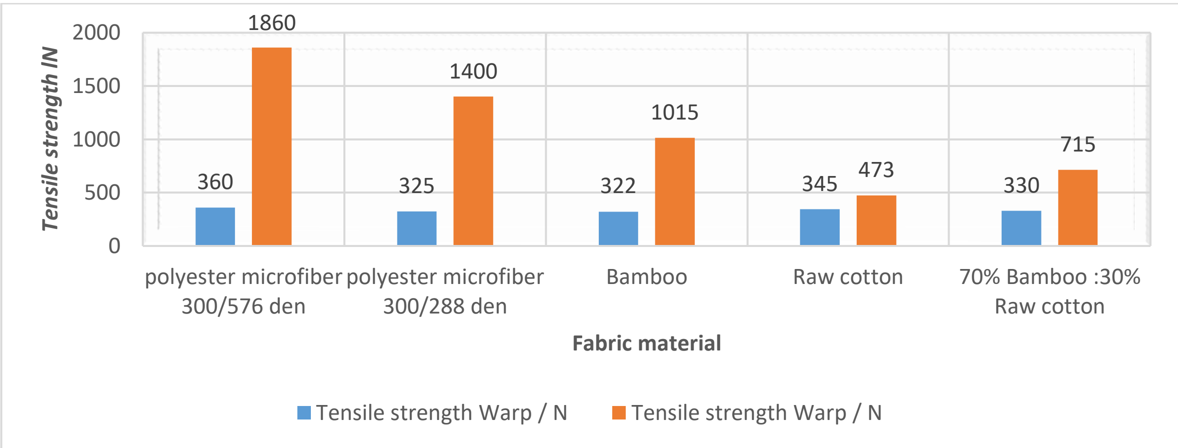


Figure 1 Variation of fabric tensile strength in the direction of the warp and the weft

3.2 Effect of fabric materials and the thickness on the stiffness

The resistance of a fabric to bending or flexing is known as its stiffness. It is dependent upon the fabric's composition, thickness, weave, finish, and yarn properties. The shape, fit, and movement of clothing, as well as the longevity and resistance to wrinkles, can all be impacted by the stiffness of the fabric. Table 5 shows the different results of the fabric stiffness.

Table 5 Results of the fabric stiffness

S	*Weft material*	*Fabric stiffness kN/m*	*Thickness mm*
1	*Polyester microfiber 300/576 den*	*4.15*	*0.5*
2	*Polyester microfiber 300/288 den*	*4*	*0.47*
3	*Bamboo*	*3.2*	*0.48*
4	*Raw cotton*	*4.3*	*0.53*
5	*70% Bamboo :30% Raw cotton*	*3.41*	*0.49*

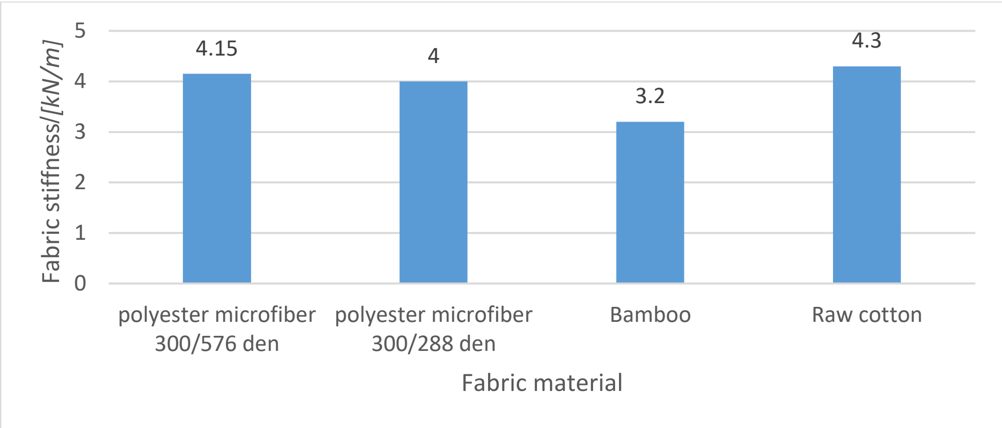


Figure 2 The effect of weft composition on the fabric stiffness

From Figure 2, it can be seen that sample 4 has the highest stiffness among all the samples, which is 4.3 *[kN/m]*, because the raw cotton fiber is surrounded by a thin layer of wax or a cuticle, which makes the fiber stiff. It is followed by sample 1, then sample 2. The high density of fibers in the cross section increases the stiffness of the fabric. Hemicellulose is a non-polymerized amorphous material found in bamboo between its fibers [30], so the bamboo fiber wefts indicate less stiffness 3.2 *[kN/m]*. Mixing bamboo wefts with raw cotton of high stiffness raises the whole fabric's stiffness.

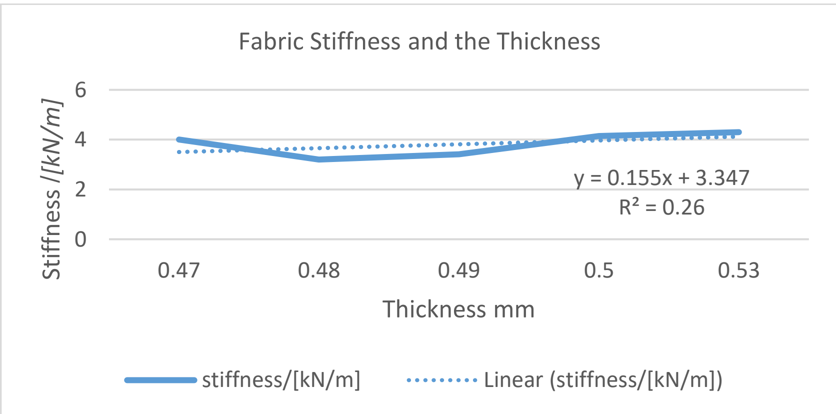


Figure 3 The relation between fabric stiffness and the thickness

As shown in Figure 3, there are a weak positive relation between the fabric thickness and the stiffness. As the thickness increases the stiffness records high values. Fiber composition factor has a greater impact on the fabric rigidity than the thickness. So sample 2 of polyester microfiber which has least thickness 0.47 mm has stiffness more than it is supposed to be according to the thickness curve of Figure 3.

3.3 *Effect of fabric materials and the thickness on the air permeability*

The air permeability of a textile material means the rate of air flow through a material when there is a pressure differential between the two fabric surfaces influenced by its void volume. In the fabric, the void volume affects by the spaces between the warp and weft yarns beside the fiber's areal density. Table 6 illustrates the results of air permeability and fabric thickness.

Table 6 Results of the fabric thickness and the air permeability test

S	*Weft material*	*Air permeability $Cm^3/cm^2.sec$*	*Thickness mm*
1	*Polyester microfiber 300/576 den*	*8.74*	*0.5*
2	*Polyester microfiber 300/288 den*	*12.4*	*0.47*
3	*Bamboo*	*11.66*	*0.48*
4	*Raw cotton*	*8.49*	*0.53*
5	*70% Bamboo :30% Raw cotton*	*10.75*	*0.49*

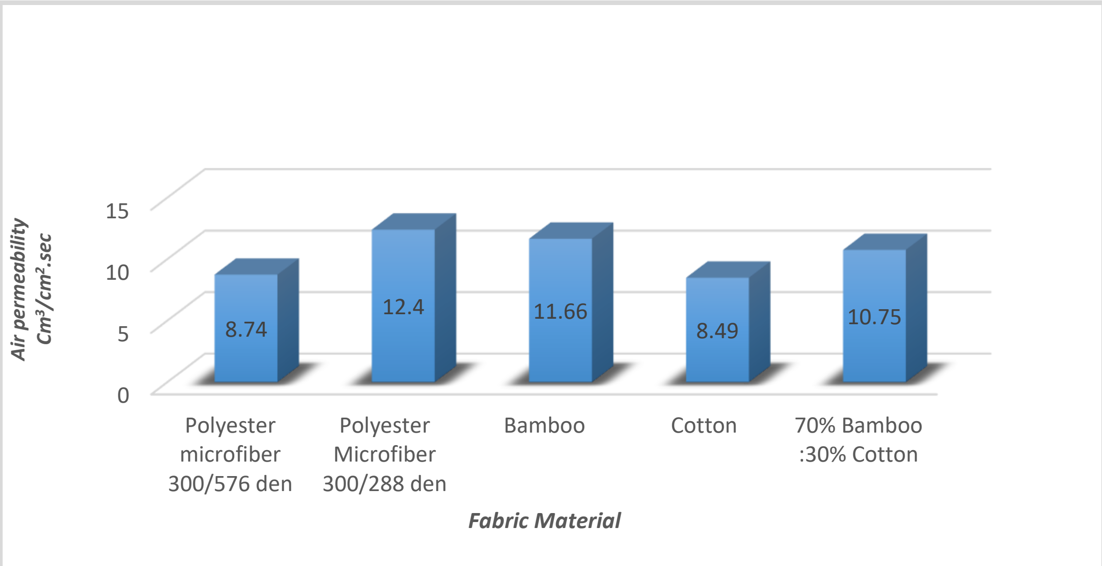


Figure 4 Effect of fabric material and air permeability

Based on Figure 4, the results of the air permeability of polyester microfiber 300/288 den are greater than those of polyester microfiber 300/576 den due to the decreasing fiber numbers in the yarn cross section. Raw cotton has less air permeability because of the wax coating layer on the yarn surface. For the same reason, blending raw cotton with bamboo fibers decreases air permeability. Bamboo fibers have walls that are naturally porous. But the pores that are being generated among the microfibers are larger, so microfibers of 300/288 density show more air permeability than bamboo fibers.

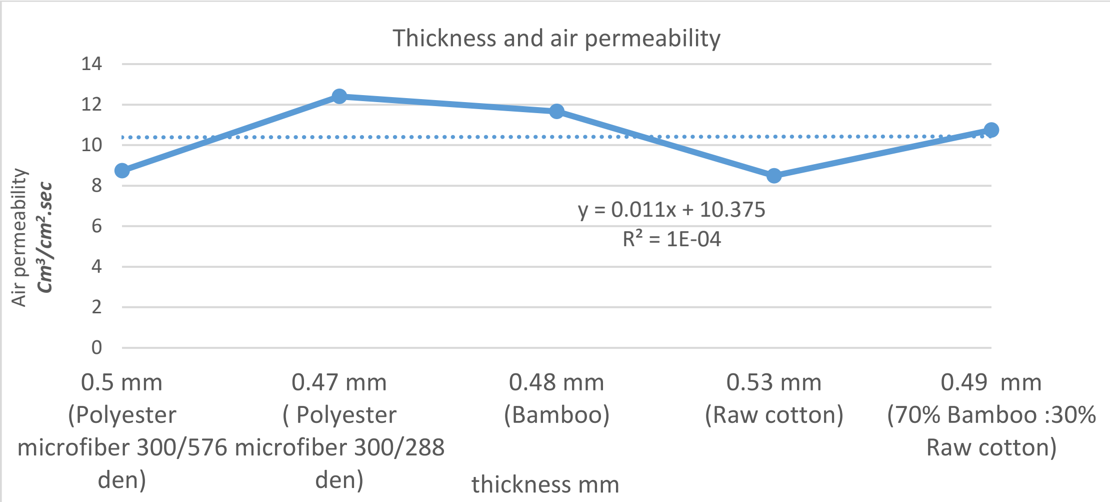
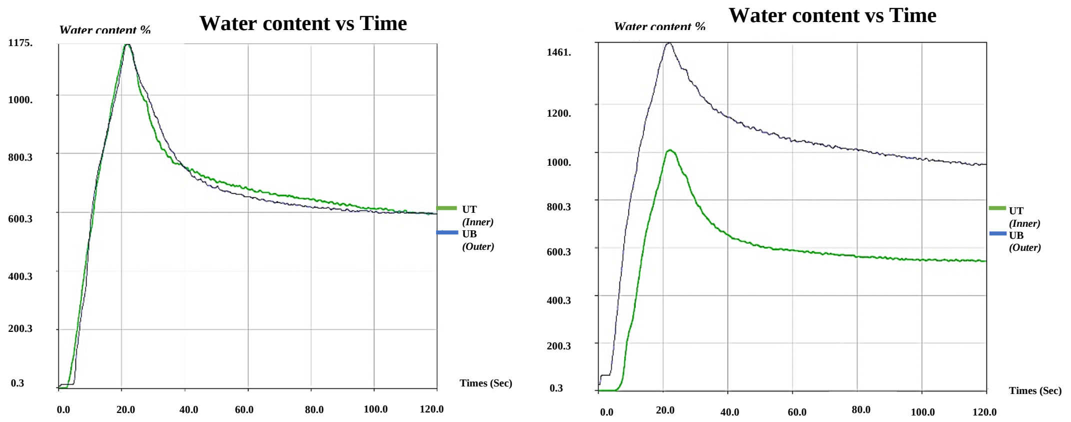


Figure 5 The variation of the air permeability of the woven different materials with the thicknesses

The air permeability affected by the pore depth, which could be expressed by the fabric thickness. Figure 5 shows a linear correlation that observes a strong positive relationship between the air permeability and the fabric thickness. The increase in fabric thickness raises the air flow rate according to the pore depth.

3.4 Effect of fabric materials on the moisture management

Liquid moisture transport behaviours in three dimensions (Top-Inside- Bottom). The following graphs illustrate the flow manner of water on the fabric's exterior and interior surfaces. The tester sensors record and measure changes in electrical resistance as the solution passes through and across the sample.



(a) (b)

Figure 6 Sample (1) water content curves through 120 seconds a) drop water on the face of the fabric (Twill 1/3) polyester microfiber 75%:bleached cotton 25% 300/ 576 den, b) drop water on the back of the fabric (Twill 3/1) polyester microfiber 25%:bleached cotton 75% 300/ 576 den

As shown in Figure 6, when the water drops at the face of the fabric of the (Twill 1/3) structure in Figure 1a, the relative water content of the top and bottom surfaces behaves differently than when the water drops at the back of the fabric of the (Twill 3/1) structure in Figure 1b. That mainly comes down to the type and the ratio of the surface material.

As a result of using the Twill (1/3) structure for S1 at the face side, the appearance ratio of polyester microfiber is 75% and that of bleached cotton is 25% in Figure 6a. In contrast, using the Twill (3/1) structure for it on the back side results in an appearance ratio of 25% for polyester microfiber and 75% for bleached cotton Figure 6b.

Table 7 Grading of MMT Indices of sample 1 applied on both sides.

		***Wetting time* (sec)**		***Absorption Rate* (% sec)**		***Max wetted radius* (mm)**		***Spreading Speed* (mm/sec)**		***OWTC***
		Top	*Bottom*	*Top*	*Bottom*	*Top*	*Bottom*	*Top*	*Bottom*	
S1	***F***	*Very fast* 2.137	*Very fast* 0.34	*Fast* 59.739	*fast* 53.5359	*Very large* 25.0	*large* 20.0	*Very fast* 6.24	*Very fast* 13.5827	*Fair* -10.362
	B	*Medium* 5.09	*Very fast* 0.325	*fast* 58.7889	*fast* 66.045	*large* 20.0	*Very large* 25.0	*fast* 3.2947	*Very fast* 16.5679	***Excellent*** 437.5997

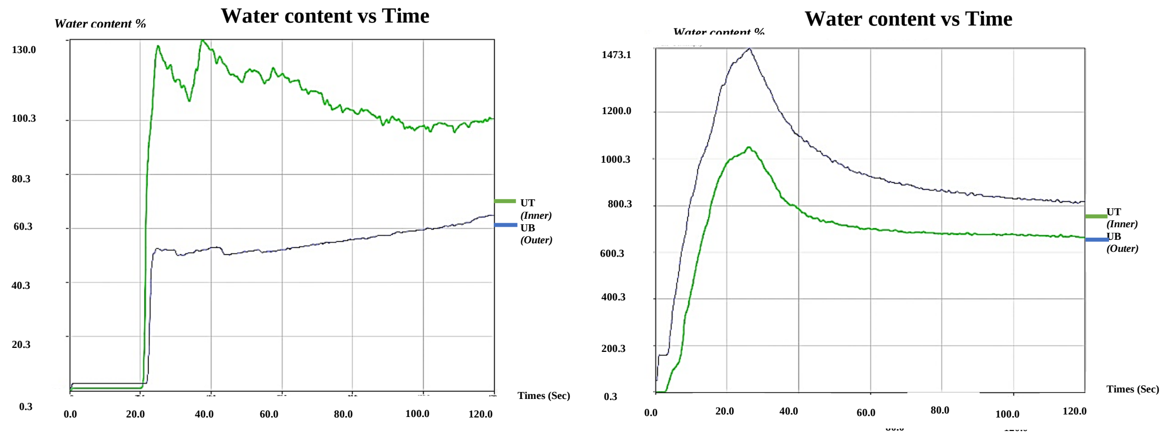
** Note: OWTC abbreviation of (One Way Transport Capacity)

As shown in Figure (6a) and Table 7, the top fibre material (75% polyester microfiber and 25% bleached cotton) contributes to getting mid-performance water-permeable fabric. That is indicated in Figure (6a) as the water content on the top surface is equal (50%:50%) to that on the bottom at almost the same time, reaching 600% at the second of 120 on both sides, indicating very quick transfer of liquid from top to bottom and fast absorption of water at the pumping time.

Most probably, the quick water transfer, which is clear through the congruence of the curve of the two surfaces, returns to the existing large percentage of polyester microfibers (75%), 300/576 den, that play as a capillary tube. It could absorb water and transfer across its tubes in record time. Accumulative one-way transport index (OWTC) gives a direct fair indication of fabric liquid transfer capability from inner to the outer layer.

On the other side, applying moisture management test on the other side of the same (back) sample as shown in Figure (6b) gives difference results. As shown in Figure (6b) and Table 7, the top fiber material (25% polyester microfiber and 75% bleached cotton) contributes to getting high-performance water-permeable fabric. That is indicated in Figure 1b as the water content on the top surface is less than the bottom and the water spread fast in the bottom side causing very large, wetted radius, also indicating very quick transfer of liquid from top to bottom and fast absorption of water at the pumping time.

Based on the presented results, Figure (6b) indicates the transfer of water from top to bottom that may occur by increasing the portion of bleached cotton compared to the microfiber yarns. As the bleached cotton is more breathable, it allows for fast water transfer. Finally, Accumulative one-way transport index (OWTC) gives a direct and excellent indication of fabric liquid transfer capability from inner to the outer layer.



(a) (b)

Figure 7 Sample (2) water content curves through 120 seconds a) drop water on the face of the fabric (Twill 1/3) polyester microfiber 75%:bleached cotton 25% 300/ 288 den, b) drop water on the back of the fabric(Twill 3/1) polyester microfiber 25%:bleached cotton 75% 300/ 288 den

Table 8 Grading of MMT Indices of sample 2 applied on both sides.

		Wetting time (sec)		*Absorption Rate (% sec)*		*Max wetted radius (mm)*		*Spreading Speed (mm/sec)*		*OWTC*
		Top	*Bottom*	*Top*	*Bottom*	*Top*	*Bottom*	*Top*	*Bottom*	
S2	***F***	*Slow* 20.325	*Slow* 21.575	*slow* 25.7919	*slow* 17.3091	*No wetting* 5.0	*No wetting* 5.0	*Very slow* 0.2441	*Very slow* 0.2301	*Fair* -43.669
	B	*Very fast* 2.2	*Very fast* 0.325	*medium* 43.6386	*fast* 54.6857	*Very large* 30.0	*Very large* 30.0	*Very fast* 6.067	*Very fast* 17.2685	*Very good* 245.2882

Sample 2 has the same specifications as Sample 1, except the number of capillary tubes is about half (300/288 denier), and so the diameter of it is bigger than that of microfiber yarns (300/576) denier.

As shown in Figure (7a) and Table 8, the top fiber material (75% polyester microfiber and 25% bleached cotton) indicates the water content on the top surface is greater than the bottom at almost the same time, indicating slow transfer of liquid from top to bottom and also slow absorption of water at the pumping time. In comparing Figure (6a) to Figure (7a), the effect of decreasing the number of capillary tubes helps slow the absorption of water and, as a result, makes it difficult to get the fabric wet. Accumulative one-way transport index (OWTC) gives a direct and fair indication of fabric liquid transfer capability from the inner to the outer layer. Moving to figure (7b), applying the MMT on the back of the gives an inverse result as the top fiber. (25% polyester microfiber and 75% bleached cotton), so the cotton here is the most effective material, and the 25% of the polyester microfiber 200/288 just decreases the OWTC by one degree from excellent to very good.

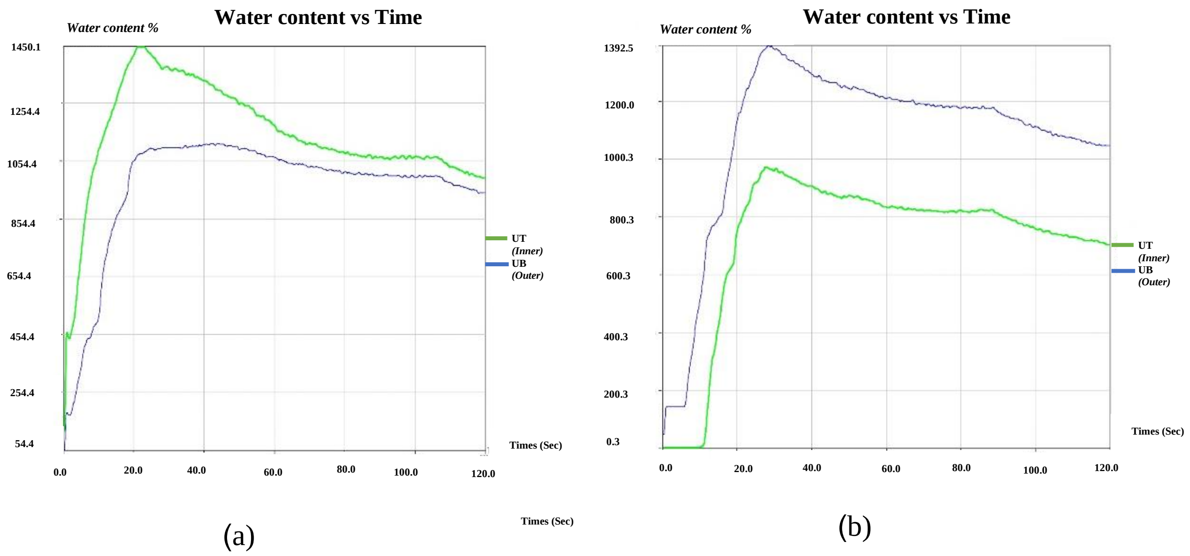


Figure 8 Sample (3) water content curves through 120 seconds a) drop water on the face of the fabric (Twill 1/3 Bamboo75%: bleached cotton 25%), b) drop water on the back of the fabric(Twill 3/1) Bamboo25%: bleached cotton 75%

As shown in Figure 8, when the water drops at the face of the fabric of the (Twill 1/3) structure in Figure (8a), the relative water content of the top and bottom surfaces behaves differently than when the water drops at the back of the fabric of the (Twill 3/1) structure in Figure (8b). That mainly comes down to the type and the ratio of the surface material.

As a result of using the Twill (1/3) structure for sample 3 at the face side, the appearance ratio of Bamboo is 75% and that of bleached cotton is 25% in Figure (8a). In contrast, using the Twill (3/1) structure for it on the back side results in an appearance ratio of 25% for Bamboo and 75% for bleached cotton.

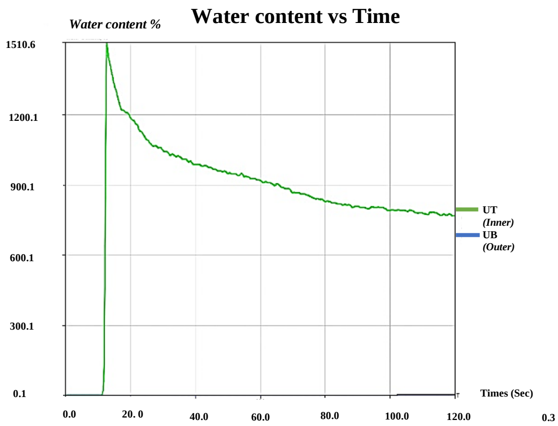
Table 9 Grading of MMT Indices of sample 3 applied on both sides.

		Wetting time (sec)		Absorption Rate (% sec)		Max wetted radius (mm)		Spreading Speed (mm/sec)		OWTC
		Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom	
S3	F	Very fast 0.325	Very fast 0.325	fast 61.7639	medium 42.3354	Large 20.0	Medium 15.0	Very slow 1.0	Very fast 13.5653	poor -177.1167
	B	Medium 9.778	Very fast 0.325	fast 53.1676	medium 47.3792	Medium 15.0	medium 20.0	slow 1.2566	Very fast 17.4069	Very good 361.8436

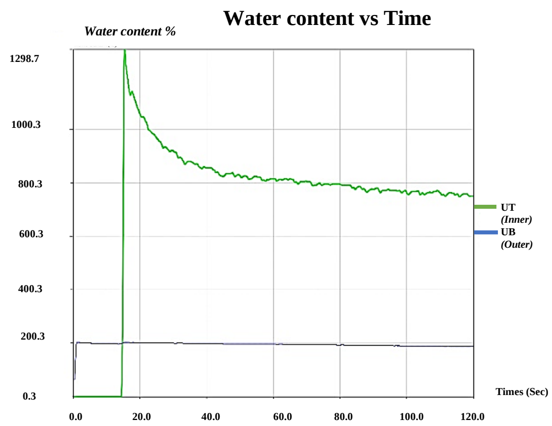
As shown in Figure (8a) and Table 9, the water content on the top surface (75% bamboo and 25% bleached cotton) is higher than the bottom at almost 120 seconds on both sides, indicating very slow transfer of liquid from top to bottom, although it gives fast absorption of water at the pumping time.

Most probably, the slow water transfer, which is illustrated by the curve, returns to the large amount of bamboo fibers (75%) that is supposed to receive the water. This is because the cell walls of bamboo are made up of cellulose layers, which have many tiny spaces between them. When these spaces become filled with water, the bamboo absorbs quickly and expands due to the increased pressure. so it has the ability to save water inside its cells, causing a very large water drop. Consequently, the spreading speed from the center to the maximum wetted radius is very slow. The previous analysis could explain the poor fabric liquid transfer capability from the inner to the outer layer.

As it is expected, applying a moisture management test on the back side, as shown in Figure 3b, increases the ability of the fabric to transfer liquid from top to bottom to a very good degree.



(a)



(b)

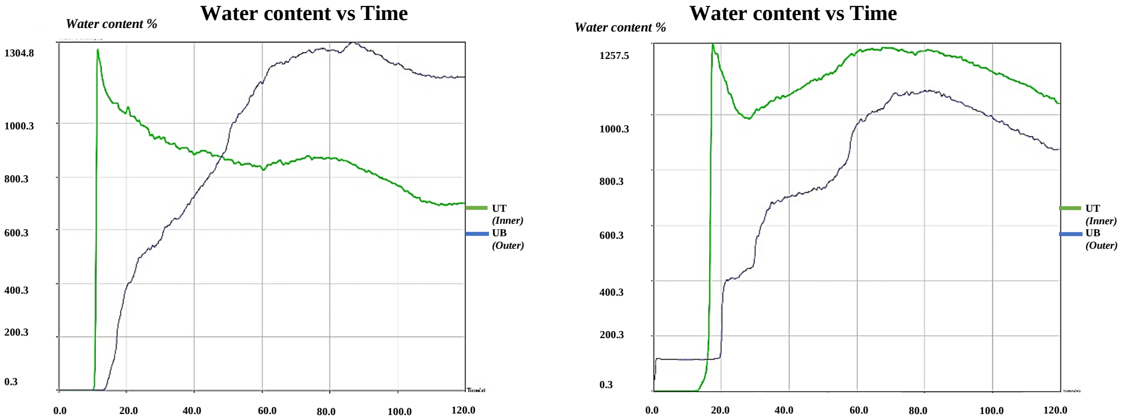
Figure 9 Sample (4) water content curves through 120 seconds a) drop water on the face of the fabric (Twill 1/3) Raw cotton 75%: bleached cotton25%, b) drop water on the back of the fabric(Twill 3/1) Raw cotton 25%: bleached cotton75%

As shown in Figure 9, when the water drops at the face of the fabric of (Twill 1/3) structure in Figure 4 a, it reaches its maximum very quickly. The graph also indicates that the water could not transfer to the bottom. Also, it can be seen that water absorption is the least or hydrophobic.

As a result of using the Twill (3/1) structure for sample 4 as a face side, the appearance ratio of bleached cotton becomes 75% and that of raw cotton is 25% in Figure (9b) . so, water content on the back side raise to reach 200.3% fixed all the time compared to Figure (9a).

Table 10 Grading of MMT Indices of sample 4 applied on both sides.

		Wetting time (sec)		*Absorption Rate (% sec)*		*Max wetted radius (mm)*		*Spreading Speed (mm/sec)*		***OWTC***
		Top	*Bottom*	*Top*	*Bottom*	*Top*	*Bottom*	*Top*	*Bottom*	
S4	***F***	*Medium 10.731*	*No wetting 120.0*	*Very fast 543.7847*	*Very slow 0.0*	*No wetting 5.0*	*No wetting 0.0*	*very slow 0.4593*	*very slow 0.0*	*Poor -830.6575*
	B	*Medium 13.684*	*Very fast 0.325*	*Very fast 520.8007*	*Fast 86.5114*	*No wetting 5.0*	*medium 15.0*	*very slow 0.3613*	*Very fast 17.4069*	*poor -536.3279*



(a) (b)

Figure 10 Sample (5) water content curves through 120 seconds a) drop water on the face of the fabric (Twill 1/3) Bamboo 52.5 %: Raw cotton 22.5 %: bleached cotton 25%, b) drop water on the back of the fabric(Twill 3/1) Bamboo17.5 %: Raw cotton 7.5%: bleached cotton 75%

As it is expected, using sample 4 on the face side the top fiber material (75% raw cotton and 25% bleached cotton) gain poor ability of the fabric to transfer liquid from top to bottom as shown in Table 10. The reason behind this is that raw cotton fiber represents 75%which is coated with natural oils and waxes that prevent any liquid from being absorbed. Also using the fabric in inverse occur a tight increasing in transferring some liquid to the other side by the help of decreasing the use of raw cotton fibers.

As shown in Figure 10, when the water drops at the face of the fabric of (Twill 1/3) structure in Figure (10a), the relative water content of the top and the bottom surfaces behave totally different than when the water drops at the back of the fabric of (Twill 3/1) structure in Figure (10b). That mainly comes down to the type and the ratio of the surface material.

Table 11 Grading of MMT Indices of sample 5 applied on both sides.

		Wetting time (sec)		*Absorption Rate (% sec)*		*Max wetted radius (mm)*		*Spreading Speed (mm/sec)*		***OWTC***
		Top	*Bottom*	*Top*	*Bottom*	*Top*	*Bottom*	*Top*	*Bottom*	
S5	***F***	*Medium 9.622*	*Medium 13.132*	*Very fast 475.922*	*Slow 23.5737*	*Medium 15.0*	*Large 20.0*	*Very Slow 0.711*	*Slow 1.0521*	*Fair 90.8272*
	B	*Medium 12.699*	*Very fast 0.325*	*Very fast 221.1461*	*Slow 15.3189*	*Large 20.0*	*Large 20.0*	*Slow 1.198 8*	*Very Fast 19.9069*	*Poor -249.6918*

As shown in Figure (10a) and Table 11, the top fiber material (Bamboo 52.5 %: Raw cotton 22.5 %: bleached cotton 25%) contributes to getting unregularly-performance water-permeable fabric. As the water content on the top surface decreases by the time, indicating medium transfer of liquid from top to bottom and fast absorption of water at the pumping time. After passing 40 seconds the content of water at the top reach the max and so the water transfer to the other side becoming greater than the water content on the top side.

That is as a result of using 52% of Bamboo fibers that can absorb liquids quickly and expands due to the increased pressure. Also, 22.5% of the fibers are from raw cotton that is a hydrophobic material.25% of fibers is from bleached cotton that can absorb liquids and transfer it to the other side. That can explain the fair degree of the OWTC that happen as a mean being poor at the first half time then excellent at the last half time. As shown in table 11 sample 5 shows poor water transferring as Bamboo and raw cotton become 17.5 % and 7.5% which are responsible for the spreading spread of water that become slow.

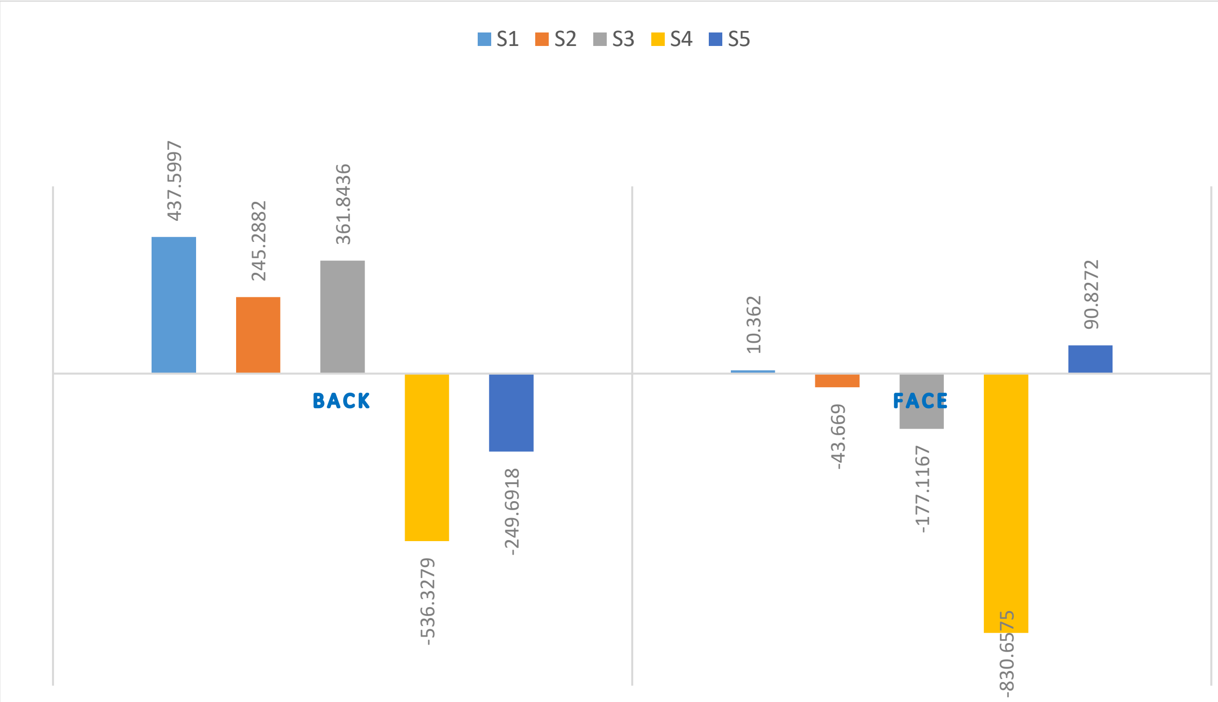


Figure 11 one-way transport capacity while using the fabrics on the face and on the back

As illustrated in Figure 11, sample 1 (used on its back) of 25% polyester microfiber and 75% bleached cotton shows the best water transport fabric sample (437.5997). That could back to the capillary tube property of the polyester microfiber (300/576 den), which has more fibers in its cross section than sample 2 of the polyester microfiber (300/288 den).

But sample 4 shows the least water transport capacity of the fabric, either using it on the face or back. The material of sample 4 (raw cotton) is the most likely reason for failing to move water into the other side of the fabric. The raw cotton is coated with wax that prevents water from being absorbed or transported to the other fabric side.

3.5 Banana Morphological changes

As shown in Table 12, there is a great change in packaging results before (Day 1) and after (Days 4, 7, and 10). As a result, the dark areas could be noticed to be enlarged, and on the other side, the yellow light colors decreased.

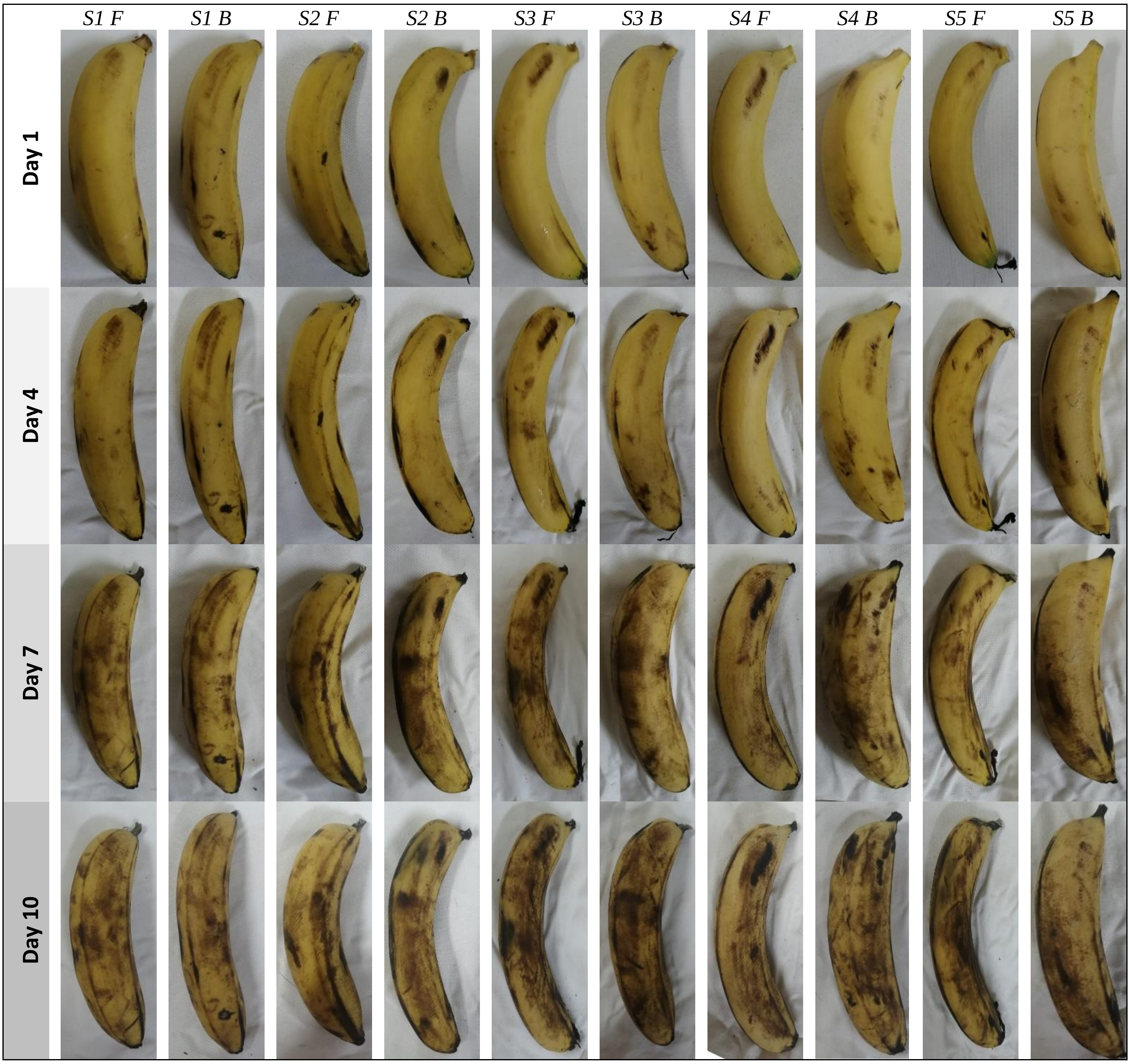


Figure 12 Banana ripenes chart wrapped in fabrics through 10 days

By analysing the banana colors through the ten ripeness days, the common dark colors of them are black, bister, dark brown, and raw umber, but the light ones are dark tan, sepia, sand dunes, and golden brown. The results, as shown in Figure 12, represent the percentages of image pixels' area. The dark areas increase with time. But the light color changes to other tones or darker ones, and sometimes it disappears.

Table 12 Color summerizing of bananas before and after wraping through 10 day

	COLOR	Black	Elster	Dark Brown	Raw Umber	Dark Tan	Sepia	Sand Dune	Golden Brown
***S1** F*	***Day 1***	*47.31%*	*04.20%*	*05.91%*	*02.92%*	***10.75%***	***07.00%***	***16.01%***	***01.12%***
	Day 4	*49.86%*	*05.48%*	*15.99%*	*03.40%*	***00.00%***	*12.87%*	*07.73%*	*02.01%*
	Day 7	*50.59%*	*05.62%*	*16.25%*	*09.75%*	*01.78%*	*00.21%*	***00.00%***	***00.00%***
	Day 10	*54.04%*	*09.56%*	*20.84%*	*12.08%*	*01.99%*	*00.19%*	*00.12%*	***00.00%***
	36.14%	*6.69%*	*5.36%*	*14.93%*	*9.16%*				
S1 B	***Day 1***	*51.33%*	*03.25%*	*06.32%*	*04.89%*	***02.42%***	***07.78%***	***16.93%***	***01.56%***
	Day 4	*51.44%*	*06.75%*	*08.40%*	*05.64%*	*00.46%*	*12.43%*	*10.00%*	*01.82%*
	Day 7	*51.70%*	*06.89%*	*09.67%*	*06.62%*	*05.89%*	*02.74%*	*02.59%*	*0.18%*
	Day 10	*52.51%*	*09.79%*	*12.04%*	*09.15%*	*02.70%*	***00.00%***	*00.00%*	***00.00%***
	17.7%	*1.18%*	*6.54%*	*5.72%*	*4.26%*				
***S2** F*	***Day 1***	*49.70%*	*03.55%*	*05.99%*	*04.26%*	***00.87%***	***07.11%***	***12.43%***	***01.90%***
	Day 4	*52.80%*	*04.31%*	*08.70%*	*07.14%*	*00.25%*	*15.68%*	*10.29%*	*02.62%*
	Day 7	*53.48%*	*05.00%*	*11.44%*	*09.99%*	*05.52%*	*02.39%*	*01.71%*	*00.10%*
	Day 10	*53.90%*	*07.53%*	*15.55%*	*15.11%*	*07.35%*	*00.88%*	*01.70%*	*00.17%*
	28.59%	*4.2%*	*3.98%*	*9.56%*	*10.85%*				
S2 B	***Day 1***	*49.50%*	*01.36%*	*03.84%*	*05.30%*	***00.39%***	***06.00%***	***26.32%***	***00.98%***
	Day 4	*55.22%*	*01.86%*	*04.99%*	*06.54%*	*00.21%*	*04.89%*	*22.16%*	*02.39%*
	Day 7	*56.13%*	*03.55%*	*08.87%*	*09.56%*	*05.51%*	*00.38%*	*00.25%*	***00.00%***
	Day 10	*60.03%*	*06.80%*	*11.87%*	*13.21%*	*04.62%*	***00.00%***	***00.00%***	***00.00%***
	31.91%	*10.53%*	*5.44%*	*8.03%*	*7.91%*				
***S3** F*	***Day 1***	*54.44%*	*01.05%*	*04.65%*	*03.37%*	***14.10%***	***04.01%***	***07.99%***	***00.51%***
	Day 4	*59.79%*	*01.98%*	*05.46%*	*04.72%*	*02.66%*	*07.76%*	*10.19%*	*01.66%*
	Day 7	*61.36%*	*09.39%*	*11.57%*	*6.73%*	***00.00%***	*00.34%*	***00.00%***	***00.00%***
	Day 10	*61.90%*	*11.36%*	*l5.23%*	*07.20%*	*2.12%*	***00.00%***	***00.00%***	***00.00%***
	32.1%	*7.46%*	*10.31%*	*10.58%*	*3.83%*				
S3 B	***Day 1***	*48.22%*	*00.45%*	*02.53%*	*02.67%*	***12.77%***	***01.11%***	***13.71%***	***00.22%***
	Day 4	*52.88%*	*2.37%*	*09.84%*	*9.45%*	*0.20%*	*3.78%*	*12.9%*	*01.19%*
	Day 7	*53.61%*	*7.26%*	*11.02%*	*12.65%*	*9.61%*	*0.25%*	***00.00%***	***00.00%***
	Day 10	*53.62%*	*17.43%*	*12.84%*	*14.08%*	***00.00%***	***00.00%***	***00.00%***	***00.00%***
	44.1%	*5.4%*	*16.98%*	*10.31%*	*11.41%*				
***S4** F*	***Day 1***	*51.47%*	*01.67%*	*07.20%*	*08.06%*	***16.75%***	***02.29%***	***03.05%***	***00.00%***
	Day 4	*51.89%*	*02.33%*	*07.40%*	*09.87%*	*08.06%*	*02.69%*	*17.60%*	*00.38%*
	Day 7	*53.92%*	*03.99%*	*11.87%*	*10.85%*	*0.60%*	*0.77%*	***00.00%***	***00.00%***
	Day 10	*67.07%*	*15.55%*	*20.66%*	*13.84%*	*05.45%*	***00.00%***	***00.00%***	***00.00%***
	48.39%	*15.6%*	*13.55%*	*13.46%*	*5.78%*				
S4 B	***Day 1***	*45.08%*	*00.44%*	*06.49%*	*4.53%*	***06.40%***	***03.84%***	***06.37%***	***00.00%***
	Day 4	*46.89%*	*01.68%*	*09.43%*	*09.76%*	*10.36%*	*05.67%*	*20.62%*	*1.04%*
	Day 7	*44.72%*	*08.55%*	*10.96%*	*11.61%*	*08.78%*	***00.00%***	***00.00%***	***00.00%***
	Day 10	*55.01%*	*08.97%*	*14.32%*	*09.87%*	*00.70%*	***00.00%***	***00.00%***	***00.00%***
	31.63%	*9.93%*	*8.53%*	*7.83%*	*5.34%*				
***S5** F*	***Day 1***	*59.27%*	*01.79%*	*03.08%*	*02.73%*	***07.65%***	***07.65%***	***14.03%***	***01.08%***
	Day 4	*58.30%*	*02.16%*	*04.88%*	*05.79%*	*01.18%*	*05.35%*	*18.38%*	*02.32%*
	Day 7	*57.55%*	*04.54%*	*08.50%*	*06.96%*	*06.30%*	*02.34%*	*01.22%*	*00.23%*
	Day 10	*61.30%*	*12.06%*	*11.11%*	*11.05%*	***00.00%***	***00.00%***	***00.00%***	*00.67%*
	28.65%	*2.03%*	*10.27%*	*8.03%*	*8.32%*				
S5 B	***Day 1***	*44.42%*	*00.5%*	*03.78%*	*07.13%*	***24.98%***	***03.33%***	***07.58%***	***00.60%***
	Day 4	*48.59%*	*07.17%*	*07.70%*	*11.33%*	*8.87%*	*1.06%*	*3.19%*	*00.14%*
	Day 7	*49.90%*	*07.34%*	*08.60%*	*15.94%*	*10.50%*	***00.00%***	*0.37%*	***00.00%***
	Day 10	*61.66%*	*07.77%*	*09.30%*	*18.27%*	*02.17%*	***00.00%***	***00.00%***	***00.00%***
	41.17%	*17.24%*	*7.27%*	*5.52%*	*11.14%*				

Note: the black color in control banana wrapping with plastic bag exceeds 79.8 % after ten days.

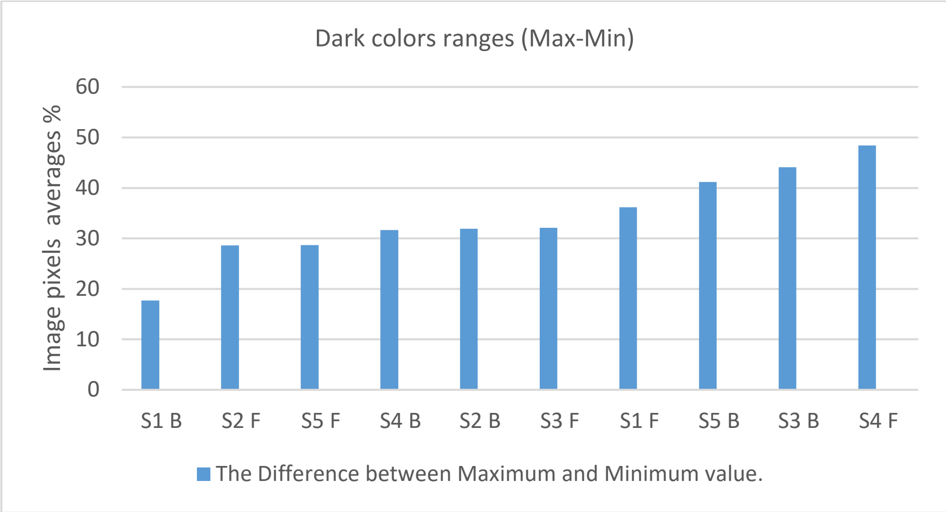


Figure 13 The changing in dark color ranges of banana peels through ripeness process inside fabrics according to fiber type

As shown in figure 13, wrapping banana with sample 1 on its back (polyester microfiber 25%: bleached cotton 75%) shows the best results as the differences between maximum and minimum results of dark colors is the least. That may be explained by fiber materials that are faced to the banana through packaging which is made from polyester microfiber with capillary action 25%. If the diameter of the fiber on the other side of 75% microfibers is sufficiently small, then the combination of surface tension (which is caused by cohesion within the liquid) and adhesive forces between the liquid and container wall act to propel the liquids that produced from the banana peel.

It is followed by sample 2 on its face (polyester microfiber 75%: bleached cotton 25%). The ratio of microfibers here more than sample 1 on its back but the number of fibers in the cross section of sample 1 is more than sample that enhance more liquid absorption. Sample 3 ,4 and 5 cause most damage on the banana peel.

Table 13 The banana weight results in grams through 10 days

S.	***Day 1***	***Day4***	***Day 7***	***Day 10***	***The difference Max-min(a-b) (gm)***
1 f	*122 [a]*	*102*	*97*	*90 [b]*	***32***
1 b	*120*	*118*	*114*	*106*	***14***
2 f	*118*	*114*	*110*	*103*	***15***
2 b	*115*	*110*	*107*	*100*	***15***
3 f	*111*	*95*	*91*	*86*	***25***
3 b	*115*	*100*	*96*	*84*	***31***
4 f	*117*	*115*	*100*	*96*	***21***
4 b	*119*	*106*	*99*	*95*	***24***
5 f	*110*	*101*	*96*	*94*	***16***
5 b	*115*	*106*	*95*	*93*	***22***
Control	*120*	*99*	*89*	*80*	***40***

Weighing the fruit is crucial because it indicates how the fluids in the banana are expressed. Table 13 indicates the weight test results of the banana through the 10 days. The difference between the weight on the first day and the last-day value has been calculated for each sample. It is clear from below Figure 14 that the weight decreases by days because of liquid loss. The relation between them is strong positive.

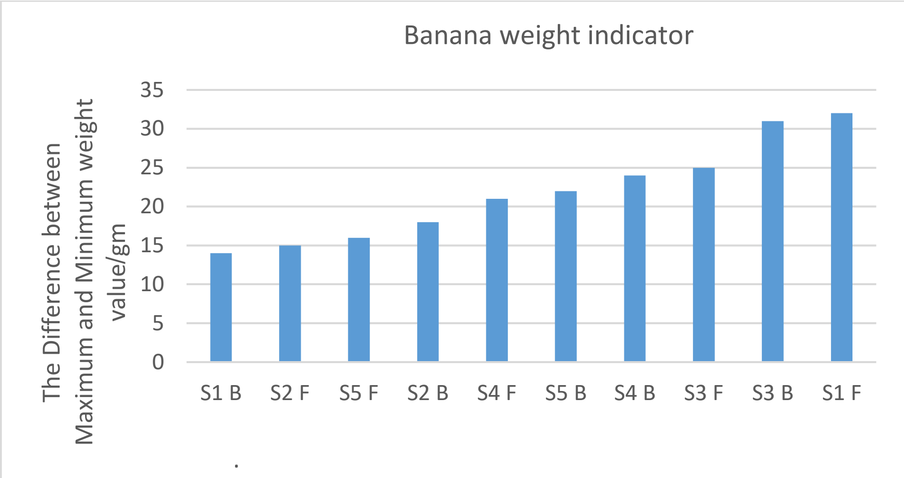


Figure 14 The changing in banana weight through ripeness process inside fabrics according to fiber type

As seen in Figure 14, sample 1 on its back and sample 2 on its face both support the banana fruit from not losing its liquids. Compared to Figure 14, the results of the weight test are very similar to those of the image color analysis test. These findings suggest that the weight test plays an indicator of liquid loss in banana fruit. Additionally, the consistency between the weight test and image color analysis test further validates the effectiveness of the samples in preserving the fruit's quality.

3.6 Evaluation of quality factor for produced samples.

According to the following Figures 15 and 16, sample 1 on its back (25% microfiber 300/576 den: 75% bleached cotton) has achieved excellent performance for use as a banana wrapping fabric, which has the ability to prolong its shelf life. It is followed by sample 2 on its face (75% polyester microfiber 300/288:25% bleached cotton).

The common factor between those effective samples that not found in the other samples is using polyester microfibers as wefts. The capillary tubes of microfibers can absorb liquids and transfer them from the inner to the outer layer. Also, the content of the fabric surface of microfibers helps to spread the water vapour away from the banana fruits, avoiding bacterial mildew. Not only the microfibers effect on the moisture management but also the air permeability as a result of high porosity. There is a strong positive relation between the fabric thickness that found by areal density of the weft fibres, the air permeability and the stiffness.

On the other side sample 4 either on face (Raw cotton 75%: bleached cotton25%) or back (Raw cotton 25%: bleached cotton 75%) represents the least performance. Actually, using Raw cotton of waxy texture has a negative effect on the fabric performance. It is coated with natural oils and waxes that prevent any liquid from being absorbed. Also using the fabric in inverse occur a tight difference in the moisture management. For the same reason, there are a difficulty in air passing through the fabric.

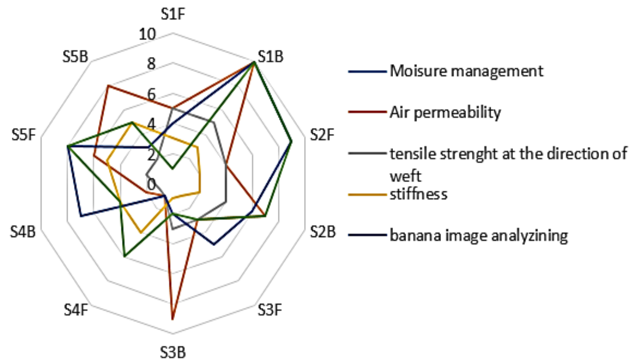


Figure 15 Radar chart of the produced samples

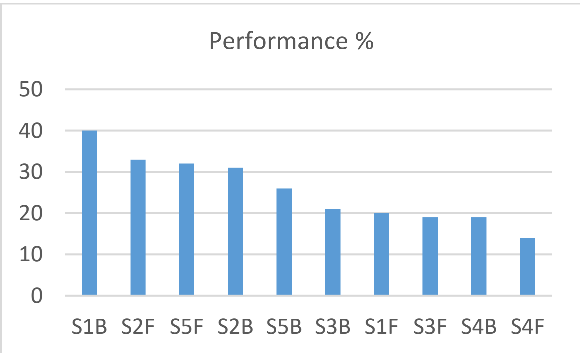


Figure 16 the performance of the samples according to all tests by the radar chart results

4. Conclusion

The main objective of this paper was manufacturing a woven wrapping fabric to enhance the shelf time of banana fruit and investigate the effect of research parameters (weft materials) on the mechanical, physical and functional properties of produced samples. From the results and statistical analysis concerned with the functional properties of produced wrapping fabrics evidently showed that:

1. polyester microfiber (300/576) has recorded the highest rates of tensile strength in weft direction followed by polyester microfiber (300/288), Bamboo ¸blended bamboo cotton and raw cotton respectively.
2. Bamboo has recorded the lowest rates of stiffness followed by blended bamboo cotton, polyester microfiber (300/288), polyester microfiber (300/576) and raw cotton.
3. For fabric air permeability property, polyester microfiber (300/288) increased the air flow through the fabric followed by Bamboo, blended bamboo cotton, polyester microfiber (300/576) and raw cotton respectively.
4. Back side of sample 1 produced from polyester microfiber (300/576) has recorded the highest rate of moisture management (MMT), whilst the sample 4 produced from raw cotton recorded the lowest rate of MMT.
5. wrapping banana with sample 1 on its back (polyester microfiber 25%: bleached cotton 75%) shows the best results as the differences between maximum and minimum results of dark colors is the least, addition to decrease the weight loss in banana fruit after ten days compared with another produced samples.
6. From radar chart it can be concluded that, sample 1 on its back (25% microfiber 300/576 den: 75% bleached cotton) has achieved excellent performance for use as a banana wrapping fabric, which has the ability to prolong its shelf life.

The results of this study indicate that the use of specific fabrics can effectively prevent liquid loss in banana fruit. The weight test and image color analysis test both support this conclusion and provide a reliable indicator of the fruit's quality preservation. These findings have implications for the development of packaging materials that can extend the shelf life of perishable fruits like bananas.

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