Egypt. J. Chem. **Vol. 68**, No. 11 pp. 309- 324 (2025)

Egyptian Journal of Chemistry

http://ejchem.journals.ekb.eg/

Mechanical and Biodegradation Properties of Warp Knitted Polylactic Acid (PLA) for Smart Food Packaging Applications

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Abstract
Packaging is one of the essential elements of today's life and it plays a major role in our daily lives. Packaging is inevitable to different communities of people: manufacturer's shopkeepers, sellers, and consumers. Food packaging is crucial for prevents contamination and preserves quality by reducing spoilage, extending shelf life, and ensuring safety. In the recent years, various studies have been executed on biodegradable materials to replace petroleum based plastics for food packaging applications. The demand of biodegradable packaging is increasing as it can be disposed with minimum environmental impact, but the growing market is still in its infancy predominantly due to the lack of materials. Biodegradable polymers such as PLA has given a significant attention in food packaging because it has an excellent properties such as environmenilly friendly, biocompatibility and energy savings. . So, this study investigates the mechanical and biodegradation properties of 18 warp knitted polylactic acid (PLA) samples, produced with pick densities of 2, 3, and 4 courses/cm and mesh sizes ranging from 0.03 to 10.37 cm², for smart food packaging applications. Mechanical tests (tensile strength, burst resistance, abrasion resistance) revealed an inverse relationship between mesh size and strength, with sample P4M (mesh size 0.03 cm²) achieving the highest tensile strength (78.67 N/m²) and burst resistance (773.33 kPa). Biodegradation tests showed complete decomposition in soil after 8 months. PLA fabrics infused with red cabbage indicator exhibited color changes to detect banana ripening, demonstrating smart packaging functionality."

Keywords: Poly (lactic acid), Food packaging, biodegradable, biopolymer, Environmental, Indicator

1. Introduction:

Packaging is essential for all types of food, which is why the food packaging industry is experiencing rapid growth in order to keep up with changing lifestyles and population growth. Packaging plays a crucial role in preventing food waste, making packaging systems necessary for the protection, transportation, and storage of food products [1]. Additionally, attractive packaging also serves as a means to attract customers and encourage them to purchase the product. Packaging plays a crucial role in preserving the quality of food products by offering protection against environmental, chemical, and physical challenges. Innovations in packaging technology are vital in meeting customer demands and finding solutions for foodborne microbes, ensuring the quality and safety of food products [2,3]. Food packaging plays a crucial role in preserving the desired atmosphere around the product. The food packaging industry has evolved due to the advancements of the industrial revolution and the demand for new packaging materials that can effectively preserve the flavor and moisture of food. [4]. The use of these materials helped to improve food quality and provided consumers with access to a wider variety of foods throughout the year. However, there is now a push to find more sustainable alternatives to petroleum-based plastics. Today, companies and organizations are actively seeking biodegradable materials to replace petroleum-based plastics. These alternative materials are designed to be more environmentally friendly and sustainable. The focus is on creating materials that are made from renewable resources and can biodegrade easily without causing harm to the environment [5,6]. Petrochemical-based plastics like polyethylene, polypropylene, PVC, and polystyrene are widely used in packaging due to their affordability and high performance. However, these materials pose a significant threat to the environment as they are non-recyclable and non-biodegradable. Therefore, there is an urgent need to reduce their use in packaging [7]. With the increasing awareness of environmental issues, there is a growing demand for eco-friendly packaging materials. These materials are designed to have a minimal impact on the environment and are usually made from renewable resources. The use of sustainable packaging materials can help reduce the amount of plastic waste that ends up in landfills and oceans, and can contribute to creating a more sustainable future [8]. In addition to being biodegradable, biopolymers possess other desirable characteristics such as air

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Receive Date: 04, February 2025, Revise Date: 08 March 2025, Accept Date: 07 April 2025
DOI: 10.21608/ejchem.2025.332808.11254

permeability, low temperature sealability, availability, and affordability. The current trend in food packaging involves the utilization of blends of various biopolymers, such as starch-PLA blends and starch-PCL blends. Technological advancements have also been made to create biodegradable materials for packaging that offer similar functionalities to traditional plastic packaging derived from oil-based sources [8,9] .

One of the newest innovations in food and vegetable preservation is smart packaging, which attempts to increase the quality and shelf life of these products. This kind of packaging uses cutting-edge materials and technologies to track storage conditions and prolong product freshness. There are various types of smart packaging, such as sensitive packaging, which has smart indicators like labels that change color in response to temperature or humidity, which helps determine the product's validity, and active packaging, which contains materials that absorb oxygen or release antimicrobial substances to stop bacteria from growing and slow down food spoilage [10].

Poly Lactic Acid (PLA) is a highly innovative material that has been extensively developed. It is a thermoplastic and biodegradable polymer, making it particularly attractive for applications in the biological and medical fields. The chemical formula of PLA is $(C3H4O2)n$. Initially, PLA was primarily used for biomedical purposes. However, it has gained significant attention due to its mechanical properties, thermoplastic processability, and biological characteristics, making it one of the most promising biodegradable polymers available [11]. PLA can be produced through the fermentation of renewable resources like corn, cassava, potato, and sugarcane. It holds a significant position in the market of environmentally friendly polymers and is considered one of the most promising options for future advancements. PLA has gained popularity as a material with diverse applications, including packaging, automotive, and biomedical sectors. This environmentally friendly biopolymer offers several desirable properties such as transparency, a glossy appearance, high rigidity, and good processability. Additionally, PLA composites can be recycled as they originate from renewable resources [12]. PLA, or polylactic acid, is a naturally sourced polymer with a global production capacity of over 140,000 tonnes per year. It offers customers the opportunity to create high-performance products using renewable resources, which are more environmentally friendly. The production process begins by extracting starch from sources like corn or beet, which is then enzymatically hydrolyzed to convert it into sugar. Bacteria are then used to ferment the sugars and produce lactic acid. This lactic acid can be polymerized to create PLA [13,14]. Currently, there are various polymerization processes through which PLA can be produced, such as polycondensation, ring-opening polymerization, and direct methods. The life cycle of PLA begins with the cultivation of corn and sugar beets. In this process, biological systems utilize solar energy through photosynthesis, as depicted in Figure 1 .PLA possesses remarkable qualities including biocompatibility (it does not generate toxic or carcinogenic effects), environmental friendliness (PLA is biodegradable, recyclable, and compostable), energy efficiency (it requires 25-55% less energy for production), and processability (PLA exhibits superior thermal processability) [15,16]. PLA-made textiles are suitable for food packaging because of their good mechanical qualities, which include flexibility and durability. In order to minimize condensation and preserve freshness, PLA textile materials are ideal for packing fresh fruits and vegetables since they provide air exchange[17]. PLA is a healthy option for food packaging because it is free of dangerous chemicals and is safe for direct food contact. In order to create multi-layer packaging with improved qualities like improved heat and moisture resistance, PLA fabrics have been mixed with other materials (such cornstarch or nanocomposites) [18].

Figure 1. PLA life cycle [16].

Textile packaging serves multiple purposes such as containing, carrying, storing, and protecting goods. It encompasses a wide range of materials, from heavyweight wovens used for bags, sacks, and carpets, to lightweight nonwovens employed in durable papers for wrapping food and industrial products. The market for packaging textiles is projected to witness substantial growth, estimated to increase by more than 50% in the foreseeable future. Packaging textiles encompass all textile materials utilized for packing industrial, agricultural, and other goods [19]. The demand for such materials is directly correlated with economic growth, industrial production, and trade. As goods are manufactured and subsequently distributed both locally and internationally, the need for packaging materials also rises. Additionally, the increasing environmental consciousness has led to the emergence of new opportunities for textile products in this market. Reusable packages and containers are becoming more sought after, prompting the use of textile materials[20]. As a consequence, traditional materials like jute, cotton, and natural fibers in sacks and bags are gradually being replaced by modern synthetic fibers. These specialized textiles, known as

"PACKTECH," are used in packaging and transportation. Packtech includes lightweight non-woven materials that are used as durable papers, tea bags, and wrappings for food and industrial products. Textile materials are commonly used in consumer packaging, and some examples include Flexible Intermediate Bulk Containers (FIBCs), which are shown in figure 2. These containers are used for packaging powdered and granular materials such as chemicals, foodstuffs, minerals, grain, and building materials. FIBCs offer several advantages, including low weight for efficient transport, cost-effectiveness, resistance to chemicals and organic substances, easy filling and discharging, and time savings during loading and unloading due to their easy handling capabilities[21].

Figure 2. FIBC bags [16].

Warp knitting is the fastest method for transforming yarn into fabric. This technique involves using needles to create rows of loops that are interlocked in a zigzag pattern. The resulting fabric is produced in a flat sheet form using one or more sets of warp yarn. The yarns used in warp knitting are fed from warp beams to a row of needles that stretch across the width of the machine. This allows for the creation of a large number of narrow width fabrics within the needle bed width [22]. These fabrics can be separated after finishing. Compared to weft-knit structures, warp knits are known for being more resistant to runs and are flatter, closer, and less elastic. There are several types of warp-knit fabrics commonly used today in intimate apparel, shape wear, and swimwear. These include tricot, mirror satin, powernet, satinet, weftlock, tri-skin, jacquard, and simplex. In warp knitting, the yarns are fed from warp beams to a set of needles that span the width of the machine. This enables the production of numerous narrow-width fabrics within the needle bed's width, which can be separated afterwards. Warp knitting is a high-speed technique used to convert yarn into fabric quickly. It involves using needles to create interconnected loops in a diagonal pattern. This method produces fabric in a flat sheet form, utilizing one or more sets of warp yarn [23]. Compared to weft-knit structures, warp knits are recognized for their resistance to runs and their flatter, denser, and less stretchy nature. Various types of warp-knit fabrics are commonly employed in intimate apparel, shapewear, and swimwear. These include tricot, mirror satin, powernet, satinet, weftlock, tri-skin, jacquard, and simplex [24,25].

2. Materials and methods

In this study, polylactic acid (PLA) yarns were selected. The yarns count were 300 denier. Table 1 shows the design of experiment (DOE) for this study. The study involves using different pick densities namely 2, 3, and 4. The purpose of having different pick or course densities is to study the effect of changing the course densities on mechanical and biodegradability's properties.The other parameter in this DOE is the mesh size as the used knitted structure is made of a repeated unit of a hexagonal shape. The hexagonal shape is made of 6 sides and the study will involve using 6 different hexagonal sizes, these sizes are controlled by changing the length of the hexagonal sides.

Table 1. Design of Experiments

Parameters	Level	samples
Course (pick) densities (**z**)	2, 3, 4	3
Mesh size	1, 2, 4,8, 9, 16	6
Total number of treatments		18

According to Table 1, 18 samples were executed to study the effect of different production parameters on the physical, mechanical and biological properties. These samples are different in mesh size and pick
density, 6 different warp knitting structure based on mesh sizes with 3 different pick density (The number of courses /cm) symbolize by z letter. The following data in Table 2 represents the produced samples specifications such as sample ID, pick density (The number of courses /cm), and warp knitting structure (mesh size), mesh shape and its area(cm2) and yarn material, yarn count, tenacity and elongation.

Table 2 .Specifications of the of the produced knitted fabric sample

Sample ID	Pick density (courses/min)	Warp knitting Structure	Mesh area (cm2)	Mesh shape	Yarn material	Yarn count (denier)	Yarn tenacity (CN/tex)	Yarn elongation %
P2M	2	mesh	.23					
P2M1-2	2	Mesh(1-2)	.64					
P2M1-4	2	Mesh(1-4)	1.29					
P2M2-8	2	Mesh (2-8)	2.58					
P2M3-9	2	Mesh(3-9)	5.85					
P2M4-16	2	Mesh(4-16)	10.37					
P3M	3	mesh	.11					
P3M1-2	3	Mesh(1-2)	.4		PLA	300	17.6	92.3
P3M1-4	3	Mesh(1-4)	.64					
P3M2-8	3	Mesh (2-8)	1.29					
P3M3-9	3	Mesh(3-9)	2.58					
P3M4-16	3	Mesh(4-16)	5.85					
P4M	4	mesh	.03					
P4M1-2	4	Mesh(1-2)	.23					
P4M1-4	4	Mesh(1-4)	.4					
P4M2-8	4	Mesh (2-8)	.94					
P4M3-9	4	Mesh(3-9)	2.58					
P4M4-16	4	Mesh(4-16)	3.75					

2.1 Methods

The research samples were carried out using the warp knitting technique for its previously mentioned advantages by using Rashel Machine (a computerized double needle bed warp knitting machine (DH 1000-DNBAC).The mesh structure was chosen because it is suitable for packing vegetables and fruits in order to obtain an adequate ventilation that helps prevent rapid mold from occurring. The size of the mesh was varied to obtain different amounts of oxygen entry to suit each fruit according to its needs.The stitch patterns of fabrics are also shown in Figure 3

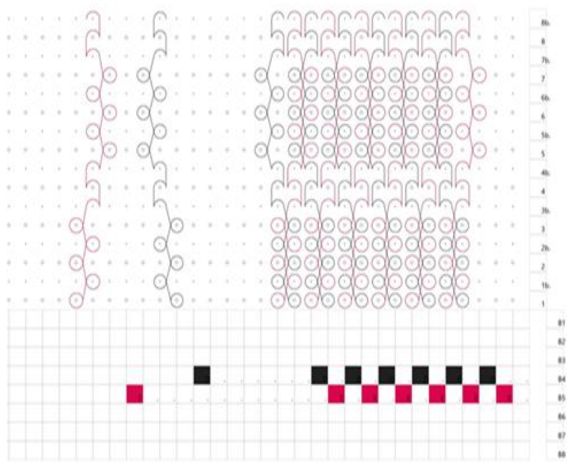
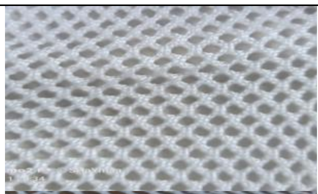
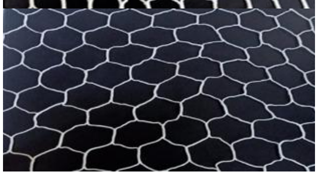


Figure 3. The stitch patterns of fabrics

Table 3 shows images of the eighteen executed mesh samples and it shows that the difference between samples in terms of pick density (the number of courses /cm) and Warp knitting Structure (mesh size). It is clear that the diversity in the size of the mesh, the diversity in number of mesh unit /cm2 and increasing the width of the fabrics to increase the mesh size with a constant number of yarns/inch. It also shows sample of the mesh bag executed on the machine without the need for cutting and sewing stages

Table 3. The executed mesh samples

Warp knitting Structure	**Pick density**		
	Z=2	**Z=3**	**Z=4**
Mesh			
Mesh (1-2)			
Mesh (1-4)			
Mesh (2-8)			
Mesh (3-9)			
Mesh (4-16)			
		Z3	
Mesh bag			

3. Mesh samples evaluation

Laboratory and experimental testing of the aforementioned mesh samples were performed at the Textile Testing Lab. at the National Research Centre. Laboratory tests of the executed samples were carried out to check the functional properties of the PLA samples to be used as food packages . These tests were carried out under standard conditions of temperature (20°C±2°C) and humidity (65%±2%) for 24 hours before testing according to ISO/IEC and American Standard Society of Testing Materials (ASTM) standards. Mechanical, chemical and biological tests were performed on the executed samples as shown in the figure4

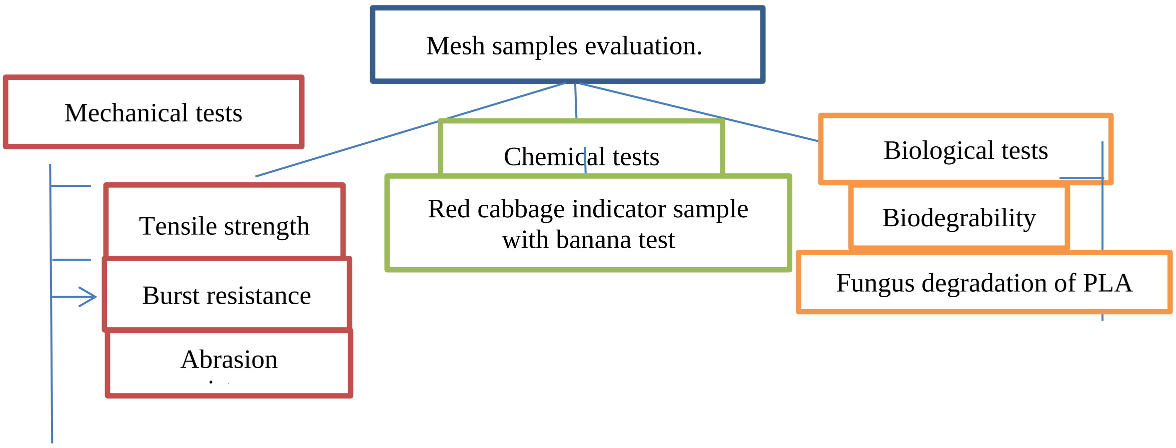


Figure 4. Tests were performed on the executed samples

4.Tests Applied to the executed samples

4.1 Mechanical tests

Mechanical tests were used to determine the behaviour of a sample while under an axial stretching load , to determine the suitability of samples to the required functional properties of the final product , improve packaging performance in different conditions and determine the resistance of the package to pressure and vibration.

4.1.1 Tensile strength test

This test is carried out by using "Textile tensile strength tester" no.6202 according to the American Standard Specification of (ASTM-D-5035-11). 3 readings were taken from different areas of each sample and the average of each one was calculated. Samples tensile was calculated in (N/m²).

4.1.2 Burst resistance test

This test is carried out by using "Toyoseiki" according to the American Standard Specification of (ASTM-D-3786-01). 3 readings were taken from different areas of each sample and the average of each one was calculated. Samples burst strength was calculated in kpa.

4.1.3 Abrasion resistance test

This test is carried out by using "Toyoseiki" according to the American Standard specification of (ASTM-D-4158-08). Weight loss is estimated for samples and tensile strength after abrasion.

4.2 Chemical tests (PH indicators tests)

Chemical testing is the test of the fabric samples either using chemicals to give them new properties. Excuted samples were saturated with red cabbage indicator (natural indicator) to give them smart properties that enable them to change their color when vegetables and fruits rot.

4.2.1 Red cabbage indicator sample with banana test

This test is carried out by placing the executed samples of PLA into the red cabbage solution in the bowel, then let it soak for about 3 hours until it is completely saturated in the solution and its color changes to purple or dark blue, then we leave the samples to dry completely as shown im figure 5. When the samples dried completely, we notice that their color became light blue. Then we do a test of samples prepared with the indicator on the rotting fruit.

After that, the response of samples saturated with red cabbage indicator with ammonia gas is observed daily and whether the response is affected by ultraviolet radiation or not. The results of this experiment are estimated by the researcher. This experiment is carried out for samples with concentrations 1 and 2 because concentration 3 and 4 did not respond to ammonia gas from the beginning.

Figure 5. The four red cabbage indicator concentrations and their role in smart packaging

4.3 Biological tests

Biological testing is important in determining how effective an antibacterial,antimicrobial, or anti-fungal is on a textile. The mesh samples were laboratory tested with fungi directly and were also buried in the soil and exposed to all soil elements including microorganisms, bacteria and fungi. These experiments determine the degree of decomposition of PLA material and the time period for decomposition.

*4.3.1 Biodegrability tes*t

This test is carried out by burying two samples of executed PLA in soil such as garden soil as shown in figure 6 and noting the occurrence of decomposition 6 months after the burial, and the sample is tracked every month and changes to it are noted. The first sample was not photographed, while the second sample was followed monthly. Must be available in the soil three basic conditions.

1-The temperature is 60 oc or greater
2-Very high humidity
3-Presence of microorganisms

Figure 6. Buried mesh samples of PLA in soil

4.4.2 Fungus degradation of PLA test

This test is carried out at Faculty of Agriculture Research Park-Faculty of Agriculture-Cairo University.The test sample of PLA was placied with a specified number of Penicillium fungi in a laboratory tube as shown in figure 7. The lab has been accredited by EGAC in compliance with the requirements of ISO/IEC 17025:2017. The temperature and RH% of the environment during the analysis were 25.oc and 44.4% respectively.

Figure 7. Mesh sample fabric of PLA with Penicillium fungi

5. Results and Discussion

The following data in Table 4 represents the results of the applied tests to the executed mesh samples. It shows the results of areal density test (g/m2), thickness test (mm), shown results of tensile strength test (kg), results of bursting test (kpa) and results of elongation test (%).

Table 4. Results of the applied tests to the executed mesh samples

Sample ID	**Study Parameters**		**Tests applied to the samples**				
	Pick density	**Mesh size**	**Areal density (g/m^2)**	**Thickness (mm)**	**Tensile strength (N/m^2)**	**Burst resistance (kpa)**	**Elongation (%)**
P2M	2	mesh	225.18	1.004	70.00	736.67	58.33
P2M1-2	2	Mesh(1-2)	134.87	0.9212	47.33	473.33	53.33
P2M1-4	2	Mesh(1-4)	76.16	0.774	36.00	286.67	50.00
P2M2-8	2	Mesh (2-8)	29.68	0.745	7.67	213.33	30.00
P2M3-9	2	Mesh(3-9)	23.59	0.715	6.67	253.33	28.33
P2M4-16	2	Mesh(4-16)	22.77	0.68	4.00	253.33	28.33
P3M	3	mesh	261.66	1.079	77.00	833.33	60.00
P3M1-2	3	Mesh(1-2)	150.28	1.002	44.33	500.00	51.00
P3M1-4	3	Mesh(1-4)	94.89	0.93	40.00	413.33	52.33
P3M2-8	3	Mesh (2-8)	54.15	0.861	13.33	233.33	52.67
P3M3-9	3	Mesh(3-9)	34.13	0.77	9.67	226.67	50.00
P3M4-16	3	Mesh(4-16)	31.45	0.736	8.67	240.00	33.33
P4M	4	mesh	295.46	1.183	78.67	773.33	75.00
P4M1-2	4	Mesh(1-2)	212.09	1.069	63.33	566.67	49.33
P4M1-4	4	Mesh(1-4)	117.37	0.977	47.33	433.33	47.00
P4M2-8	4	Mesh (2-8)	58.37	0.954	18.33	273.33	46.67
P4M3-9	4	Mesh(3-9)	38.41	0.946	14.67	260.00	36.67
P4M4-16	4	Mesh(4-16)	37.91	0.913	9.00	226.67	33.67

5.1 Tests results for the executed samples.

5.1.1 Mechanical tests

5.1.1.1 Fabric tensile strength of the produced mesh samples

From Table 4 and figure 8, the samples are divided into 3 groups, and each group is compared separately .

The first group (z2) contains 6 sample

Sample (p2m) recorded the highest tensile strength of 70.00N/m².This may be due to the increase in the number of mesh units in the unit area that increased the amount of yarns in the unit area and therefore the fabric's bearing increase, leading the tensile strength to increase. While the sample (p2m4-16) recorded the least tensile strength of 4.00 N/m². That may be because of the low number of mesh units in the unit area decreased the amount of yarns in the unit area and therefore the fabric's bearing decreased and the tensile strength decreased.

The second group (z3) contains 6 samples

The tensile strength of all samples of this group is higher than the previous group due to the increase in pick density, therefore the fabric's bearing increases. Sample (p3m) recorded the highest tensile strength of 77.00 N/m² followed by the (p3m1-2), while the sample (p3m4-16) recorded the least tensile strength of 8.67 N/m².

The third group (z4) contains 6 samples

This group has the highest pick density. Therefore, all samples are higher in the tensile strength than the previous two groups. Sample (p4m) recorded the highest tensile strength of 78.67 N/m², while the (p4m4-16) recorded the least tensile strength of 9.00 N/m².

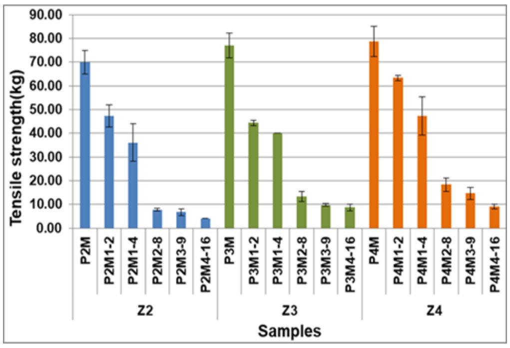


Figure 8. The effect of mesh size on fabric tensile strength

5.1.12 Burst resistance of the produced mesh samples

From Table 4 and figure 9 the samples are divided into 3 groups, and each group is compared separately.

The first group (z2) contains 6 samples

Sample (p2m) recorded the highest burst resistance of 736.67 kpa because of increasing the mass of mesh unit per unit area, therefore the force of the yarn within a unit area increases which cause increase in the fabric burst resistance.

Sample (p2m4-16) recorded the lowest burst resistance of 253.33 kpa because of decreasing the mass of mesh unit per unit area, therefore the force of the yarn within a unit area decreased which caused a decrease in the fabric bursting resistance.

The second group (z3) contains 6 samples

In this group fabric burst resistance is higher for all samples compared to the previous group whereas with an increase in the pick density during the knitting process, the loop length decrease, then the mesh becomes smaller, therefore the force of the yarn within a unit area increased. Sample (p3m) recorded the highest burst resistance of 833.33 kpa. Sample (p3m4-16) recorded the lowest burst resistance of 240.00 kpa.

The third group (z4) contains 6 samples.

This group achieved the best result in burst resistance compared or all the mesh samples because it has the highest number pick denisty. Sample (p4m) recorded the highest burst resistance of 773.33 kpa. Sample (p4m4-16) recorded the lowest burst resistance of 226.67kpa

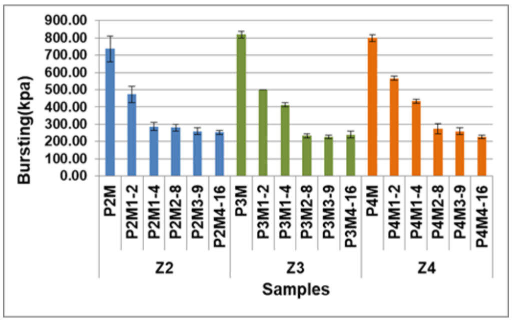


Figure 9. The effect of mesh size on fabric burst resistance

5.1.2.3 Abrasion resistance (weight loss %).

Table 5 represents the results of abrasion resistance (weight loss%) for the best three samples are perfect p4m,p3m and p2m in mechanical properties with constant the number of cycles of the device.

Table 5. Abrasion resistance (weight loss%)

Sample ID	Abrasion resistance (weight loss %)	Number of abrasion cycles
P4M	0.8%	1500
P3M	0%	1500
P2M	0.4%	1500

From figure 10 and 11 it was found the friction has caused only a small change in weight, meaning that the weight loss is very small or almost non-existent, but the friction has a significant effect on the tensile strength, as the tensile strength of the samples decreased after friction, as shown in figure 12 and figure 13. P4M sample gave the best results for abrasion resistance and also the amount of change in tensile strength after friction was small.This is due to the sample a large pick density, where the number of courses increases in the weft direction /cm, which makes the fabric more able to resist friction. Abrasion resistance affects the life of the package, and this can be known by measuring the tensile strength of the packaging and reducing the friction factors for a longer life.

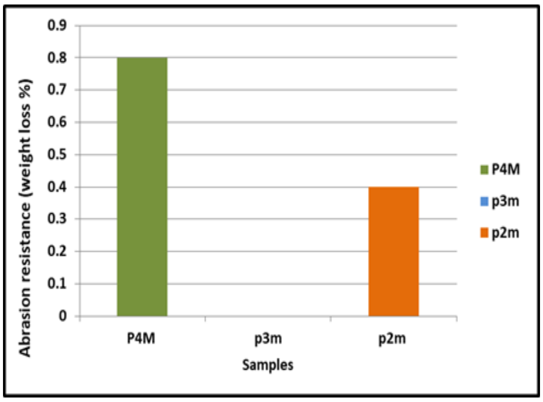


Figure 10. Abrasion resistance (weight loss%) for the best three samples in properties

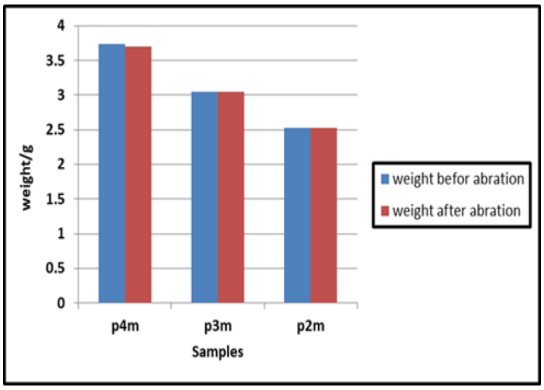


Figure 11 The effect of abrasion resistance on weight of samples

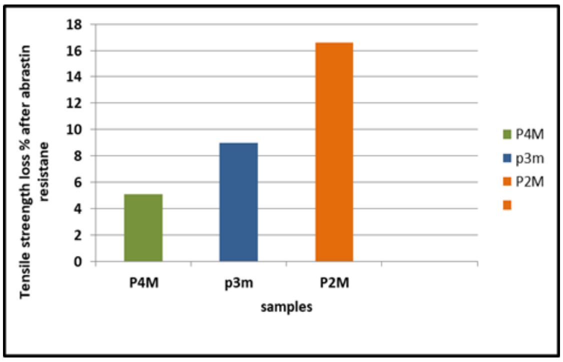


Figure 12. The effect of abrasion resistance on the tensile strength of samples

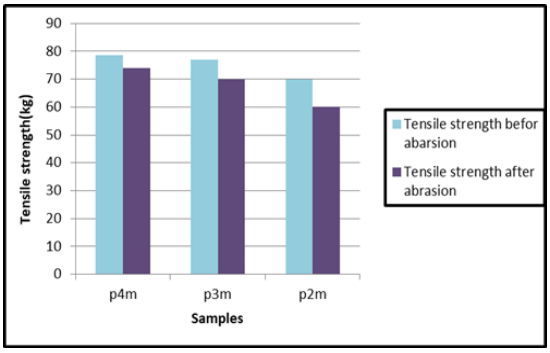


Figure 13. Tensile strength before and after abrasion

5.1.3 Chemical indicators test

5.1.3.1 Red cabbage indicator sample test with banana

The objective of this test is to know the change that will occur in the PLA sample saturated with red cabbage when exposed to the stages of banana ripening.

The sample of PLA saturated with indicator of red cabbage was placed in a bowl with a banana as shown in figure 14 and figure 15.Then the bowel is closed with the sample and the banana fruit inside. Part of the sample was placed inside the container and part outside it as shown in figure 16. The bowl is opened after 12 hours there has been a change in the color of the sample that is inside the bowl and the appearance of purple spots as a result of the ripening of the banana fruit and the start of the exit of ethylene gas and some volatile organic compounds such as terpenes, carboxylic acids, alcohols, aldehydes, sulfur compounds and ammonia as shown in figure 17.The change was observed at different times after 24 hours, then after two days, and then after three days, we find that the purple spots gradually increase as shown in figure 18 and figure 19, but it reaches a certain stage and the violet spots fade as shown in figure 20

Figure 14. Produced sample of PLA saturated with indicator of red cabbage

Figure 15. The sample was placed in a bowl with a banana

Figure 16. The bowel is closed with the sample and the banana fruit inside

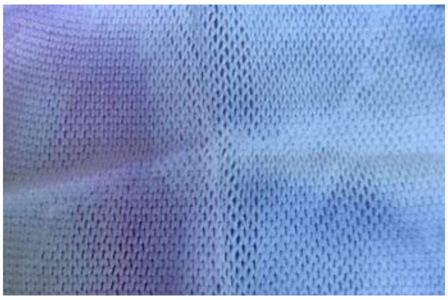


Figure 17. The sample after 12 hours with purple spots

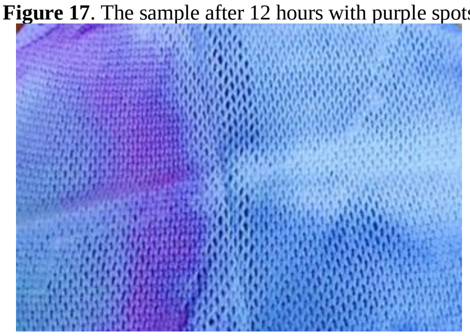


Figure 18. The sample after 24 hours with purple spots

Figure 19. The sample after 2 days with purple spots

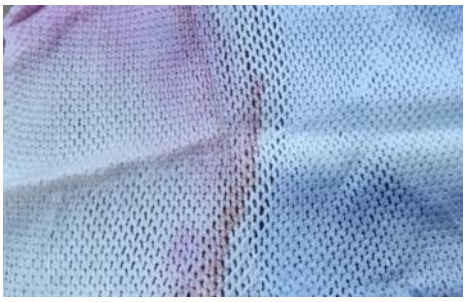


Figure 20. The sample after 3 days with purple spots

5.1.4 Biological tests

5.1.4.1 Biodegrdation test

In this test, two mesh samples of PLA knitted fabrics were buried in the soil. The first sample decomposed after 8 months of complete burial without opening the soil on it, while the second sample was weighed before burial as shown in the figure 21 and the change in the figure was tracked monthly as in the figure 22 and figure 23 Then it was weighed 3 months later. From figure 22after a month of burial, we found that there was corrosion of the buried sample from below, and we also find that in the second and three month this corrosion increased as shown in the figure 24 and figure 23. This indicates the beginning of the decomposition of the knitted PLA sample, where the fungi and bacteria in the soil feed on it, because the material is of natural origin from corn and sugar beets. We also found that there has been a loss in the weight of the knitted sample, as the weight before the experiment was 2,58 /gm and after the experiment it became 1.73 /gm, therefor the weight loss% is 32.945%.This indicates that the sample has corroded.

-To calculate the percentage of weight loss, the weight before loss was represented as one hundred percent of the weight, and two ends were multiplied by two means, and the result was subtracted from one hundred.

Figure21. The second sample befor burial

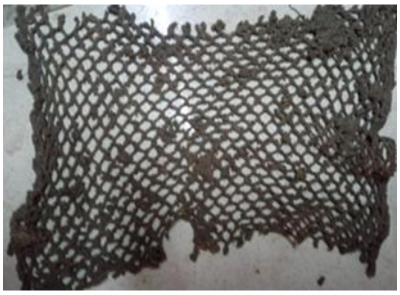


Figure 22. The second sample after one month of burial

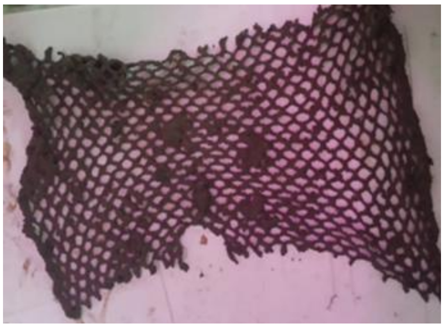


Figure 23. The second sample after two months of burial

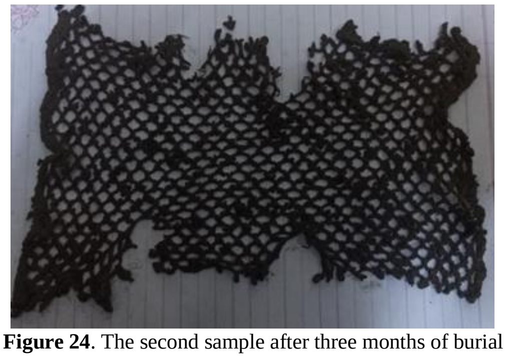


Figure 24. The second sample after three months of burial

5.1.4.2 Fungus degradation of PLA test

Table 6 shows that determination of total penicillium chrysogenu within two weeks when put it with a sample of executed PLA in a test tube. Fungus were counted under a magnifying microscope.To study the effect of the fungus on the PLA fabric.

Table 6. Determination of total penicillium chrysogenu

sample	Test	Unit	Result	Un
PLA fabric	Determination of total penicillium chrysogenu –zero time.	Cfu/g	4.5×10^3	±0.03
	Determination of total penicillium chrysogenu –after one week .		8.5×10^4	
	Determination of total penicillium chrysogenu –after two weeks .		2.5×10^5	

Table 6 and figure 25 show that when a sample of PLA with a certain amount of Penicillium fungi was placed in a laboratory tube, the total penicillium determination increased (Cfu/g),this means that the Penicillium determination increased. The Penicillium fungus feeds on the polylactic fabric, which is derived naturally from corn and sugar beets, this implies that the degradation of PLA knitted fabrics is due to Penicillium fungus corrosion of PLA knitted fabrics.The effect of penicillium chrysogenu on the shape and weight of PLA knitted fabrics is shown in figure 26, 27 and 28. In the first week of the experiment, corrosion occurs in the PLA sample, as the fungus started feeding on it as shown in figure 27, and then the corrosion increases in the second week as shown in figure 28. The sample was weighed before and after the experiment, and the results were as follows: the weight before the experiment was 0.95/gm and after the experiment it became 0.84/gmweight loss% = 11.57% .There is a loss in the sample weight, which indicates that the sample has corroded

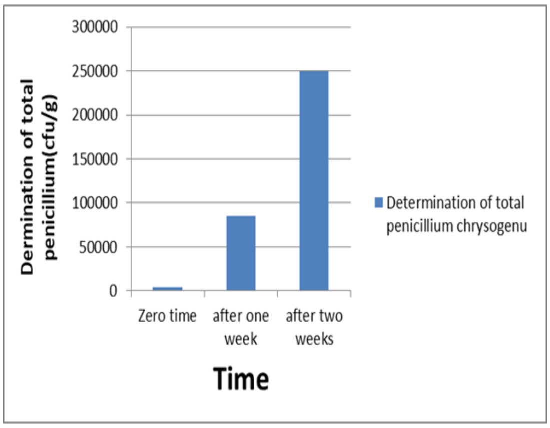


Figure 25. The effect of PLA fabric on the number of total penicillium chrysogenu

Figure 26. Sample of PLA mesh fabric in zero time

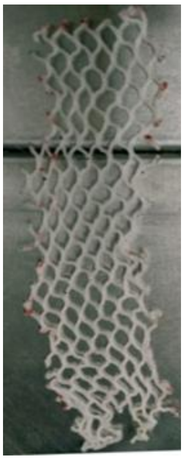


Figure 27. Sample of PLA mesh fabric after one week

Figure 28. Sample of PLA mesh fabric after two weeks

6. Conclusion

In this research, a number of (18) samples were In this research, a number of (18) samples were produced from PLA yarn. Practical and laboratory tests were conducted on the executed samples, and by discussing the results of the practical and laboratory tests conducted on the research samples, the results were drawn.

The results can be summarized as follows:

According to the previous figures, tables, relationships and graphs

-The effect of mesh size on tensile strength and burst resistance

Results indicate an inverse relationship between mesh size and areal density, tensile strength, and burst resistance. Sample P4M, with the smallest mesh size (0.03 cm²) and a pick density of 4 courses/cm, exhibited the highest tensile strength (78.67 N/M2) and burst resistance (773.33 kPa), while P2M4-16 (mesh size 10.37 cm², pick density 2) showed the lowest values (4.00 N/M2, 253.33 kPa)."

-The quality evaluation of the research samples for the physical and mechanical properties was as follows:

Sample (p4m) achieved the best quality parameters for this type of fabric from where tensile strength, burst resistance and elongation properties.

The effect of abrasion resistance on weight loss and tesile strength

It was found that friction has caused only a small change in weight, meaning that the weight loss is very small or almost non-existent, but the friction has a significant effect on the tensile strength, as the tensile strength of the samples decreased after friction.

-PH indicators

-Red cabbage indicators with banana fruit

The results showed that the PLA Fabric sample saturated with the red cabbage indicator when placed with the banana fruit in one container begins hours later to change the color of the sample from blue to purple spots appear as a result of the exit of ethylene gas and some volatile gases.

-Biological tests

-Biodegradation test

The results showed that the occurrence of complete decomposition of the PLA knitted fabric sample after 8 months of burial in the soil without opening the soil on it, while while the second sample appeared to have erosion after a month of burial and also a loss of weight.

-Fungus degradation of PLA test

The results showed that corrosion of PLA knitted fabrics by Penicillium fungus as previously shown in the figures. The increase in the number of Penicillium fungi indicates the occurrence of the decomposition of PLA fabrics. Evidence for the occurrence of decomposition is also the occurrence of a loss in the weight of the sample after the test by a percentage 11.57%

To enhance and develop food packaging made of textile materials, more research is required. This includes comparing biodegradable textile materials with PLA, using the findings in fruit and vegetable packing plants in Egypt, and introducing the packaging into supermarket chains. In addition, we need to experiment with alternative manufacturing methods like 3D printing and design containers in a variety of shapes to accommodate different uses. We should also test the containers on a variety of fruits and vegetables, particularly those that are most prone to spoiling, and conduct experiments on how different fungi and bacteria break down containers. Additionally, it is advised to search for innocuous ethylene indicators and utilize smart packaging, such as the red cabbage signal, with fruits and vegetables that spoil quickly. In addition, it's critical to investigate the Egyptian market for biodegradable packaging, connect scientific findings to marketing and environmental requirements, and broaden the focus of research on how packaging affects packaged food safety to guarantee that it complies with health regulations.

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