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Araştırma Makalesi / Research Article

ARTIFICIAL NEURAL NETWORKS TO ENHANCE THE RING MACHINE EFFICIENCY AND YARN QUALITY BY DETERMINATION AND OPTIMIZATION OF DYNAMIC YARN TENSION

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ABSTRACT: The yarn spinning process involves the interaction of large varieties of variables. The relation between the dynamic yarn tension (DYT), yarn quality, and production efficiency of the spinning frame cannot be established conclusively. Artificial neural network (ANN) is a promising step in this filed. In this research work, ANNs simulation and modeling is applied for the optimization of the DYT n to improve the production efficiency and quality of yarn. The research to date in DYT is insufficient to meet the developmental requirement of the high-speed and efficient ring spinning frame. One of the major problems facing the effective use of the ANN is the correct selection of the input parameters to be fed for the training of ANNs. Data of various input variables such as count, traveler no., spindle speed and dynamic yarn tension etc., was used for ANN modeling and simulation. DYT plays a significant role in the determination of yarn quality and its productivity in terms of end breakage rate. However, it has never been explained in terms of displacement from the original yarn path. This work is aimed to the determination and optimization of DYT at ring spinning frame. The influence of different yarn geometry parameters on DYT, measured by the tensiometer was investigated. The optimized DYT values for the machines, running at different speed and different counts were determined using ANN modeling. It is found that the optimized values predicted from ANN resulted in better quality, high production, and decreased end-breakage at industrial ring spinning frames. By the implementation of ANNs the optimum speed and effective utilization of textile raw materials can be achieved.

Keywords: Artificial neural network, dynamic yarn tension, machine efficiency, yarn quality

YAPAY SİNİR AĞLARI İLE DİNAMİK İPLİK GERİLİMİNİN BELİRLENMESİ VE OPTİMİZASYONU SAĞLANARAK RİNG MAKİNESİNİN ETKİNLİĞİ VE İPLİK KALİTESİNİN İYİLEŞTİRİLMESİ

ÖZ: İplik eğirme işlemi, çok çeşitli değişkenlerin etkileşimini içerir. Dinamik iplik gerginliği (DİG), iplik kalitesi ve eğirme makinesinin üretim verimliliği arasındaki ilişki kesin olarak kurulamamaktadır. Yapay sinir ağları (YSA) bu alanda gelecek vadeden bir araçtır. Bu araştırma çalışmasında, ipliğin üretim verimliliğini ve kalitesini iyileştirmek için dinamik iplik gerginliğinin (DİG) optimizasyonunda YSA simülasyonu ve modellemesi kullanılmıştır. DİG'de bugüne kadar yapılan araştırmalar, yüksek hızlı ve verimli ring eğirme makinesinin gelişimsel gerekliliklerini karşılamak için yetersizdir. YSA'nın etkin kullanımında karşılaşılan en büyük sorunlardan biri, YSA'ların eğitimi için beslenecek girdi parametrelerinin doğru seçilememesidir. YSA modellemesi ve simülasyonu için iplik numarası, kopça numarası, iğ hızı ve dinamik iplik gerginliği gibi çeşitli girdi değişkenlerinin verileri kullanılmıştır. DİG, iplik kalitesinin belirlenmesinde ve iplik kopuş oranı açısından iplik üretim verimliliğinde önemli rol oynamaktadır. Bu duruma karşın orijinal iplik yolu ve yer değiştirmesi açısından hiçbir zaman açıklanmamıştır. Bu çalışma, ring iplik makinasında DİG'nin belirlenmesi ve optimizasyonunu amaçlamaktadır. Farklı iplik geometri parametrelerinin tansiyometre ile ölçülen DİG üzerindeki etkileri araştırılmıştır. YSA modellemesi kullanılarak farklı hız ve sayılarda çalışan makineler için optimize edilmiş DİG değerleri belirlenmiştir. YSA'dan tahmin edilen optimize edilmiş değerlerin, endüstriyel ring eğirme makinelerinde daha iyi kalite, yüksek üretim ve azalmış iplik kopması ile sonuçlandığı bulunmuştur. YSA'ların uygulanmasıyla, tekstil hammaddelerinin optimum hızı ve etkin kullanımı sağlanabilir.

Anahtar Kelimeler: Yapay sinir ağı, dinamik iplik gerginliği, makine verimliliği, iplik kalitesi,

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1. INTRODUCTION

Although the advanced spinning technologies have solved the problem of production and automation to a great extent, the conventional ring spinning dominates the staple yarn spinning techniques due to its high quality, high strength, and flexibility compared to innovative spinning processes [1]–[3]. As ring frame cost comprises a major portion of total cost, the productivity at ring frame has assumed considerable importance and every effort to maximize production at this stage is worth exploring. Increasing spindle speed, production efficiency, and yarn quality of ring spinning has been the focus of many researchers for minimizing the cost of yarn [4]–[6]. Conventional ring spinning produces high-quality yarns, but the spinning efficiency is low and power consumption per unit of yarn production is high [1], [7], [8]. The low spinning efficiency is due to high tensions resulting from ring and traveler friction, which limits the production speeds.

Among various factors, dynamic yarn tension is the main influencing factor in the ring spinning machine which directly affects the quality and production of ring frame [6]. At the ring frame the yarn tension is divided into three tension zones namely spinning tension (from front roller nip to the snail wire), balloon tension (between snail wire and the ring), and winding tension (between the ring and the bobbin). The yarn breakage occurs mainly in the spinning zone; near the front roller nip, where the minimum twist is present. The tension in the winding tension is much higher than in the spinning tension [9]–[11]. However, the spinning yarn tension; between the front roller nip and the snail wire provides the true picture of the spinning geometry settings. The spinning tension and its fluctuations are directly associated with the ends down percentage at the ring spinning machine because mainly the yarn breakage occurs near the tip of the front roller; where the yarn has the least amount of twist inserted. When the yarn tension increases the strength of the weak place the yarn breakage occurs in the spinning tension zone. The dynamic yarn tension is the reflectance of spinning geometry parameters [12], [13]. The speed of the spindle, the frictional force of the traveler with the steel ring, traveler weight, diameter and surface of the ring, and the coefficient of friction between the ring and traveler are directly related to the spinning tension [13].

An artificial neural network (ANN) has the ability to model real-world scenarios even in the presence of noisy data. They can also model the processes with a large number of variables having non-linear relationships between them [14], [15]. In the textile industry, ANNs are being used for more than the last two decades and have proved efficient for modeling complex spinning problems [15]–[18]. However, the mathematical modelling, especially for the DYT is based on many assumptions/ideal values like traveler weight is constant, yarn density is constant throughout the length, and the ring friction is uniform throughout its diameter [19]–[23]. In the spinning industry, the DYT is measured manually at the ring frame with the hand or finger. The measurement of the yarn tension pertains to touching the yarn path in the spinning tension zone. However, as the yarn displaces from its original path an increased amount of tension is experienced that results in the breakage of the yarn and ultimately quality and production of the yarn is swearly affected [11], [24]. The solution for the best running conditions at the ring frame is to achieve an optimum yarn tension level that remains constant over a longer period. However, this optimized level is hard to achieve. The precise control of the yarn tension can help the ring spinning machines to run at higher speeds with fewer yarn breakages. It is believed that the quality and production of yarn at the ring spinning can be significantly enhanced by the determination and optimization of yarn tension using the ANNs. To the best of our knowledge ANNs are not applied for the determination and optimization of yarn tension at ring frame using the real time data to address the yarn breakage and quality issues of conventional ring frame.

In this backdrop, the proposed research work was carried out to measure the dynamic yarn tension in an efficient manner and to find out the optimum yarn tension in the relationship with the vital yarn spinning geometry variables. The results indicated that data of various factors such as yarn count, spindle speed, traveler no., ring life in months, displacement from the original position, and tension at different cop build up position can be used for the determination and optimization of the yarn tension using ANNs. It was found that at the optimized dynamic yarn tension, the speed of the ring frame can be increased. The increase in the spindle speeds resulted in the increased productivity. Moreover, it is also inferred that at the optimum tension the ends down rate is also significantly reduced. Our findings indicated that ANNs can be helpful to enhance the production and efficiency of ring-frame and this model can also help in the conservation of energy and textile raw materials. It is further believed that ANN has the potential along the entire textile process that should be further investigate and exploited.

2. MATERIALS AND METHODS

The polyester and cotton blended (PC: 52/48) yarns were prepared by the conventional ring spinning process. The key characteristics for cotton and polyester are summarized in Table 1. The simplex roving with 1.05 HR and 0.5 TM was used for the preparation of the yarns used in this study. For the determination of dynamic yarn tension, research is conducted on an industrial scale. DTM 500 tensiometer was used to measure the spinning tension *(Fig. 1)*. An attachment is devised to place the tensiometer between the front roller nip and snail wire. For the proper fixation of the device on the ring frame, the stand is equipped with a magnet that provides sufficient force to strongly attach to the ring frame to avoid vibrations. The two fixed pins of the probe were removed to avoid twist blockage to the spinning zone and consequently thread breaks. A Teflon rod was placed just above the topmost position of the lappet to avoid the swinging of the yarn in the spinning zone. This keeps a constant angle of wrap of the yarn over the movable pin at 150°. This instrument works on the principle of the differential capacitor. The tension probe was positioned in the spinning zone 8 cm below the front roller nip. When yarn passes over the movable pin of the probe, the pressure applied by the yarn causes a change in the voltage which is proportional to the yarn tension. Also, an electronic microscope is attached to measure the yarn displacement from the actual position in accordance with the change in tension (cN).

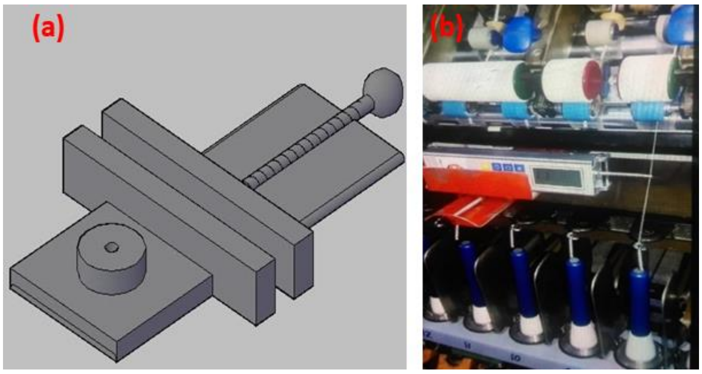

Figure 1. (a) DTM 500 Tensiometer, (b) Tension meter attachment at ring frame

The experiments of the yarn tension were performed with the polyester and cotton blended (PC) yarns. The experiments for the yarn tension measurement were conducted for three different yarn counts for PC blends (52:48) i.e., 20/1, 30/1, and 40/1. The optimum spindle speeds and traveler weights are different for every count. Therefore, the other influencing variables were varied from the optimum values. Moreover, the condition of the steel ring exerts a major influence on the yarn tension. Therefore, the working life of the steel ring was considered as a parameter. Along with the yarn tension, the displacement distance from the mean yarn passage was also considered as determining value. The displacement of the yarn from its original path increases the tension to an extent and then the yarn breaks after a certain displacement.

This mentioned arrangement is the conversion of the subjective evaluation of the yarn tension to an objective evaluation. The expert staff in the spinning industry use to check the tension by hand and try to feel the tension with a finger. Then they use the trial-and-error method to optimize the yarn tension and hence to control the end breakage and improve the quality and production efficiency at the ring frame. The dynamic yarn tension measurement arrangement that is used in this study is capable of determination of yarn tensions objectively.

RESULTS AND DISCUSSION

The present study was conducted to enhance the quality and productivity of the spinning process and to eliminate the trial and error at the ring-spinning frame. The subjective method of estimating the yarn tension was converted to the objective determination of the dynamic yarn tension as mentioned in the Section 2 (Materials and Methods). For this, the following parameters were considered in the determination of dynamic yarn tension at the ring-spinning frame and their corresponding yarn tensions were measured. The yarn tension determination using the following parameters helped to find the optimum yarn tension for a specific count,

- Yarn count
- Spindle speed
- Traveler no.
- Ring life in months
- Displacement from the original position
- Tension at different cop build up position.

In order to collect the reliable industrial data for this study, all the experiments were conducted in the Shahzad Textile Mills Sheikhupura, Pakistan on the ring spinning machines. The collected data was further used for the artificial neural network training for the determination of the optimum yarn tension. After the determination of the optimum yarn tension for different counts, the dynamic yarn tensions on all the ring spinning machines in the industry were determined. The difference between the optimum yarn tensions and determined yarn tensions were adjusted by changing the spindle speeds and adjusting the traveler nos. The increase in the spindle speeds has resulted in increased productivity. Moreover, it is also inferred that at the optimum tension, the ends down rate is also reduced which results in the conservation of energy and raw materials.

Table 1. Parameters of Cotton and Polyester fibers used in this study.

Cotton										
SCI	Moisture (%)	Mic	Mat	UHML (inch)	UI (%)	SF (%)	RD	+b	Strength (g/tex)	C. Grade
125	8	4.23	0.87	1.059	81.6	7	76.7	8.7	30.2	31-2
Polyesters										
Denier		Length (mm)								
1.2		38								

3.1 Influence of yarn count (ne)

The yarn tension with respect to counts were determined at the optimized spindle speeds of the ring-frame and the results are shown in *Fig. 2*. The tensiometer was used to measure the yarn tension. Different yarn counts have different spinning tension mainly due to differences in the number of fibers in the cross-section of yarn. This results in more cohesion between the fibers and hence more tensile strength. Therefore, courser counts can bear more tension than the finer counts. The same has been proved when the yarn tension was measured by displacing the yarn from its original path. The average spinning tension for 20/1, 30/1, and 40/1 is 11 cN, 9.4 cN, and 8.6 cN, respectively.

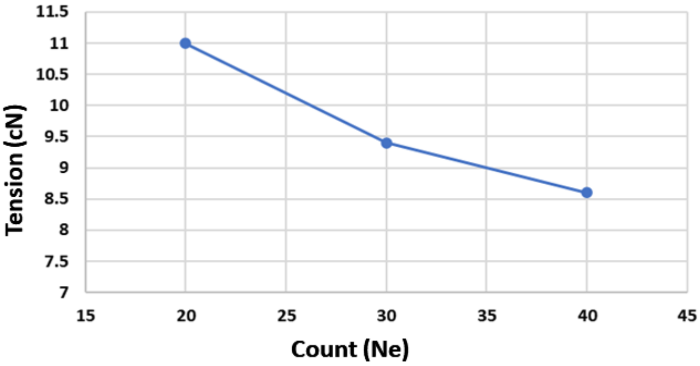

Figure 2. Measurement of spinning tension for different counts with a tensiometer

3.2 Influence of spindle speed:

The yarn tension of various counts (20/1, 30/1, and 40/1) at different the ring frame at different doffing positions; start, mid, and full of doff were determined and the results are shown in *Fig. 3*. It is obvious from the results that the yarn tension and ring frame speed increases with an increasing doff time. For 20/1 PC, at the start of doff at the spindle speed of 13000 rpm, the spinning tension is 11.8 cN, at the mid of doff, at the spindle speed of 15000 rpm the average spinning tension is 12.4 cN, and at the full of doff on the spindle speed of 16000 rpm, the average spinning tension is 12.8. So, the above graph presents that with the increase of spindle speed, the average spinning tension for 20/1 PC is increased. Similar findings were observed for PC 30/1 and PC 40/1. The yarn tension is increased with an increasing spindle speed. It can also be seen that the trend is quasi-linear. However, other factors like the condition of the steel ring and traveller also influence the yarn tension. However, the quasi-linear trend shows that other factors exert the same influence on all ring machines tested for the study.

The yarn tension is the result of many factors including spindle speed, condition of the steel ring, type and condition of the ring flange, weight condition of the ring traveler, friction of the spindle, centricity of the spindle, and yarn count etc. All these ring geometry paraments increase or decrease the yarn tension due to the friction between ring and traveler, and yarn and traveler, the smoothness of the spindle rotation and traveler rotation on its track on steel ring may decrease the friction and as a result yarn tension is reduced. This intern can reduce the yarn breakage and if the yarn tensions are optimized the spindle speeds can be increased which can increase the productivity of the spinning operation.

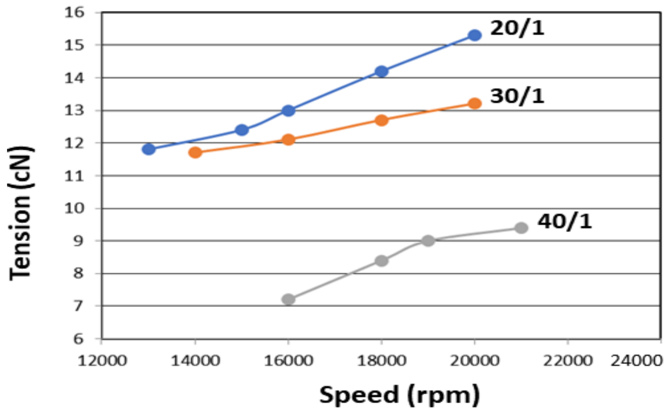

Figure 3. Dynamic yarn tension of different counts at different speeds

3.3 Influence of traveler and displacement distance

The core of the study depends on the measurement of the yarn tension at different displacement levels from the original yarn path. This method shows that how much spinning tension the yarn can bear before being broken. The displaced distance is directly proportional to the increase in the yarn tension. However, due to friction between the ring and traveler, there are tension peaks, especially in the winding tension and balloon tension which are then transported to spinning tension, i.e. between the snail wire and the nip of the front roller. If this tension increases than the strength of the weakest place in the yarn, the end down occurs. Therefore, yarn tension at a displacement is a vital measurement parameter to understand and predict the spinning geometry interactions and the optimum yarn tension. For this, the yarn tension at different displacement levels were determined and the results are shown in *Fig. 4*. The yarn tension was measured using different traveler numbers (no.3, no, 4, and no. 5) as shown in *Fig 5*.

The dynamic yarn tension of 20/1 was determined using traveler no. 3 at the spindle speed of 15800 rpm. It can be seen from *Fig. 4* that for 20/1 that an average tension at break was found to be 12.4 cN. At the displacement of 2.5 mm, 2.75 mm, 3.0 mm, and 3.75 mm, dynamic yarn tension of 7.0 cN, 8.0 cN, 10 cN, and 11 cN was observed, respectively. It can be inferred that the yarn tension increases with the increase of displacement until it breaks after achieving a maximum average tension of 12.4 cN. Similarly, an average tension at break was found to be 11.8 cN using the traveler no. 4 at the spindle speed of 15400 rpm. At the displacement of 1.75 mm, 2.5 mm, 3.0 mm, and 3.25, dynamic yarn tension of 5.0 cN, 7.0 cN, 10 cN, and11 cN was observed, respectively. It can be inferred that the yarn tension increases with the increase of displacement until it breaks after achieving a maximum average tension of 11.8 cN. The same is the case with traveler no. 5, an average tension at break was found to be 12.5 cN. At the displacement of 1.5 mm, 2.0 mm, 2.5 mm, and 3.0 mm, dynamic yarn tension of 6.0 cN, 7.0 cN, 9 cN, and 11 cN was observed, respectively. It can be inferred that the yarn tension increases with the increase of displacement until it breaks after achieving a maximum average tension of 12.5 cN.

The force generated by the motion of the traveller and the pulling of the yarn through the traveller around the spindle axis as well as the winding of the yarn onto the spinning cop causes yarn tensions, which define the actual shape of the spinning balloon [25]. There is a direct relationship between the number of travelers, which are metal rings guiding yarn during spinning, and the resulting tension in the spun yarn. The yarn experience increased tension with an increasing traveler number during spinning process. This inference has practical implications in the textile industry, where yarn quality and consistency are paramount. Choice of traveler no. can be strategic choice for manufacturers to control and optimize yarn tension, ultimately influencing the quality of the final product. Understanding this relationship is crucial for achieving desired yarn characteristics and production efficiency in the world of textile manufacturing. It can be inferred from the above discussion that an increase in the traveler no. tends to increase the spinning yarn tension. However, the ability to withstand the tension under the displacement from the original path decrease and so the ability to withstand the peaks in the tension originated from the ring traveler friction.

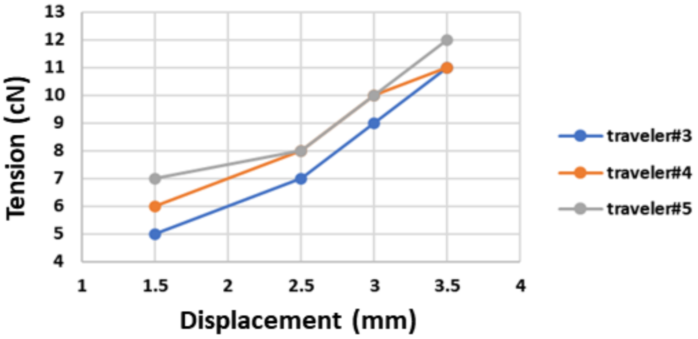

Figure 4. Dynamic yarn tension measurement of 20/1 using different travelers

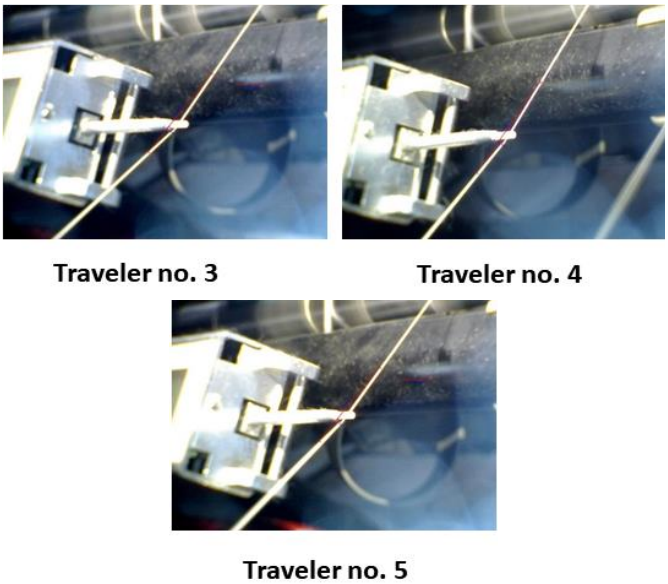

Figure 5. Yarn tension measurements at ring frame

Similarly, the relation between the dynamic yarn tension and different yarn displacements was determined for 40/1 and the results are shown in *Fig. 6*. For this experiment, the values for the dynamic yarn tensions were determined using traveler no. 1 at the spindle speed of 21000 rpm. The result reveals that an average tension at break was found to be 9.4 cN on this count. At the displacement of 1.0 mm, 1.5 mm, 2.0 mm, and 3.0 mm, tension of 4.0 cN, 6.0 cN, 7 cN, and 9 cN was observed, respectivley. It can be inferred that the yarn tension increases with the increase of displacement until it breaks after achieving a maximum average tension of 9.4 cN.

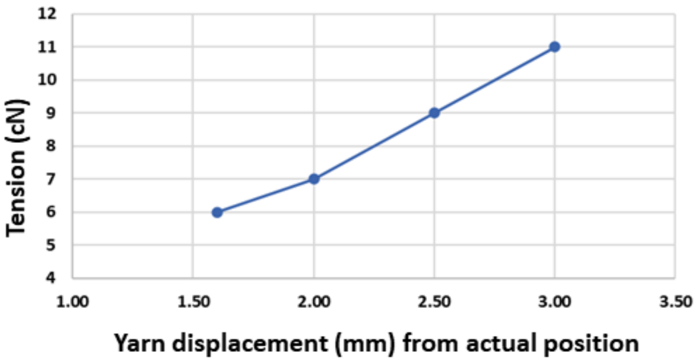

Figure 6. Dynamic yarn tension of 40/1 (Ne) at different yarn displacements

3.4 Influence of spindle speed and displacement distance

As the objective of the study is to enhance productivity and quality by reducing the end breakage and increasing the spindle speed. Therefore, this part of the study was designed to develop the relationship between the spinning yarn tension and the spindle speed at different displacement distances. As the spindle speed and traveler no. are the only two parameters in the spinning geometry that can be changed to increase or decrease the yarn tension.

The dynamic yarn tension of the 20/1 was determined at different speeds and different displacement distances and the results are shown in *Fig. 7*. It is evident from the results that the average tension increases with an increase in the spindle speed. However, as far as the displacement distance is considered it is shown that the trend is not quite linear. The increase in the displacement from 2.5 mm up to 3.5 mm, has a steeper slope in comparison with the yarn tension values at displacement distances below 2.5 mm.

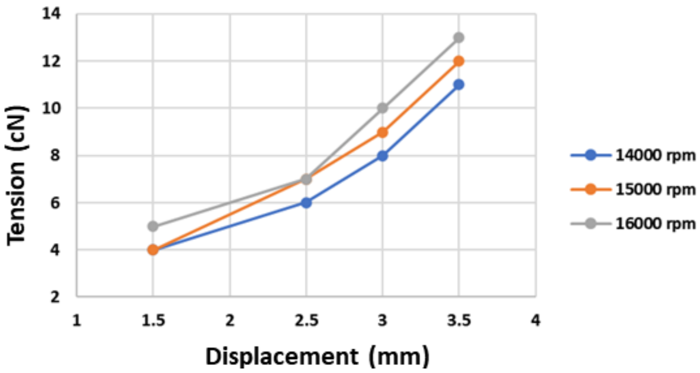

Figure 7. Measurement of dynamic yarn tension at different displacement and spindle speeds

Furthermore, the data reveals that at higher spindle speeds the yarns tend to break at lower displacement distances, which is attributed to the ability to bear less tension. The same case was observed when the heaver travelers were used. The same experiments were performed with the other yarn counts at higher spindle speeds and the data for artificial neural networks were collected.

For clarity and ease of understanding the results for the produced counts are summarized in Table *2*.

3.5 Artificial neural networks modeling and simulation

The data collected by changing different parameters at the ring spinning machine was subjected to artificial neural network training software Matlab Neural Networks Toolbox. The concept is to predict the optimum yarn tension at the given parameters. Different combinations of network structures, training parameters, and training algorithms were applied to achieve the best training of the neural network. Then the trained networks were tested against the unseen data both by the "hold-out" method and cross-validation technique. The training parameters are given in Table 3 while the performance of Artificial Neural Networks during training and testing is given in Table 4. The values measured were validated with values calculated from a model developed for the prediction of yarn tension at different zones and the results are shown in *Fig. 8*. The Fig shows the Artificial Neural Network on unseen data using the "hold-out" method. The mean absolute error expressed in terms of yarn tension is 0.6 cN. Cross-validation was also applied to the yarn tension data. The results show a mean absolute error of 0.45 cN for 10% Cross validation while an error of 0.74 cN is observed in the case of 20% Cross-validation.

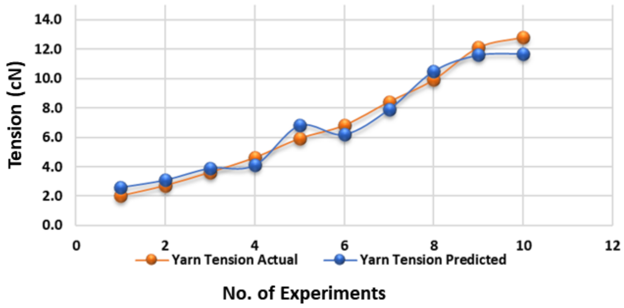

Figure 8. Test Performance for Yarn Tension.

Ring spinning geometry is of vital importance to control the end breakage rate in the spinning mill. The input parameters considered for the training of ANNs were the most influencing parameters. The parameters like steel ring condition cannot be considered in the other mathematical or statistical modelling. Whereas the steel ring condition generates uneven friction with the traveler and hence cause the yarn breakage. The above-mentioned ANN model was used to optimize the yarn tension on 25 spinning machines and the end breakage rate was calculated. It was found that the optimized DYN can results in low end breakage rate. Similarly, for the ring spinning machines having less dynamic yarn tension at different displacement points, the productivity of ring spinning machinery can be enhanced by increasing the spindle speeds.

Table 2. Summary for the 20/1, 30/1, and 40/1 yarn produced in this study.

Nec	U%	CV%	CV 1m	CV 10m	Thin -50	Thick +50	Neps +200	IPI	H	CLSP	TM	Speed (rpm) Thousand
40/1	12.0	15.01	4.34	2.69	9	300	491	800	4.00	2750	3.35	20800
30/1	11.23	14.35	4.84	2.63	4	179	290	473	5.49	3100	3.07	18000
20/1	9.41	11.95	4.07	2.01	0	36	83	119	6.6	3400	2.9	15000

Table 3. Neural network training parameters for yarn tension

Network Parameters	Values	Network Parameters	Values
No. of Input Neurons	6.0	Momentum	0.3
No. of neurons in the first hidden layer	6.0	Maximum Epochs	1000
No. of neurons in the second hidden layer	4.0	Stopping error	0.001
No. of neurons in the outer layer	1.0	Trained algorithms	Trainbr
Learning rate	0.1		

Table 4. Neural network training parameters for yarn tension

Network Performance	Mean absolute error (Expressed in terms of yarn tension)
Training Performance	0.4 cN
Testing Performance	0.6 cN
10 % Cross Validation	0.45 cN
20 % Cross Validation	0.74 cN

4 CONCLUSION

The optimization of the yarn tension at ring frame can reduce the yarn breakage and can improve the quality of the yarn produced. Artificial neural networks are one of the techniques by which the influence of complex relationship between the numerous variables on the predicted with accuracy. In this proposed project, the individual and combined influence of traveler weight, yarn count, spindle speed was studied on the dynamic yarn tension. Moreover, the method to determine the dynamic yarn tension on ring frame was also devised. Furthermore, industrial scale experiments were conducted, and their data was used as input for the neural network training and a model for the prediction of the dynamic yarn tension was developed. The results reveal that using optimized values predicted from artificial neural networks has decreased end-breakage at spinning frame, with improved yarn quality. The finding of this study can be used as a basis for the determination and optimization of yarn tension and reducing end breakage at ring spinning frame. Based on the findings, using artificial neural network can be a good step towards the automation of ring frame and it will result in the reduction of waste, conservation of energy. Factors like higher spindle speed and position of the ring rail also influence the yarn tension remarkably. These factors may be considered for future research work in this direction.

Limitations of the study

There are many parameters like elative humanity and raw materials that influence the quality and production. However, the proposed study pertains to the PC (52:48) blend of polyester and cotton.

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Araştırma Makalesi / Research Article

INVESTIGATING THE CLOTHING COMFORT PROPERTIES OF KNITTED FABRICS USED IN CYCLING SPORTSWEAR

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ABSTRACT: In this research, it was aim to investigate the clothing comfort properties of knitted fabrics intended for summer cycling sportswear. Five different fiber types and five different knitted structures commonly used in cycling sportwear were selected and totally 25 fabrics were manufactured by using a seamless circular knitting machine namely Santoni SM8-TOP2V in a controlled manner. To assess the impact of material type and knitted structures on clothing comfort properties, mass per unit area, thickness, air permeability, thermal conductivity, thermal resistance, overall moisture management capability and relative vapour permeability tests were conducted. The statistical significance of variations in the obtained results was evaluated using the analysis of variance (ANOVA) method. In conclusion, the most suitable material and knitted structure have been recommended for summer upper body cycling clothing.

***Keywords*:** Sportswear, Clothing comfort, cycling sportswear, knitted fabric.

BİSİKLET SPORU GİYSİLERİNDE KULLANILAN ÖRME KUMAŞLARIN GİYİM KONFORU ÖZELLİKLERİNİN İNCELENMESİ

ÖZ: Bu araştırmada, yaz mevsiminde kullanılan bisiklet spor giysileri için örülmüş kumaşların giyim konfor özelliklerinin araştırılması amaçlanmıştır. Bisiklet sporcu giysilerinde yaygın olarak kullanılan beş farklı lif türü ve beş farklı örgü yapısı seçilmiş ve toplamda 25 kumaş, kontrollü bir şekilde Santoni SM8-TOP2V dairesel örme makinesi kullanılarak üretilmiştir. Malzeme tipi ve örgü yapısının giyim konforu üzerindeki etkisini değerlendirmek için kumaşlara gramaj, kalınlık, hava geçirgenliği, termal iletkenlik, termal direnç, nem yönetimi yeteneği ve bağıl su buharı geçirgenliği testleri uygulanmıştır. Elde edilen sonuçlar, varyans analizi (ANOVA) yöntemi kullanılarak değerlendirilmiştir. Araştırma sonucunda, sıcak iklim koşullarında kullanılacak bisiklet sporcu giysileri için uygun malzeme tipi ve örgü yapısı önerilmiştir.

Anahtar Kelimeler: Spor giyim, giyim konforu, bisikletçi giysileri, örme kumaş.

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1. INTRODUCTION

The increasing interest sports has resulted in a rise in the worldwide sales of sportswear within recent years, hence apparel manufacturers and researchers have directed their attention this domain [1,2]. Sportswear has become increasing important for all people, as they anticipate higher expections for sports clothing to fulfill specific functions [3]. In the case of cycling, a highly popular sport globally, the clothing comfort of athletes assumes great importance. The movements of athletes generate a significiant amount of heat during activity. This sport exhibits multiple attributes, such as intensive energy consumption, a high sweating rate, and a higher level of extremity training. Therefore, cycling clothes needs to perform not only functional but also provide optimal comfort during wear [1,2,4]. Several articles were focused on the clothing comfort in the relation to type of fiber, yarn variables, knitted structure. Özkan and Meriç were investigated the thermophysological comfort features of different polyester knitted fabrics used in cycling sportswear. They were stated that warp knitted raschel fabric demonstrated greater suitability for cycling apparel used in summer. A survey was carried out with a cycling team to determine their expectations from clothes. Based on the feedback, five weft knitted and one warp knitted fabric which have different yarn counts and composition were chosen. The authors conducted the comfort tests and they were stated that %100 pes 75/36 denier trilobal cross-section warp knit raschel fabric was most convenient for summer cycling apparel [5]. Suganthi et al. focused the thermal comfort features of knitted fabrics made from modal, texturized polypropylene and micro-denier polyester yarns. Eleven fabrics were knitted in single jersey, plated and bi-layer structures. Objective and subjective evaluation of the fabrics were carried out. The results indicated that bi-layer knitted fabric with polypropylene as the inner and modal as the outer is suitable for volleyball sportswear [3]. Fan and Tsang investigated the influence of clothing's thermal characteristics on the comfort of wearers during sports activities. They utilized a thermal manikin to evaluate the thermal insulation, moisture vapour resistance, and moisture accumulation of five tracksuits. They found that the clothing comfort values after exercising were associated with the moisture vapour resistance of clothing and percentage of moisture accumulation within clothing, as measured by sweating manikin [6]. Wang et al. aim to investigate the impact of fabric structure and materials on fabric performance and produced 12 kinds of jacquard fabrics using polyester and DRYARN. Performance tests, such as air permeability and thermal resistance, were conducted on the fabrics and the results were statistically analyzed. Based on these findings, they designed professional ski underwear by using zone optimization [7]. Kun and Yanzhen analyzed the characteristics of the structural design of cycling clothes, and choose the functional fabrics, the design requirements of the pattern and the color. They concluded their study by offering the future development prospects of cycling clothing in China [8]. Taştan Özkan and Kaplangiray investigated the effect of loop length on thermal and moisture transmission properties of mesh knitted fabrics. They produced six types of fabrics with two different loop lengths in mesh and mesh rib structures. They declared that if the yarn gets finer and loop length increases, the air permeability values increases while overall moisture management capacity and thermal absorptivity values decreases [9]. Öner aimed to investigate the impact of fibers types on mechanical and thermal comfort properties of knitted fabrics. In this context, the author selected several fibers, namely cotton, flax, viscose, modal, bamboo, tencel, zein, polyester and polyamide 6.0. and produced in single jersey knitted fabrics from these fibers. The results emphasized that the type of fiber plays a crucial role in determining the mechanical and thermal comfort features of knitted fabrics [10]. Several studies have examined the influence of fiber types, yarn properties, and knitted fabric structures on clothing comfort. However, it has been observed that there are limited studies in the literature investigate the impact of fiber types on the comfort of cycling sportswear. Moreover, there are very few studies about the cocona® fiber, which is used in this study. Cocona® fiber is a type of synthetic textile fiber that used in sportswear such as cycling jerseys for athletes. Cocona® fabric, made from coconut shells, is widely used in sportswear due to its lightweight, excellent moisture management properties, which helps to regulate the body temperature of athletes within an ideal range during intense physical activity [11,12].

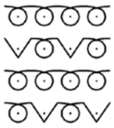
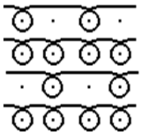
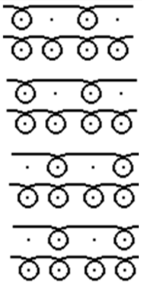
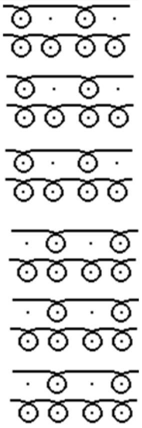
The objective of this study was to investigate the clothing comfort properties of knitted fabrics used in summer cycling sportswear. In this context, 5 different fiber types and 5 different knitted structures commonly used for cycling apparel were selected. Fabrics were manufactured on Santoni SM8-TOP2V by using seamless technology and clothing comfort performance properties were analysed. Seamless circular knitting technology was used due to its significant role in the sportswear production and its capability to offer limitless design possibilities [13]. This technology allows for the creation of continuous knitted fabric in a tubular form, and providing significant benefits to the wearers [14,15].

2. MATERIALS and METHODS

2.1. Materials

In this paper, five different fibers commonly used in cycling sportswear were selected. The fabrics were produced in five different knitted structures on a seamless circular knitting machine, namely Santoni SM8-TOP2V with a gauge (E) of 28, with the same constant machine settings. The fabrics structures were determined as the most preffered knitting structures for cycling sportswear, and single jersey, pique, jacquard 1x1, jacquard 2x2, jacquard 3x3 were knitted by using plating technique. The needle diagrams for these knitted structures were given in Table 1.

Table 1. The needle diagram of the knitted structures of the fabrics.

Fabric Structure	Single Jersey	Pique	Jacquard 1X1	Jacquard 2x2	Jacquard 3x3
Needle Diagram					

Different yarns were used on the surface and interior sides of the fabrics during production process. Poliamid multiflament yarn was choosen as the outside yarn, which is in contact with the environment, for all fabric structures. Polyester (83D/72f), polyamide (78D/68f), polypropylene (78D/50f), coolmax® (75D/72f) and cocona® (75D/48f) with the yarn counts as close to each other as possible were selected for inner side of the garment in contact with the wearer's skin. Totally twenty-five knitted fabric samples were manufactured and systemactically coded as between S1- S25.

This research focussed on examining the influence of inner material and knitted structures on the clothing comfort properties of fabrics. Therefore, the dyeing and finishing processes were kept constant for all fabrics. All the fabric samples were dyed in a garment dye machine with the suitable dyestuffs. Afterward, they were washed with a nonionic detergent at 40°C for 20 minutes followed by tumble drying for 30 minutes.

2.2. Methods

The fabric samples were conditioned at 65% ± 4% relative humidity and 20 °C ± 2 °C temperature for at least 24 h under the standard atmosphere conditions according to EN ISO 139:2005 [16]. Afterwards, the tests namely mass per unit area, thickness, air permeability, thermal resistance, thermal conductivity, overall moisture management capacity (OMMC) were conducted. The testing instruments and corresponding standards were referenced in Table 2.

The air permeability values were measured with a 100 Pa air pressure difference and 20 cm2 testing area. The results represent the average of ten random measurements taken from various regions of the fabric. To measure the thermal conductivity, thermal resistance and fabric thickness using Alambeta testing instrument, three repetitions were performed. Moisture management properties were tested by cutting square samples in 80 mm × 80 mm dimensions, and the average of five repetitions was evaluated. The PERMETEST Sensora instrument, simulates the human skin, was utilized to measure the relative water vapour permeability.

Table 2. The tests, testing instrument and corresponding standards

Fabric Tests	Testing Instrument	Related Standard
Course and wale density	-	CSN EN 14971:2006
Loop length	H.A.T.R.A device	EN 14970:2006
Air permeability	Textest FX 3300	TS 391 EN ISO 9237 [17].
Thickness Thermal conductivity Thermal resistance	Alambeta	ISO 8301
OMMC	MMT	AATCC 195-2009 [18].
Relative water Vapour Permeability	Permetest	TS EN ISO 11092 [19].

2.2.1. Statistical Evaluation

The analysis of variance (ANOVA) method was used to assess the statistical significance of the variations, utilizing PASW18 statistical analysis package program. In order to deduce the significance of the parameters, namely inner material type and knitted structure, the p values were evaluated at the confidence level of 95%. Following that, multiple comparison tests (post-hoc tests) were conducted to analyze any differences among the parameters. Initially, Levene's homogeneity test, with a 95% confidence interval, was applied to assess whether the variances exhibited a homogeneous structure or not. If a homogeneous variance was detected, the Student-Newman-Keuls (SNK) post hoc test was conducted to examine the variations between the means. If a heterogeneous variance was detected, the Tamhane's T2 test was applied.

3. RESULTS and DISCUSSIONS

The tests were conducted to investigate the effects of knitted structure and inner side material on the clothing comfort properties of fabric samples. The obtained average values of mass per unit area, thickness, air permeability, thermal resistance, thermal conductivity, overall moisture management capacity and relative water vapour permeability were presented in Table 3.

Detailed evaluation of the loop structure was perfomed to obtain a better explanation of the relationship between the loop length and the comfort test results (Table 4).

Table 3. Test results of fabric samples

Inner material	Knitted structure	Cpc	Wpc	Stitch density (stitch/cm^2)	Mass per unit area (g/m^2)	Thickness (mm)	Air permeability (l/m^{2}s)	Thermal conductivity (W/m K)	Thermal resistance (m^{2}K/W)	OMMC (-)	Relative water vapour permeability
PES	Jersey	19	25	475	178,6	0,79	342	0,048	0,017	0,4853	49,6
	Pique	18	18	324	163,6	0,61	367	0,051	0,012	0,4263	52,8
	Jac. 1x1	18	19	342	147,6	0,77	630	0,045	0,017	0,3836	53,6
	Jac. 2x2	20	19	380	143	0,83	632	0,045	0,018	0,3843	54,8
	Jac. 3x3	19	19	361	144,9	0,8	642	0,044	0,018	0,4101	56,7
PA	Jersey	18	25	450	158,5	0,83	227	0,053	0,015	0,3918	52,4
	Pique	21	20	420	150,1	0,71	272	0,057	0,012	0,3347	53,5
	Jac. 1x1	18	19	342	132,4	0,79	430	0,051	0,016	0,333	55
	Jac. 2x2	18	19	342	136,9	0,83	406	0,051	0,016	0,3276	58
	Jac. 3x3	18	19	342	137,2	0,83	443	0,051	0,016	0,3351	58,3
PP	Jersey	17	24	408	144,1	0,83	350	0,054	0,015	0,7269	49,6
	Pique	18	19	342	125,9	0,69	421	0,055	0,013	0,7165	51,4
	Jac. 1x1	18	19	342	111,7	0,78	725	0,052	0,015	0,429	52,2
	Jac. 2x2	18	19	342	110,4	0,81	728	0,052	0,015	0,4527	53,7
	Jac. 3x3	18	19	342	110,6	0,85	730	0,052	0,017	0,4817	54,8
Coolmax®	Jersey	18	26	468	163	0,81	420	0,056	0,015	0,8308	47,4
	Pique	18	19	342	149,1	0,71	417	0,058	0,012	0,8212	48,8
	Jac. 1x1	18	20	360	133,6	0,81	605	0,052	0,016	0,641	50,7
	Jac. 2x2	18	21	378	137,2	0,88	619	0,051	0,017	0,6761	51,5
	Jac. 3x3	18	21	378	135,4	0,89	658	0,052	0,017	0,6784	53
Cocona®	Jersey	19	25	475	131,7	0,76	438	0,052	0,015	0,7119	53
	Pique	19	17	323	115,4	0,65	430	0,053	0,012	0,7345	58
	Jac. 1x1	21	19	399	88,7	0,75	716	0,046	0,016	0,4055	60,1
	Jac. 2x2	20	19	380	94,8	0,83	720	0,046	0,018	0,5705	62,8
	Jac. 3x3	20	19	380	97,3	0,83	731	0,046	0,018	0,6019	62,9

Table 4. The loop length values of each sample

Knitted Structure	Loop Structure	Loop Length (mm) / Inner Material				
		PES	PA	PP	Coolmax®	Cocona®
Jersey	Knit loops	2,21	2,17	2,22	2,26	2,29
Pique	Knit loops	2,30	2,20	2,40	2,50	2,60
	Tuck loops	1,40	1,40	1,40	1,41	1,50
Jac. 1x1	Knit loops	2,30	2,26	2,36	2,38	2,50
	Miss loops	2,34	2,30	2,41	2,40	2,58
Jac. 2x2	Knit loops	2,32	2,30	2,42	2,40	2,50
	Miss loops	2,38	2,35	2,50	2,42	2,60
Jac. 3x3	Knit loops	2,50	2,40	2,56	2,60	2,54
	Miss loops	2,58	2,50	2,60	2,68	2,63

To get a better understanding, additional statistical analysis such as multiple comparison tests were performed in order to investigate the effect of knitting structure and interior side material on clothing comfort properties and to determine differences between the samples.

3.1 Air Permeability

Air permeability is the measure of air flow through the fabric due to a pressure difference. It is playing an important role in determining the fabric's breathability and permeability, and mostly affected by the fabric's porosity in addition to its thickness. [10, 20].

Figure 1 illustrates that fabrics with jacquard knitted structures exhibited higher air permeability values compared to other fabrics. This can be explained by the relationship between loop length values and air permeability values. Due to the miss loop based structure in jacquard fabrics, their loop lengths were higher than the other fabrics (Table 4). This observation aligns with the insights from the study by Taştan Özkan and Kaplangiray [9], which demonstrated that an increase in loop length correlates with higher air permeability values. Furthermore, Tamhane's T2 test results revealed that the differences in knitted structures significantly affect air permeability features. Jacquard fabrics exhibited greater values, and statistically, there was no significant difference among them. Due to the tuck loops, pique fabric had lower loop length values and therefore exhibited lower air permeability values compared to jacquard structures. There was no statistically significant difference between pique and jersey fabrics.

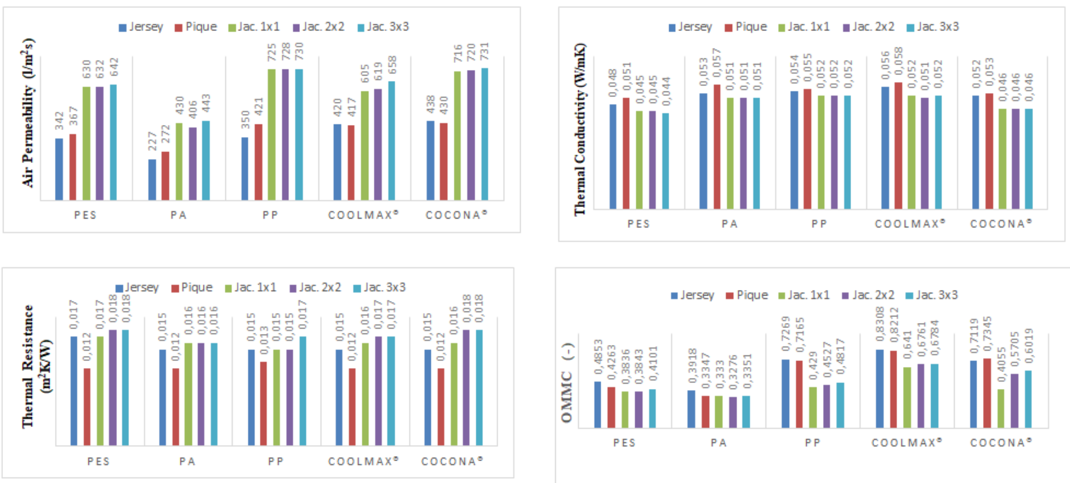


Figure 1. The results of air permeability, thermal resistance, thermal conductivity and overall moisture management capacity tests average values.

As stated in the literature, the air flow principle states that the flow of air will be less in thicker fabric and more in thinner fabric [3]. Supporting this argument, in this study, the jacquard fabrics with lighter weights presented higher air permeability features. To evaluate the influence of inner yarn material type on air permeability properties, Tamhane's T2 tests were conducted. As illustrated in Table 5, the results revealed that the air permeability values of polyamide fabrics were lower than the others and exhibited significant differences. To explain this situation, the thickness value of fabrics was first evaluated. However, there was no significant difference in thickness values among the fiber types. This observation may be caused due to the yarn counts. While polyamide fibers contain 68 filaments, polypropylene had 50 filaments at the same denier. Therefore, it could be said that the air permeability values were lower in polyamide fabrics due to the reduced voids. On the other hand, cocona® and coolmax® fabrics demonstrated the highest air permeability values, with no statistically significant difference observed among cocona®, coolmax® and polypropilen fabrics.

It is a fact that the fabrics with high air permeability values are choosen for summer cycling clothes. This emphasizes the important role of breathability in the fabric; therefore, the jacquard knitting structures come to forefront to be preffered for these clothes.

3.2 Thermal Conductivity

The thermal transfer features are important for ensuring the thermal comfort. Extensive thermal conduction facilitates the transfer of heat generated by the human body through the fabric to the outside environment. This property is expected in summer and sportswear [21].

In the terms of the thermal conductivitiy property, the results of the SNK test analysis (Table 6) indicated that both pique and single jersey fabrics exhibited high thermal conductivity values, and there was no significant difference observed between these fabric samples. On the other hand, jacquard fabric structures had lower thermal conductivity values, although there was no statistical significant difference observed between the jacquard knitted structures.

Table 5. Effects of inner material type on air permeability Tamhane's T2 test analysis results.

Inner type material (I)	Inner type material (J)	The difference between means (I-J)	Standard Error	p.	95% Confidence ınterval	
					Lower bound	Upper bound
PES	PA	166.760	23.624	0.000	98.83	234.69
	PP	-68.200	31.349	0.278	-158.07	21.67
	COCONA®	-21.540	24.920	0.993	-93.03	49.95
	COOLMAX®	-84.760	28.425	0.036	-166.17	-3.35
PA	PES	-166.760	23.624	0.000	-234.69	-98.83
	PP	-234.960	27.431	0.000	-314.10	-155.82
	COCONA®	-188,300	19,766	0,000	-244,95	-131,65
	COOLMAX®	-251.520	24.035	0.000	-320.65	-182.39
PP	PES	68.200	31.349	0.278	-21.67	158.07
	PA	234.960	27.431	0.000	155.82	314.10
	COCONA®	46.660	28.554	0.674	-35.49	128.81
	COOLMAX®	-16.560	31.659	1.000	-107.30	74.18
COCONA®	PES	21,540	24,920	0,993	-49,95	93,03
	PA	188,300	19,766	0,000	131,65	244,95
	PP	-46,660	28,554	0,674	-128,81	35,49
	COOLMAX®	-63,220	25,309	0,134	-135,85	9,41
COOLMAX®	PES	84,760	28,425	0,036	3,35	166,17
	PA	251,520	24,035	0,000	182,39	320,65
	PP	16.560	31.659	1.000	-74.18	107.30
	COCONA®	63.220	25.309	0.134	-9.41	135.85

Table 6. Effects of knitted structure on Thermal Conductivity SNK post hoc test analysis results

Knitted structures	N	Subsets	
		1	2
Jacquard 3x3	15	0,049	
Jacquard 2x2	15	0,049	
Jacquard 1x1	15	0,049	
Pique	15		0,053
Single jersey	15		0,055
p.		**0,933**	**0,050**

The analysis conducted using Tamhane's T2 test demonstrated that the fabrics made from coolmax® and polyester materials had lower thermal conductuvity values compared to the other fabrics, with a significant difference observed between the remaining fabrics. However, there was no significant difference was found between the thermal conductivity values of polyester and coolmax® fabrics. The thermal conductivity values of polypropylene, cocona® and polyamide fabrics were higher than the other fabrics, but no significant difference was observed among these three fabrics.

3.3 Thermal Resistance

Thermal resistance, which plays an important role in assessing the thermal insulation of clothing, is closely associated with the thickness of the fabric [22]. Regarding the influence of knitted structure on thermal resistance values, the results of the Tamhane's T2 test indicated that single jersey fabrics had the lowest thermal resistance values. Pique and jacquard 1x1 fabrics' thermal resistance values did not differ significantly in statistical terms. However, the thermal resistance values of jacquard 2x2 and jacquard 3x3 knitted structures were not statisitically significant and were higher compared to the other structures. Karthikeyan et al. (2016) stated that there is a negative correlation between thermal conductivity and thermal resistance, indicating that as thermal conductivity values decrease, there is an increase in thermal resistance values [23]. Supporting this paper, the thickness values of single jersey fabrics were found to be lower compared to jacquard fabrics. An increase in fabric thickness leads to an increase in the amount of stagnant air within the fabric. Due to its high thermal insulation properties, stagnant air exhibits more resistance to heat transfer. Consequently, this results in higher thermal resistance values and lower thermal conductivity values. As seen in Table 1, the thermal resistance values of fabrics knitted from polyester and coolmax® yarns were higher compared to the other materials. However, upon examining the results of the variance analysis, it was observed that the difference between the thermal resistance values of inner material types is not statistically significant.

3.4 Moisture Management Capability

MMT equipment measures various parametres associated with the fabric moisture management properties and OMMC is one of these parameters [24]. As illustrated in Table 1, the presented results demonstrate the overall (liquid) moisture management capability (OMMC) values of the fabrics. The value of the OMMC parameter is in the range of 0 to 1 with a higher OMMC value indicating a greater capacity to effectively manage liquid moisture [1, 25]. The five-grade indices represent the following levels: (1) poor, (2) fair, (3) good, (4) very good, and (5) excellent (Table 7) [26]. Based on the results, it can be stated that the OMMC values of single jersey and pique fabrics exhibited higher values compared to the jacquard fabrics. However, it is noted that no statistically significant difference was observed among the knitted structures of the fabrics.

Evaluating the influence of the inner side material on moisture management properties, Tamhane's T2 statistical tests (Table 7) were carried out. The findings showed that polyamide fabrics had the lowest OMMC values (poor grades) followed by polyester fabrics. The differences in OMMC values between polypropylene and coolmax® fabrics were statistically insignificant. Coolmax® single jersey and pique fabrics had the highest OMMC values and showed excellent grades. Fabrics knitted from cocona® yarns were observed to have another highest OMMC values (very good-excellent grades), ranking after coolmax® and polypropylene yarns. Based on the OMMC evaluation scale, fabrics knitted from polypropylene, coolmax®, and cocona® yarns demonstrated excellent liquid management performance.

It is stated that coolmax® fibers have the highest OMMC values due to their channeled cross-section structure, which provides capillary effect. This enables the fabric to absorb the liquid from the body more fastly and efficiently. Furthermore, cocona® fibers exhibited high OMMC values due to the activation of carbon particles during contact with water, which incereases the surface area of fabric and provide an increase its OMMC values.

During cycling sports activity, athletes sweat instensly; therefore, it is crucial for liquid water (perspiration) need to escape from the human body in order to keep the body dry. The liquid moisture transfer capability on fabric selection plays a significiant role to ensure optimal comfort for wearers. In this paper, it was stated that cocona® and coolmax® material types exhibited the best capability to manage liquid moisture.

3.5 Relative Water Vapour Permeability

The relative water permeability of a fabric is indicating the ability of its capacity to transmit water vapour. The human body regulates its temperature by producing sweat and allowing it to evaporate, during periods of high activity. The sweat in its vapour state, permeates through the fabric's thickness via macro pores by yarns and through the micro-pores within the fiber's organization in the structure of yarns [28, 29].

Table 7. MMT grading scale for OMMC values [5,27].

Index / Grade	1	2	3	4	5
OMMC	0-0.19 Very Poor	0.2-0.39 Poor	0.4-0.59 Good	0.6-0.8 Very Good	>0.8 Excellent

It was observed that knitted structure had an impact on the relative water vapour permeability. Jacquard 3x3 fabrics exhibited the highest values, and all the jacquard fabrics displayed high values. However, there was no statistically significiant difference between them. Single jersey and pique fabrics demonstrated similar results, and there was no statistically significant difference between them.

Table 8. Effects of knitted structure on relative water vapour permeability SNK test analysis results

Knitted structures	N	Subsets		
		1	**2**	**3**
Pique	15	50,393		
Single jersey	15	52,893	52,893	
Jacquard 1x1	15		54,327	54,327
Jacquard 2x2	15			56,160
Jacquard 3x3	15			57,147
p.		**0,057**	**0,271**	**0,081**

The influence of material type on relative water vapour permeability reveals that coolmax® material, with their channeled structure, exhibited higher values, and there was a statistically significant difference between them and other fabrics. Polyamid material followed coolmax®. The difference between polypropylene and polyester materials was not statistically significant. On the other hand, cocona® material have the lowest relative water vapour permeability values.

4. CONCLUSION

In this paper, it was aimed to examine the clothing comfort properties of 25 knitted fabrics used in summer cycling sportswear. In this context, 5 different fiber types (polyester, polyamid, cocona®, polipropilen, coolmax® and 5 different knitted structures (single jersey, pique, jacquard 1x1, jacquard 2x2, jacquard 3x3) commonly used for cycling apparel, were selected and the fabrics were manufactured using seamless technology. Since the fabrics have two faces with different materials, it was focused on investigating the impact of the inner material and knitted structure on the clothing comfort properties of the fabrics. To assess the clothing comfort features, mass per unit area, air permeability, thermal conductivity, thermal resistance, relative water vapour permeability, and overall moisture management capacity tests were conducted. Regarding the test results obtained, the influence of inner material type and knitted structures on the clothing comfort features were statistically analyzed and discussed. It was also found that material types and knitted structures significantly impacted the clothing comfort properties of the knitted fabrics.

As summer cycling races, which often involve long periods of physical exertion under hot weather condtions, the clothing comfort properties plays a vital role. Athletes experience intense perspiration with high sweat rates, and it becomes essential for the body to effectively dissipate this perspiration in vapour form. To ensure optimal comfort in this sport, factors such as having lightweight, high air permeability, great thermal conductivity, low thermal resistance, high relative water vapour, and high OMMC values become forefront.

It can be concluded that to ensure clothing comfort in this sport for summer, the single jersey knitting structure is a suitable choice for the main body fabric in such products due to its lightweight, high thermal conductivity values, and lower thermal resistance compared to other fabrics. Jacquard fabrics are also good choise for heavy sweating areas such as underarms, as they exhibit high air permeability and demonstrate good liquid moisture management values. Considering the material type, besides coolmax®, cocona® fiber is a new popular material in sportswear and is highly recommended for summer cycling clothing owing to its high air permeability and excellent liquid moisture management values, as indicated by test results. There are many studies in the literature about the clothing comfort features of knitted fabrics, but limited researches have explored on seamless cycling sportswear. Additionally, there are almost very few studies on cocona® fiber, which is a new fiber in sportswear. Investigating the potential usage of cocona fiber in cycling apparel, among the other fibers, enhances the academic value of this study. Consequently, this study presents a distinctive and original contribution by diverging from existing researchs.

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Araştırma Makalesi / Research Article

ÖRME KUMAŞLARDA DİKİM İŞLEMİNİN KUMAŞ ÖZELLİKLERİNE ETKİSİNİN İNCELENMESİ

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ÖZ: Kumaşların birleştirilmesinde en sık kullanılan yöntem olan dikiş yoluyla birleştirme işlemi, kumaşların çeşitli özelliklerinde değişimlere sebep olmaktadır. Bu çalışmada, günlük giysilerde sık kullanılan üç farklı kumaş yapısının (interlok, 1x1 rib ve pike) dikim sonrasında bazı konfor özelliklerinin değişimi incelenmiştir. Bu amaç kapsamında, belirlenen kumaşlar hazır giyim üretiminde sıklıkla tercih edilen üç farklı dikiş ipliği (%100 pamuk, %100 kesikli PES ve PES-PES özlü iplik) ile dikilmiştir. Dikilen numunelerin dikim öncesi ve sonrasındaki durumlarında hava geçirgenliği, dökümlülük katsayısı ve elastikiyet özelliklerindeki değişimler ele alınmıştır. Ayrıca dikilmiş numunelerin dikiş mukavemeti ve dikiş büzgüsü özellikleri de incelenmiş, kumaş yapısı ile dikim işleminin performansı arasındaki ilişki de irdelenmiştir. Sonuçlar incelendiğinde dikim bölgesinde hava geçirgenliği, dökümlülük ve elastikiyet özelliklerinde azalma olduğu gözlenmiştir. Hava geçirgenliği ve elastikiyet değerlerindeki en büyük azalma pamuk ipliği ile gerçekleştirilen dikişlerde gözlenmiştir. Polyester iplik ise daha iyi dökümlülük değerleri vermiştir. İnterlok kumaşta yapılan dikişin en yüksek mukavemete ve büzgüye sahip olduğu saptanmıştır. Dikiş ipliği açısından ise PES-PES özlü dikiş ipliği en iyi mukavemet ve en yüksek büzgüye sahiptir. Çalışmada elde edilen sonuçlar dikim işleminin konforu etkileyen bazı temel kumaş özellikleri üzerinde önemli ölçüde etkili olduğunu göstermektedir. Bunun yanı sıra, kullanılan dikiş ipliği cinsinin de bu özellikleri etkilediği saptanmıştır.

Anahtar Kelimeler: Örme kumaş, dikiş, konfor, dikiş ipliği

INVESTIGATION OF THE EFFECT OF SEWING PROCESS ON KNITTED FABRIC PROPERTIES

ABSTRACT: Sewing, the most common method for assembling fabrics, leads to changes in various fabric properties. Variations in some comfort characteristics of three fabric structures (interlock, 1x1 rib, and piquet) often used in casual clothes were investigated after the sewing process. For this purpose, samples were sewn with three different sewing threads (100% cotton, 100% staple PES and PES-PES core-spun) commonly used in the apparel industry. Changes in air permeability, drapeability coefficient, and elasticity properties of the samples were examined after sewing. Furthermore, seam strength and seam pucker characteristics of the sewn samples were determined, and relations between fabric structure and sewing performance were considered. Results presented that decreases in air permeability, drapeability, and elasticity characteristics were observed at seam areas. 100% cotton sewing thread resulted in the largest decrease in air permeability and elasticity values, whereas 100% staple PES thread had the best drapeability results. Seams on interlock fabric had the highest seam strength and seam pucker, while PES-PES core-spun thread provided the best seam strength and highest seam pucker. Results demonstrated that the sewing process affected some fundamental fabric properties regarding comfort. Moreover, sewing thread type affected these characteristics, as well.

Keywords: Knitted fabric, sewing, comfort, sewing thread

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1. GİRİŞ

Bir giysinin veya bitmiş bir ürünün performansı, sadece kullanılan kumaşların kalitesinden değil, aynı zamanda uzun ve karmaşık üretim süreçleri sırasında kullanılan teknolojilerden de etkilenmektedir. Kumaşların birleştirilmesinde en sık kullanılan yöntem, ürünün son kullanım alanına bağlı olarak seçilen ve çeşitli tipleri bulunan dikiş yoluyla birleştirmedir (1). Bir kumaşın dikilmesi, dikiş makinesinin türü, dikiş hızı, dikiş işleminin yapısı, işçinin çalışma şekli ve yeteneği, dikiş parametrelerinin seçimi gibi birçok faktörün etkisi altındadır ve elde edilen dikim görüntüsü ile performansı bu faktörlerin etkileşiminin bir sonucudur (2).

Giysinin kullanım ömrünü ve görünümünü önemli oranda etkileyen kaliteli dikimin yanı sıra, günümüzde tüketiciler giysilerden yüksek seviyede konfor da talep etmektedirler. Konfor, memnuniyetsizliğin veya konforsuzluğun olmadığı, nötr durum olarak tanımlanmaktadır (3). Giysi konforu termofizyolojik, duyusal ve psikolojik konfor olarak üç temel sınıfa ayrılabilmektedir (4). Her bir konfor tipi çeşitli parametrelerden etkilenmekte ve ürüne bağlı olarak bazı konfor özellikleri diğerlerine göre daha önemli olarak algılanabilmektedir. Bu kapsamda, bazı dikiş parametreleri ile konfor özelliklerinin değişimi literatürde çeşitli çalışmalarda incelenmiştir.

Maanvizhi vd. (2020) dikiş adımı sıklığı ve dikim tipinin kumaşların nem yönetimi özellikleri üzerindeki etkisini incelemişlerdir. Bu amaçla, %100 polyester süprem kumaş farklı dikiş (Tip 607 ve Tip 514) ve dikim tipleri (birleştirme ve katlamalı) kullanılarak, dört farklı dikiş sıklığında dikilmiştir. Sonuçlar dikiş sıklığı azaldıkça, nem yönetim özelliklerinin iyileştiğini göstermiştir. Ayrıca, katlamalı dikim tipi kullanıldığında, kumaşların nem yönetimi kabiliyetinin daha iyi olduğu saptanmıştır (5).

Daukantiene ve Vadeike (2018) elastan içeren örme kumaşların birleştirme işlemi sonrasındaki hava geçirgenliği özelliklerini incelemişlerdir. Çalışmada, elastan oranı farklı sekiz polyester örme kumaş (süprem, interlok ve çözgülü örme) üç farklı dikiş tipi (yapıştırma yöntemi, Tip 512, Tip 607) kullanılarak dikilmiştir. Sonuçlar kumaşların hava geçirgenliği özelliklerinin sadece kumaş yapısından değil, dikiş tipinden de etkilendiğini göstermiştir. Dikiş işleminin numunelerin hava geçirgenliğini azalttığı gözlenmiştir. Çalışmada incelenen dikişler arasında hava geçirgenliğini en büyük oranda azaltan yöntemin yapıştırma tekniği olduğu, hava geçirgenliği üzerinde en az etkisi olan yöntemin ise 512 kodlu dikiş tipi olduğu belirlenmiştir (6).

Beaudette ve Park (2017), spor giyimde kullanılan çeşitli dikiş tiplerinin ısıl özelliklere etkisini incelemişlerdir. Bu amaçla %100 polyester süprem kumaş, overlok dikişi (Tip 514), flatlock dikişi (Tip 607) ve yapışkan film ile yapıştırma yöntemleri ile birleştirilmiştir. Çalışma sonucunda, yapışkan filmlerin diğer yöntemlere göre daha ince dikiş oluşturduğu, flatlock dikişin ise ağırlıkta en çok artışa sebep olan dikiş tipi olduğu gözlenmiştir. Termal manken ile gerçekleştirilen testler flatlock dikişin önemli ölçüde yüksek ısıl izolasyon sağladığını ve hava geçirgenliğinde azalışa sebep olduğunu göstermiştir. Su buharı geçirgenliği açısından üç birleştirme yöntemi arasında anlamlı fark gözlenmemiştir (7).

Oğlakcıoğlu vd. (2013) bisikletçi giysilerinde dikim işleminin ısıl konfor üzerindeki etkilerini araştırmışlardır. Bu amaçla, iki atkılı örme (şardonlu ve şardonsuz petek örgü) ve iki çözgülü örme (şardonlu ve şardonsuz triko örgü) kumaş reçme, overlok ve flatlock dikişleri ile dikilmiştir. Kumaşların dikiş öncesi ve sonrası ısıl direnç, ısıl soğurganlık, bağıl su buharı geçirgenliği ve hava geçirgenliği değerleri ölçülmüştür. Sonuçlar flatlock dikişin yüksek ısıl iletkenlik ve su buharı geçirgenliği sağladığını göstermektedir. Overlok dikişin ise yüksek ısıl izolasyon ve hava geçirgenliğine sahip olduğu saptanmıştır (8).

Erayman Yüksel ve Korkmaz (2019), farklı su iticilik bitim işlemi etken maddeleri ve dikiş ipliği cinslerinin dokuma kumaşların su itici özelliği ve dikiş performansına etkilerini araştırmışlardır. %100 polyester dokuma kumaşa üç farklı etken madde ile su itici özellik kazandırılmış ve kumaşlar dört farklı dikiş ipliği (poliamid, su itici özellikteki poliamid, PES-pamuk özlü iplik, su itici özellikteki PES-pamuk özlü iplik) ile dikilmiştir. Sonrasında numunelerin mekanik özellikleri, dikiş performansları ve su itici özellikleri incelenmiştir. Test sonuçları bitim işleminin çözgü yönünde dikiş mukavemeti ve her iki yönde dikiş verimliliği üzerinde etkili olduğunu göstermiştir. Poliamid iplik ile dikilen kumaşların dikiş mukavemeti, dikiş verimliliği, dikiş kayması ve dikiş büzgüsü değerlerinin daha yüksek olduğu belirlenmiştir. Dikim işleminin kumaşların suya karşı direncini azalttığı, ancak su itici bitim işlemi uygulanmış dikiş ipliklerinin bu direnci arttırdığı saptanmıştır (9).

Mukhopadhyay vd. (2020), çok katlı birleştirmelerde dikişin ve dikiş deseninin sıvı iletimi üzerindeki etkisini incelemişlerdir. Çalışmada, üç katlı kumaş yapısı (polyester örme-iç katman, polyester spacer ya da polyester futter-orta katman, poliüretan kaplamalı naylon kumaş-dış katman) ile çalışılmıştır. Kumaşlar düz dikiş makinesi kullanılarak, kesikli polyester ipliklerle farklı desenlerde dikilmiştir. Çalışma sonuçları dikişin sıvı iletimini önemli ölçüde etkilediğini göstermiştir. Bununla birlikte, dikiş deseninin nem iletim davranışı ve dolayısıyla giysi konforu üzerinde önemli bir etkisi olduğu gözlenmiştir (10).

Literatürde çeşitli hammaddelerden farklı konstrüksiyonlarda örülmüş kumaşların dikim işlemi sonrasında belirlenen özelliklerindeki değişimleri inceleyen çalışmalar mevcuttur. Ancak kullanıcının en uzun süre üzerinde bulunan ürün olan günlük giysilerde, sıklıkla kullanılan bazı kumaş yapılarının dikim işleminden nasıl etkilendiğini hem konfor hem de giysinin dayanımı açısından araştıran bir çalışmaya rastlanmamıştır. Bu çalışmada, günlük giyimde sıklıkla kullanılan üç farklı kumaş yapısı, konfeksiyonda en çok tercih edilen dikiş iplikleri ile dikilmiştir. Kumaşların giysi konforu açısından önemli olan bazı temel özellikleri dikim öncesi ve sonrasında incelenmiştir. Bunun yanı sıra, kumaş yapısı ve dikiş ipliğinin dikiş mukavemeti ve dikiş büzgüsü üzerindeki etkileri de değerlendirilmiştir.

2. MATERYAL VE YÖNTEM

2.1. Materyal

Çalışma kapsamında Ne 30 numara, tek kat, ring iplik ile örülmüş üç farklı yapıdaki (interlok, 1x1 rib ve pike) örme kumaş piyasadan tedarik edilmiştir. Kumaşların özellikleri Tablo 1'de, dikiş ipliklerinin özellikleri ise Tablo 2'de yer almaktadır.

2.2. Yöntem

Tüm numuneler, deneysel çalışma öncesinde en az 24 saat standart atmosfer koşullarında (20 ± 2ºC sıcaklık, %65 ± 4 bağıl nem) bekletilerek kondisyonlanmıştır.

Dikiş ipliklerinin özelliklerinin belirlenmesi amacıyla kopma mukavemeti, kopma uzaması, büküm sayısı, eğilme uzunluğu ve tüylülük ölçümleri gerçekleştirilmiştir. Dikiş ipliklerinin kopma mukavemeti ve kopma uzaması değerleri, Zwick Roell ZO10 marka universal iplik ve kumaş mukavemeti test cihazında TS EN ISO 2062 standardına göre 15 tekrarlı olarak ölçülmüştür. Dikiş ipliklerinin büküm sayısı, Uster Zweigle D315 büküm test cihazında, TS EN ISO 2061 standardına göre, açma-kapama metodu kullanılarak on tekrarlı olarak ölçülmüştür. Dikiş ipliklerinin eğilme uzunluğu, ipliklerin 41,5° eğilme açısına kadar eğilmesi için gereken uzunluğun ölçülmesi prensibine dayanan Cantilever metoduna göre Shirley Sertlik Ölçeri kullanılarak mm cinsinden ölçülmüştür. İplik tüylülüğü testi Uster Tester 5 cihazında tüylülük modülü yardımıyla ölçülmüştür. İplik tüylülüğü gösteren H değeri, 1 cm uzunlukta iplik yüzeyinden dışarı çıkan liflerin toplam uzunluğunu belirtmektedir.

Kumaşların gramaj ölçümü TS EN 12127 standardında tanımlanan metoda göre 100 cm^2'lik alana sahip daire şablonu kullanılarak kesilen üçer adet numunenin ağırlıklarının ortalaması alınarak hesaplanmıştır. Kumaşların ilmek sıra ve çubuk sayısı ölçümleri, TS EN 14971 standardına göre lup yardımıyla numunelerin on farklı yerinden 1 cm^2'lik alanda yer alan sıra ve çubuk sayılarının sayılmasıyla belirlenmiştir. Kumaşların ilmek iplik uzunluklarını ölçmek için enine yönde 50 ilmek sayılarak işaret konulmuş ve kumaşın 50 ilmek uzunluğundaki kısmı sökülmüştür. Sökülen ipliklerin uçlarına 10 g ağırlık asılarak uzunlukları ölçülmüştür. Ölçüm işlemi her numune için on tekrarlı olarak gerçekleştirilmiş, ölçümlerin ortalaması alınmış ve elde edilen ortalamalar 50'ye bölünerek bir ilmeğin iplik uzunluğu tespit edilmiştir. Kumaş kalınlıkları TS 3374 standardına göre baskı ayağı 2 kPa basınç uygulayan Wira Digital Thickness Gauge ile beş tekrarlı olarak ölçülmüştür.

Kumaşlar, kesikli ve özlü dikiş iplikleri kullanılarak (Tablo 2), reçme dikiş makinesinde, 3 adım/cm sıklığında, 80 numara SES uçlu dikiş iğnesi ile sıra yönüne paralel olacak şekilde dikilmiştir. Dikim işlemi sırasında, dikiş ipliği gerginliği ve ayar değişiminin test sonuçlarını etkilemesini engellemek için bu parametreler sabit tutulmuştur.

Dikilmemiş numunelerin patlama mukavemeti, hava geçirgenliği, dökümlülük ve elastikiyet özellikleri, dikilmiş numunelerin ise dikiş mukavemeti, dikiş büzgüsü, hava geçirgenliği, dökümlülük ve elastikiyet özellikleri ölçülmüştür.

Kumaşların patlama mukavemetleri James Heal marka TruBurst[4] cihazı kullanılarak TS EN ISO 13938-2 standardına göre 50 cm^2'lik deney alanında üç tekrarlı olarak ölçülmüştür. Hava geçirgenliği ölçümü TS 391 EN ISO 9237 standardına göre 100 Pa basınç farklılığında 5 cm^2'lik deney alanı kullanılarak Textest FX 3300 cihazı ile on tekrarlı olarak gerçekleştirilmiştir. Dökümlülük testi, TS EN ISO 9073-9 standardına göre Cusick Dökümlülük Test Cihazı kullanılarak gerçekleştirilmiştir.

Dikişsiz ve sıra yönüne paralel olacak şekilde dikilmiş numunelerin kumaş elastikiyeti ölçümü TS 10985 standardına göre belirlenmiştir. 10 cm x 40 cm boyutlarında hazırlanan numuneler ikiye katlanarak kısa kenarından reçme dikişi ile birleştirilmiştir. Elde edilen halka şeklindeki numunenin üzerine aralarındaki mesafe 13 cm (l_1) olacak şekilde iki referans çizgi çizilmiş, numuneler alt ve üst kenarlarından birer askı ile asılmıştır. Alt kenarda kalan askıya asılan dinamometre dört kere 5 kPa uygulayacak şekilde çekilip bırakılmış ve beşinci kuvvet uygulaması sonucunda iki referans çizgi arasındaki mesafe (l_2) ölçülmüştür. Test üç tekrarlı olarak gerçekleştirilmiştir. Numunelerin elastikiyet değerleri (%) aşağıdaki formüle göre hesaplanmıştır.

Tablo 1. Çalışmada kullanılan kumaşların özellikleri

Kumaş kodu	Konstrüksiyon	Hammadde	İplik Numarası (Ne)	Çubuk sayısı (çubuk/cm)	Sıra sayısı (sıra/cm)	İlmek iplik uzunluğu (mm)	Gramaj (g/m^2)	Kalınlık (mm)	Kumaş yoğunluğu (g/cm^3)
İ	İnterlok	%100 Co	30	15	18	2,59	200	0,72	0,28
R	1x1 rib	%100 Co	30	12	16	2,67	200	0,81	0,25
P	Pike	%100 Co	30	10	17	2,56	200	1,01	0,20

Tablo 2. Çalışmada kullanılan dikiş ipliklerinin özellikleri

Dikiş ipliği kodu	Dikiş ipliği cinsi	Dikiş ipliği numarası (tex)	Kat sayısı	Büküm (tur/m)	Kopma mukavemeti (N)	Kopma anında uzama (%)	Eğilme uzunluğu (mm)	Tüylülük (H)
C	%100 Co	30	2	795	7,35	4,70	50	3,14
P	%100 kesikli PES	30	2	925	10,25	16,50	41	5,70
PP	PES-PES özlü	30	2	950	15,50	20,15	54	5,31

$$Elastikiyet\ (\%) = \frac{l_2 - l_1}{l_1}\ x\ 100 \quad (1)$$

Dikiş mukavemeti testi, Zwick Roell Z010 marka universal iplik ve kumaş mukavemeti test cihazında, TS EN ISO 13935-1 standardına göre beş tekrarlı olarak gerçekleştirilmiştir. Dikiş büzgüsü, sabit bir yük altında orijinal kumaş üzerinde dikilmiş kumaşın kalınlığındaki yüzdesel artış ölçülerek belirlenmiştir. Bu amaç doğrultusunda, Wira Digital Thickness Gauge kalınlık ölçer kullanılarak, dikilmiş numunenin on farklı yerinden ölçümler alınmış ve aşağıda yer alan formülden yararlanılarak dikiş büzgüsü yüzde olarak hesaplanmıştır.

$$Dikiş\ Büzgüsü\ (\%) = \frac{Dikilmiş\ kumaş\ kalınlığı - 2\ x\ Kumaş\ kalınlığı}{2\ x\ Kumaş\ kalınlığı}\ x\ 100 \quad (2)$$

Çalışmada elde edilen ölçüm sonuçlarının istatistiksel olarak değerlendirilebilmesi için PASW 18 paket programı kullanılmıştır. %95 güven aralığında gerçekleştirilen istatistiksel değerlendirmeler sonucunda elde edilen “p” değerleri, değişimin önemlilik düzeyini belirlemede kullanılmıştır. “p” değerinin önemlilik derecesinin 0,05 değerinden büyük olması durumunda değişim önemli değildir ve ihmal edilebilir olarak kabul edilmiştir. İncelenen gruplar arasında önemli düzeyde farklılığın bulunduğu durumlarda ($p<0,05$) ise varyansların homojen dağılıp dağılmadığını belirlemek amacıyla Levene homojenite testi gerçekleştirilmiştir. Levene testi sonucunda homojen varyans saptanması durumunda, ortalamalar arasındaki farkları daha ayrıntılı incelemek için Student-Newman-Keuls (SNK) testi, heterojen varyans saptanması durumunda ise Tamhane’s T2 testi uygulanmıştır.

3. BULGULAR

Dikişsiz numunelere ait test ve istatistiksel analiz sonuçları Tablo 3’te yer almaktadır. Kumaş konstrüksiyonu bazında ayrı ayrı incelenen, dikişsiz ve dikişli numunelere ait sonuçlar ise Tablo 4’te yer almaktadır. Test sonuçlarının ortalama değerleri a, b ve c harfleri ile işaretlenmiştir. “a” harfi en düşük, “c” harfi en yüksek değerleri göstermektedir. Ortalama değerler arasında istatistiksel olarak anlamlı fark bulunmadığı durumlarda, bu değerler aynı harf ile işaretlenmiştir.

3.1. Patlama Mukavemeti

Kumaşların patlama mukavemeti değerleri incelendiğinde (Tablo 3 ve Şekil 1), interlok kumaşın en yüksek, pike kumaşın ise en düşük sonuçları verdiği görülmektedir. Bu sonuçlar, Ibrahim vd. (2009) tarafından elde edilen sonuçlar ile de paralellik göstermektedir (11). Sonuçlar üzerinde pike kumaşın tek katlı, interlok ve rib kumaşların ise çift katlı yapıda olmasının önemli bir etken olduğu düşünülmektedir. İnterlok kumaşın iki tane 1x1 rib kumaşın birlikte örülmesiyle oluşmasından dolayı (12) daha yüksek patlama mukavemetine sahip olduğu düşünülmektedir.

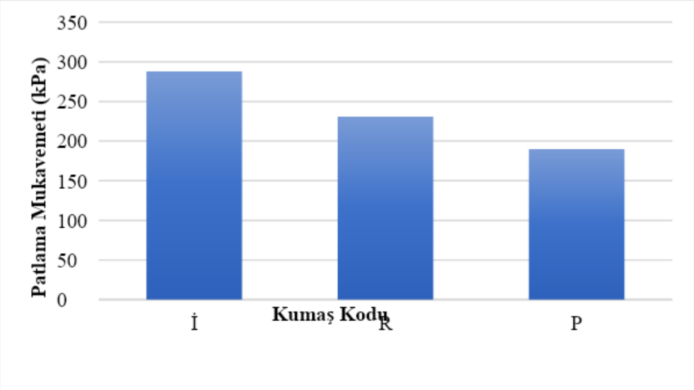
Tablo 3. Dikişsiz numunelere ait test sonuçları

Kumaş kodu	Patlama mukavemeti (kPa)	Hava geçirgenliği ($l/m^2/s$)	Dökümlülük katsayısı (%)	Elastikiyet (%)
İ	288 c	165 a	10,89 b	95 b
R	231 b	324 c	6,95 a	117 c
P	190 a	235 b	14,10 c	52 a

Tablo 4. Kumaş konstrüksiyonu bazında dikişli ve dikişsiz numunelere ait test sonuçları

Kumaş kodu	İplik kodu	Hava geçirgenliği ($l/m^2/s$)	Dökümlülük katsayısı (%)	Elastikiyet (%)	Dikiş mukavemeti (N)	Dikiş büzgüsü (%)
İ	D	165 b	10,89 a	95 b	-	-
	C	152 a	12,20 c	59 a	135,83	22,62
	P	160 b	10,73 a	62 a	153,19	25,69
	PP	164 b	11,47 b	65 a	169,38	29,78
R	D	324 b	6,95 a	117 b	-	-
	C	276 a	8,09 b	94 a	122,72	21,23
	P	307 b	8,07 b	95 a	133,64	24,93
	PP	321 b	8,33 c	96 a	185,57	26,85
P	D	235 c	14,10 b	52 c	-	-
	C	205 a	14,69 c	39 a	119,54	1,00
	P	219 b	12,46 a	42 b	145,12	4,30
	PP	222 b	15,49 d	43 b	146,19	6,77

*D: dikişsiz



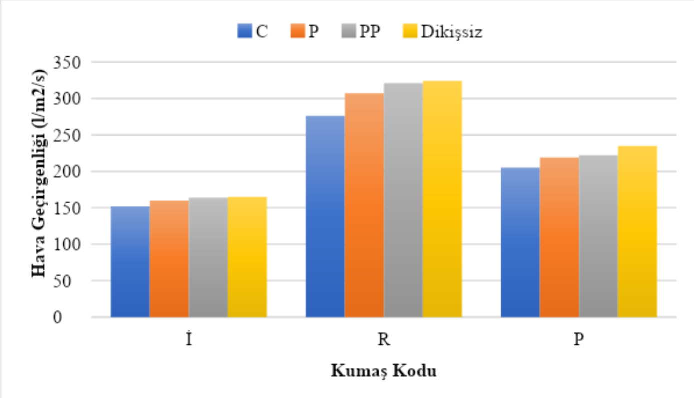
Şekil 1. Patlama mukavemeti değerleri

3.2. Hava Geçirgenliği

Çalışma kapsamında elde edilen hava geçirgenliği sonuçları Tablo 3-4 ve Şekil 2'de yer almaktadır. Assefa ve Govindan (2020) tarafından belirtildiği üzere pike kumaşta yer alan askılar kumaşı daha gözenekli hale getirmektedir (13). Kumaş gözenekliliği arttıkça, hava geçirgenliğinin arttığı da bilinmektedir (14). Ayrıca, sonuçlar incelendiğinde rib kumaşın hava geçirgenliği değerinin interlok kumaştan oldukça yüksek olduğu görülmek-tedir. Bu durumun, interlok kumaş yapısının iki tane 1x1 rib kumaşın birbirine örülmesiyle elde edilmesinden kaynaklandığı düşünülmektedir (12). Kumaşların yapısal özellikleri dışında, birim hacimdeki kumaşın ağırlığı olarak tanımlanan kumaş yoğunluğu da kumaşın geçirgenlik özelliklerini önemli ölçüde etkilemektedir. Tablo 1'de yer alan kumaş yoğunlukları incelendiğinde, bu değerlerin hava geçirgenliği değerleri ile ters orantılı olduğu gözlenmiştir. Kumaş yoğunluğu en yüksek olan interlok kumaşta hava geçişi daha zor olduğundan hava geçirgenliği değeri düşük, kumaş yoğunluğu en az olan rib kumaşın ise hava geçirgenliği değeri en yüksektir.

Dikişli ve dikişsiz numunelerin hava geçirgenliği değerleri karşılaştırıldığında (Tablo 4), bütün kumaş konstrüksiyonlarında dikim bölgesinde hava geçirgenliğinin azaldığı görülmektedir. Bu sonuç, Daukantiene ve Vadeike (2018) tarafından yapılan çalışmanın sonuçları ile paralellik göstermektedir (15). Bu durumu, dikim bölgesinde kumaş kalınlığındaki artış ile açıklamak mümkündür. Literatürde yer alan çalışmalarda da belirtildiği üzere, kumaş kalınlığı, gramajı ve yoğunluğu artıkça hava geçirgenliği azalmaktadır. Dikiş yapılan bölgelerde hava geçirgenliği azalmış olmakla birlikte, dikişli ve dikişsiz numunelerin değerleri kumaş bazında incelendiğinde dikim işleminin en çok pike kumaş üzerinde etkili olduğu gözlenmiştir. Pike kumaşın dikim sonrası hava geçirgenliği değerlerindeki değişim tüm dikiş iplikleri için istatistiksel olarak anlamlıdır.

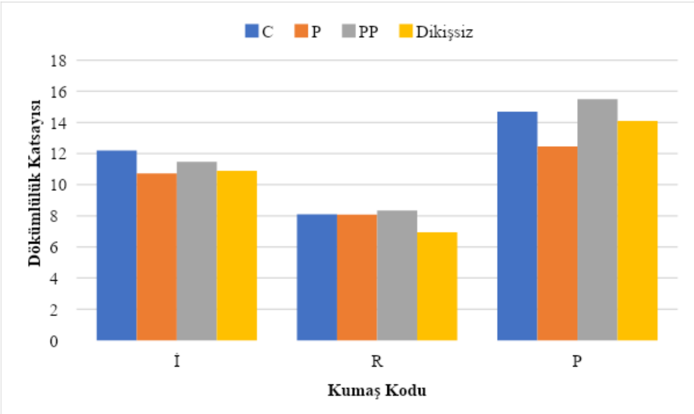
Çalışmadaki tüm örgü yapıları incelendiğinde, hava geçirgenliği değerinde en büyük düşüş pamuk ipliği ile en az değişim ise PES-PES özlü iplik ile yapılan dikişte gözlenmiştir. Kesikli poliester iplikle dikilen numunelerin hava geçirgenliği değerlerinin özlü iplikle dikilen numunelere daha fazla oranda azaldığı görülmektedir. Bu durum, dikiş ipliklerinin tüylülük değerleri ile paralellik göstermektedir. Bununla birlikte tüylülük değeri en düşük olan pamuk ipliği ile dikilen numunelerde hava geçirgenliği açısından en büyük düşüşün yaşanması beklenilenin aksine bir durumdur.



Şekil 2. Hava geçirgenliği değerleri

3.3. Dökümlülük

Bir tarafından desteklenen kumaşın kendi ağırlığı ile deformas-yonuna dökümlülük denir. Kumaşların dökümlülük davranışı, dökümlülük katsayısı ile belirlenir. Dökümlülük katsayısı ne kadar yüksekse, kumaşın dökümlülüğü o kadar düşük ve kumaş o kadar serttir (16-18).



Şekil 3. Dökümlülük katsayısı değerleri

Dikişsiz numunelerin dökümlülük sonuçları incelendiğinde pike kumaşın en az, rib kumaşın ise en dökümlü kumaş olduğu görülmektedir (Şekil 3). Pike kumaşta bulunan askılar kumaşı daha rijit hale getirmektedir. Bunun sebebi, askıda iplik gerginliğinin artması ve bu nedenle komşu ilmeklerden iplik çalarak, komşu ilmekleri diğer ilmeklere göre daha küçük ve rijit hale getirmesidir (13). Çalışmadaki kumaşlar incelendiğinde, askı içeren tek kumaş tipi olan pikenin en az dökümlü kumaş olduğu belirlenmiştir. Sadece ilmeklerden oluşan interlok ve rib kumaşlar karşılaştırıldığında, birbirini kilitleyen ters yönlü iki 1x1 rib kumaştan oluşan interlok kumaşın dökümlülüğünün daha az olduğu gözlenmiştir.

Dikişli ve dikişsiz numuneler karşılaştırıldığında, genellikle dikim işlemi etkisiyle dökümlülük katsayısının arttığı ve aradaki farkın istatistiksel olarak anlamlı olduğu gözlenmektedir. Dikilmiş bir numunede, dikim hattı aynı kumaşın birleştirilmiş iki parçasından oluşmaktadır. Dikiş hattında daha fazla kumaşın olması nedeniyle kütledeki artış, kumaş sertliğinde de bir artışa yol açmaktadır (19, 20). Dolayısıyla dikim işleminin kumaşların dökümlülük katsayısını artırdığı ve dökümlülük özelliğini olumsuz etkilediği söylenebilir.

Dikiş ipliği cinsi açısından karşılaştırma yapıldığında, polyester dikiş iplikleri ile dikilen numunelerin en düşük dökümlülük katsayısına sahip olduğunu söylemek mümkündür. Bu durum dikiş ipliklerinin eğilme uzunlukları ile açıklanabilir. Çalışmada kullanılan dikiş ipliklerinin eğilme uzunlukları karşılaştırıldığında, en küçük değer polyester dikiş ipliğinde gözlenmektedir. Bunu sırasıyla pamuk ve polyester-polyester özlü dikiş iplikleri izlemektedir. Eğilme uzunluğu ve eğilme rijitliği değerinin yüksek olması ipliğin sert ve eğilmeye karşı direnç gösteren bir yapıda olduğu anlamına gelmektedir. Dolayısıyla polyester dikiş ipliğinin çalışmada kullanılan iplikler arasında en yumuşak iplik olduğunu ve daha dökümlü bir dikiş oluşturduğunu söylemek mümkündür.

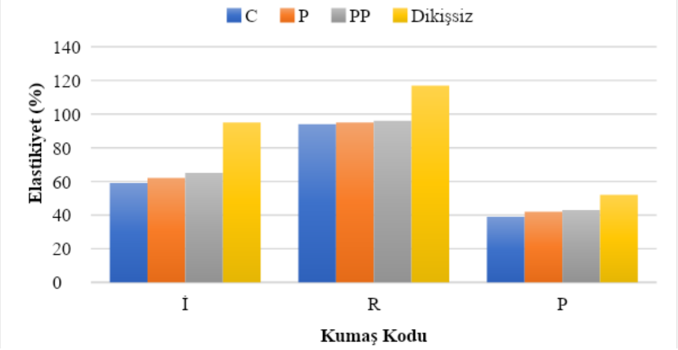
3.4. Elastikiyet

Çalışma kapsamında elde edilen elastikiyet sonuçları Tablo 3-4 ve Şekil 4'de yer almaktadır. Kumaş yapısında bulunan askılar, artan iplik gerginliği ve üzerine askı yapılan ilmeğin yan ilmeklerden iplik çalması sebebiyle kumaşın boyuna yöndeki elastikiyetini azaltmaktadır (21). Bu duruma uygun olarak, pike kumaşın çalışmadaki kumaşlar arasında en düşük elastikiyete sahip olduğu görülmektedir. Test sonuçları, sırasıyla bir düz ve bir ters ilmek çubuklarından oluşan rib kumaşın çalışmadaki kumaşlar arasında elastikiyeti en yüksek kumaş olduğunu göstermektedir. Ters yönlü iki 1x1 rib kumaşın birbirini kilitlemesi ile oluşan interlok örgünün elastikiyet değeri rib örgüden daha düşüktür.

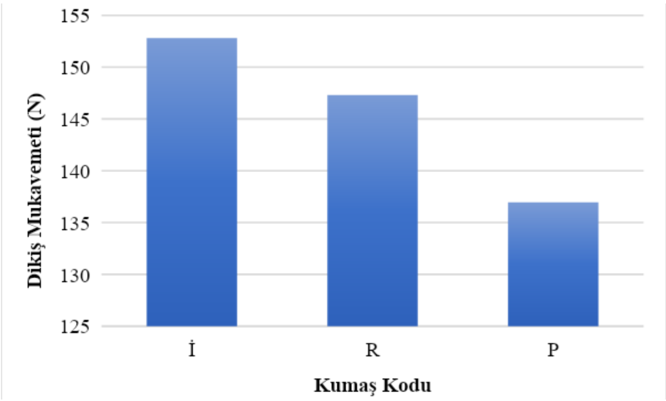
Dikişli ve dikişsiz kumaşların elastikiyet değerleri karşılaştırıldığında (Şekil 4), dikiş işleminin tüm kumaş yapıları için elastikiyeti belirgin olarak azalttığı ve bu durumun istatistiksel olarak anlamlı olduğu saptanmıştır. Dikiş ipliği cinsinin elastikiyet üzerindeki etkisinin az olduğu gözlenmekle birlikte, tüm kumaş yapıları için elastikiyette en büyük azalış pamuk ipliği ile yapılan dikişte elde edilmiştir. Bu durumu dikiş ipliklerinin uzama değerleri ile açıklamak mümkündür. Polyester-polyester özlü dikiş ipliğinin yapısındaki polyester filament nedeniyle en yüksek, pamuk dikiş ipliğinin ise lif özelliklerinden ötürü en düşük uzama değerine sahip olduğu görülmektedir (22).

3.5. Dikiş Mukavemeti

Kumaş konstrüksiyonunun dikiş mukavemetine olan etkisi incelendiğinde (Tablo 4 ve Şekil 5), en yüksek dikiş mukavemeti değerleri interlok kumaşlarda gözlenirken, en düşük değerler ise pike kumaşlarda elde edilmiştir. Sonuçların patlama mukavemeti değerleri ile uyumlu olduğu görülmektedir.

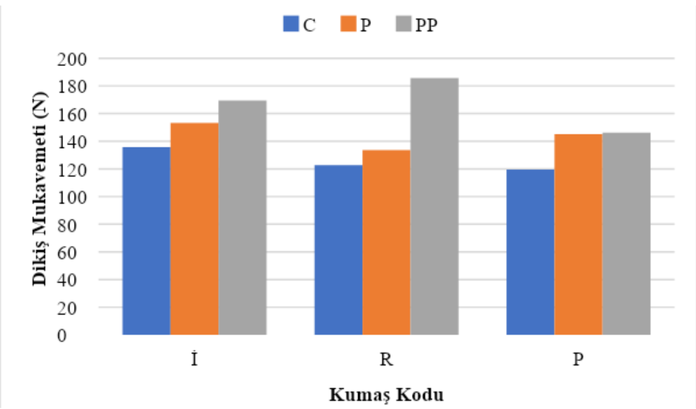


Şekil 4. Elastikiyet (%) değerleri



Şekil 5. Kumaş konstrüksiyonunun dikiş mukavemetine etkisi

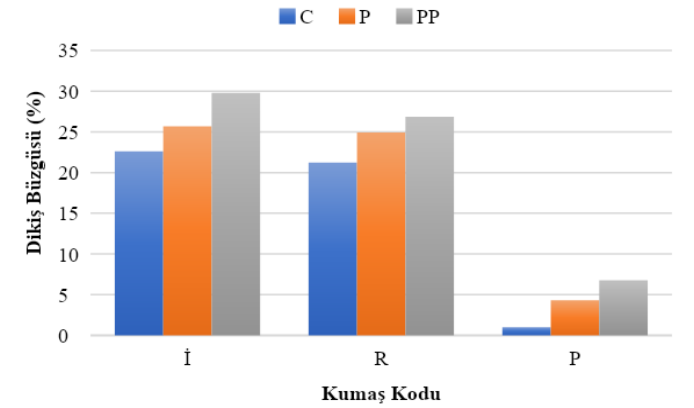
Dikiş ipliği cinsinin dikiş mukavemetine etkisine ilişkin sonuçlar (Tablo 4 ve Şekil 6) incelendiğinde, bütün örgü cinslerinde en yüksek dikiş mukavemeti değerinin PP kodlu polyester-polyester özlü dikiş ipliği ile elde edildiği, bunu P kodlu kesikli polyester dikiş ipliğinin izlediği görülmektedir. C kodlu merserize pamuk dikiş ipliği ile dikilen numunelerde ise en düşük değerlerin elde edildiği sonucuna ulaşılmıştır. Bu durum, kesikli polyester ve polyester-polyester özlü dikiş ipliklerinin mukavemet değerlerinin, merserize pamuk ipliğine göre daha yüksek olması ile açıklanabilmektedir (23).



Şekil 6. Dikiş ipliği cinsinin dikiş mukavemetine etkisi

3.6. Dikiş Büzgüsü

Çalışma kapsamında farklı dikiş iplikleri ile dikilen kumaşların dikiş büzgüsü sonuçlarının yer aldığı Şekil 7 incelendiğinde, en yüksek dikiş büzgüsünün interlok kumaşta görüldüğü, bunu sırasıyla rib ve pike kumaşların izlediği görülmektedir. Bu durumu, kalınlığın artması ile kumaş rijitliğinin artması, dolayısıyla dikimin daha kolay hale gelmesi ile açıklamak mümkündür. Bu sonuç, Behera ve Sharma (1998), Thanaa (2013) ve Malek vd. (2017) tarafından gerçekleştirilen çalışmaların sonuçları ile de paralellik göstermektedir (24-26).



Şekil 7. Dikiş büzgüsü değerleri

Bununla birlikte bütün örgü yapılarında, PP kodlu özlü iplikle dikilen numuneler en yüksek dikiş büzgüsü değerini verirken, bunu sırasıyla P kodlu kesikli polyester dikiş ipliği ve C kodlu merserize pamuk dikiş ipliği izlemiştir. Dikiş ipliğinin uzama yeteneği ne kadar fazla olursa, dikim işlemi sonrası çekme o denli fazla olmakta, dolayısıyla dikiş büzgüsü oluşma olasılığı artmaktadır (27). Bu noktadan hareketle, özlü dikiş ipliğinin uzama yeteneğinin fazla olması da dikiş büzgüsüne neden olan önemli bir faktördür (28). Benzer şekilde, Yıldız (2018) ve Sülar vd. (2015) tarafından gerçekleştirilen çalışmada, özlü dikiş ipliği ile dikilen numunelerde oluşan büzgü, merserize pamuk dikiş ipliği ile dikilen numunelere göre daha yüksek bulunmuştur (23,29).

4. SONUÇ

Günümüzde tüketici memnuniyetinin sağlanması için giysilerin hem konforlu olması hem de kullanım esnasında ilk günkü görünümlerini korumaları beklenmektedir. Ancak önceki çalışmalarda araştırıldığı üzere, dikim işlemi kumaşların çeşitli özelliklerinde değişimlere sebep olmaktadır.

Bu çalışmada, günlük giysilerde sık kullanılan üç farklı kumaş yapısının (interlok, 1x1 rib ve pike) dikim sonrasında bazı konfor özelliklerinin değişimi incelenmiştir. Bu amaç kapsamında, belirlenen kumaşlar hazır giyim üretiminde sıklıkla tercih edilen üç farklı dikiş ipliği (%100 pamuk, %100 kesikli PES ve PES-PES özlü iplik) ile dikilmiştir. Dikilen numunelerin dikim öncesi ve sonrasındaki durumlarında hava geçirgenliği, dökümlülük katsayısı ve elastikiyet özelliklerindeki değişimler ele alınmıştır. Ayrıca dikilmiş numunelerin dikiş mukavemeti ve dikiş büzgüsü özellikleri de incelenmiş, kumaş yapısı ile dikim işleminin performansı arasındaki ilişki de irdelenmiştir.

Elde edilen sonuçlar dikim bölgesindeki kalınlık artışı sebebiyle dikim işleminin hava geçirgenliğini azalttığını göstermektedir. Hava geçirgenliği değerindeki en büyük azalma pamuk ipliği ile gerçekleştirilen dikişlerde gözlenmiştir. Benzer şekilde, dikiş hattında kumaş kendi üzerine katlandığından kumaş kütlesinde artış olmakta, bu durum da kumaşın daha az dökümlü olmasına neden olmaktadır. Deney sonuçları, farklı iplikler ile dikilmiş tüm numunelerin dikim sonrasında dökümlülük katsayılarında artış olduğunu göstermektedir. Polyester iplik ile yapılan dikişlerin daha iyi dökümlülük özelliğine sahip olduğu saptan-mıştır. İncelenen tüm numunelerde dikim işlemi kumaşların elastikiyetinde azalmaya neden olmuştur. En büyük azalış pamuk ipliği ile yapılan dikişlerde gözlenmiştir.

Kumaş yapısının dikiş mukavemetine olan etkisi ele alındığında, interlok kumaşta yapılan dikişin en yüksek mukavemete sahip olduğu belirlenmiştir. En yüksek mukavemet sağlayan dikiş ipliği cinsi ise PES-PES özlü dikiş ipliğidir. Dikiş büzgüsü sonuçları en yüksek büzgünün interlok kumaşta, dikiş ipliği olarak ise tüm numunelerde PES-PES özlü iplik kullanıldığında oluştuğunu göstermektedir.

Çalışmada elde edilen sonuçlar dikim işleminin konforu etkileyen bazı temel kumaş özellikleri üzerinde önemli ölçüde etkili olduğunu göstermektedir. Bunun yanı sıra, kullanılan dikiş ipliği cinsinin de bu özellikleri etkileyebildiği saptanmıştır. Tüketicilerin oldukça bilinçlendiği ve beklentilerinin üst seviyede olduğu günümüzde tüketici memnuniyetini sağlamak için, kullanılacak kumaş yapısının konfor özelliklerini en az seviyede azaltacak, ancak gerekli performansı da sağlayacak şekilde dikim parametrelerini belirlemek oldukça önemlidir.

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Araştırma Makalesi / Research Article

ÖRME KUMAŞ KONFEKSİYON ÜRETİMİNİN ÖNCEDEN BELİRLENMİŞ ZAMAN SİSTEMLERİYLE İNCELENMESİ ÜZERİNE BİR VAKA ÇALIŞMASI

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ÖZ: Bu çalışma, işletmelerin operasyonel verimliliklerini artırmak ve hat dengeleme problemlerini çözmek için önemli bir araç olan MTM (Methods Time Measurement) yönteminin tekstil endüstrisindeki uygulamasını incelemektedir. MTM yöntemi, üretim süreçlerinin planlanması, programlanması, malzeme taşıma sürelerinin ölçümü ve insan-makine etkileşimi gibi birçok alanda etkili sonuçlar sunmaktadır. Çalışmada, işletmenin kendi veri tabanından alınan süreler ile gerçekleşen operasyon süreleri arasındaki farkı belirlemek ve hat dengeleme sorunlarının kök nedenine inmek amacıyla MTM yöntemi kullanılmıştır. Tişört üretim bandında yapılan uygulama için, prosesler video ile incelenmiştir. Video çekimlerinden elde edilen görüntüler 1/8 hızda oynatılarak metne dökülmüş ardından MTM yöntemi yardımıyla analiz edilmiştir. MTM analiz süreleri ile operasyonların firma tarafından kabul edilen süreleri karşılaştırılmıştır. MTM sonuçları, operasyon sürelerinin işletmenin kabul ettiği değerlerden daha kısa olduğunu göstermiştir.

***Anahtar kelimeler*:** Konfeksiyon Endüstrisi, Önceden Belirlenmiş Zaman Sistemleri, Video analizi, MTM

A CASE STUDY ON THE INVESTIGATION OF KNITTED FABRIC GARMENT PRODUCTION WITH PRE-DETERMINED TIME SYSTEMS

ABSTRACT: This study examines the application of the MTM (Method Time Measurement) method, which is an important tool to increase the operational efficiency of the enterprises and to solve the line balancing problems, in the textile industry. The MTM method offers effective results in many areas such as planning and programming of production processes, measurement of material handling times and human-machine interaction. In the study, MTM method was used to determine the difference between the times taken from the company's own database and the actual operation times and to get down to the root cause of line balancing problems. For the application in the t-shirt production line, the processes were examined with video. The images obtained from the video footage were played at 1/8 speed and transcribed and then analyzed with the help of the MTM method. The MTM analysis times and the times accepted by the firm of the operations were compared. MTM results showed that operation times were shorter than the values accepted by the company.

Keywords: Apparel Industry, Predetermined Time Systems, Video analysis, MTM

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1. GİRİŞ

Küreselleşen dünyada işletmeler karlarını maksimum ve maliyetlerini minimum yapmayı temel hedef olarak belirlemişlerdir. Rekabetin giderek arttığı günümüz şartlarında işletmeler pazardaki paylarını arttırmak için verimli bir üretim sürecine sahip olmak zorundadırlar. Üretim yapan işletmeler için müşteri talebinin karşılanması hususunda titizlikle çalışılması gerekmektedir. Günlük üretim kapasitesinin hesaplanması ve mümkün olduğunca iyileştirilmesi işletmelerin taleplerini en iyi şekilde karşılamasına yardımcı olmaktadır. Bu bağlamda, üretim sürelerinin tespit edilmesi ve daha optimum hale getirilmesi günlük üretim kapasitesini de arttıracaktır [1]. Mevcut kaynakların en iyi şekilde kullanılmasını sağlayan tekniklerin geliştirilmesi ve uygulanması önem kazanmaktadır [2].

İşletmelerde verimliliğin sürekliliğini sağlamak ve iş akışını yönetebilmek için standart üretim sürelerine ihtiyaç duyulmaktadır [3]. Bu sürelerin doğru tespit edilebilmesi kârlılık ve verimlilik açısından çok önemlidir. Üretim sürelerinin belirlenmesi konusunda iş etüdü yöntemlerinden yararlanmak mümkündür. Metot etüdü ve iş ölçümü olmak üzere 2 ana başlık altında incelenen iş etüdü, işgücü, makine ve hammaddeden mümkün olan en yüksek verimlilik düzeyinde yararlanmak ve çalışan açısından en uygun çalışma şeklini belirlemek amacıyla yeni metotlar geliştirmek ve geliştirilen bu metotların standart zamanlarını hesaplamak olarak tanımlanabilmektedir. Ürün veya hizmet üreten işletmeler için iş etüdü yöntemlerinin kullanılma-sının amacı verimliliği arttırmaktır.

İş etüdünün bölümlerinden biri olan metot etüdü, gereksiz olduğu düşünülen iş elemanlarının süreçten çıkarılarak gerekli iş elemanlarının en yüksek verimlilik düzeyinde yapılması için yeni metotların geliştirilmesidir. Metot etüdü ile ilgili ilk çalışmaları Frederick W. Taylor gerçekleştirmiştir. Daha sonra Frank B. Gilbreth ve Lilian Gilbreth metotların nasıl iyileştirileceği ve hareketlerin nasıl daha kolay hale getirilebileceği üzerinde çalışmışlardır [1].

İş etüdünün bir diğer bölümü olan iş ölçümü ise nitelikli bir çalışanın belirli bir işi belirlenmiş bir performans düzeyinde yapması için gerekli olan sürenin hesaplanması üzerinde durmaktadır. İş ölçümü, bir işi yapmak için gereken zamanı belirlerken kayıp zamanı da ortaya koymak suretiyle zaman kaybını engellemektedir [1].

Tekstil işletmelerinde de müşteri isteğine karşılık ön maliyet oluştururken baz alınan üretim süresi oldukça önemlidir. Bu süre; ürün maliyetini doğrudan, sipariş miktarını ise dolaylı olarak etkilemektedir. Sürenin eksik verilmesiyle eksik maliyet çıkarılacağından sipariş zarara yol açarken, sürenin fazla verilmesi halinde (müşteri tarafında) alternatif firmalara yönelim veya sipariş sayısında azalma meydana gelebilmektedir. Bu nedenle müşteriye en uygun sürenin verilmesi için operasyonların standart sürelerinin doğru belirlenmesi gerekmektedir. Operasyonlara standart sürenin belirlenmesinde bazı durumlarda firmalar kendi belirledikleri yöntemlerle belirli bir veri tabanı oluşturmakta, üretim değişkenlerine bağlı olarak Excel üzerinden hesaplar yapmaktadırlar. Söz konusu çalışmada bu tip sürecin doğruluğunu analiz etmek amacıyla MTM (Methods Time Measurement) uygulaması gerçekleştirilmiştir.

MTM, önceden saptanmış zamanlar sistemidir. Öngörülen zamanlar ya MTM tablolarından ya plan zaman kataloglarından ya da karşılaştırma ve tahminle saptanmaktadır [4]. MTM İngilizce "Methods-Time-Measurement" sözcüklerinin baş harflerinden oluşmaktadır ve metot zamanı ölçümü olarak Türkçe'ye çevrilmektedir [5]. MTM'de metotlar, çalışma zamanları için ölçü niteliğindedir [6].

MTM'in yararlarını aşağıdaki gibi özetlenmektedir [7]:

1- MTM'in zaman ölçümü, karşılaştırma ve tahmin etme gibi diğer zaman belirleme metotlarına kıyasla üstünlüğü, uygulamaya başlamadan önce çalışma metodunu tanımlayabilmesi ve verilecek zamanı belirleyebilmesidir. Bu sayede daha planlama safhasında değişik çalışma metotları arasında zaman açısından karşılaştırma yapılabilir ve iş akışları planlanabilir.

2- MTM, iş akışını kritik olarak incelemeye zorlar ve bunun sonucunda optimal metodun tespiti sağlanabilir.

3- Hareket öğelerinin kodlanmasında enternasyonal ortak bir dil kullanılmaktadır. Bu da özellikle standart plan zamanlarının düzenlenmesi için önemlidir.

4- Verilen zamanı bulmak için performansa bağlı ücretlendirmede MTM kullanımı sorunlu durumlarda objektif olarak konu ve probleme dayalı tartışmalara yol açar.

5- Plan zamanlarının belirlenmesinde, kronometre ile zaman ölçümü yardımıyla yapılan zaman tespitine karşılık etkenlerle olan ilişkisini belirlemeye gerek yoktur. Çünkü MTM standart zamanları etkenleri göz önünde tutmaktadır.

6- Çalışanlara, yönergeler daha baştan planlanan MTM analizine göre verilebilir. Böylelikle beceri kazanma zamanları en küçük değere düşürülür.

Bu yöntem konusunda yapılan araştırmalardan tespit edildiğine göre, iş akışlarının %85'i 5 temel hareketten oluşmaktadır. Bu 5 temel hareket; uzanmak, kavramak, taşımak, yerleştirmek ve bırakmaktır [8]. Temel hareketler ve diğer hareketlerin kodları Tablo 1'de belirtilmiştir.

MTM konusunda literatürde çeşitli çalışmalar bulunmaktadır. Bunlardan bazıları şu şekildedir;

Almeida ve Ferreira, çalışmalarında üretkenliği artırmak amacıyla, MTM metodolojisinin kullanımını önermektedir. Zaman cetvellerinin mevcut gelişmelerini göz önünde bulunduran ve birçok şirkette yaygın olmayan bu metodolojinin imalat şirketlerindeki uygulamasını analiz etmektedir. Ancak bu çalışmada, MTM metodolojisi izole bir şekilde değil, diğer tekniklerle birleştirilerek uygulanmaktadır. MTM'nin otomotiv sektöründe faaliyet gösteren iki şirket ve ev aletleri üreten bir şirket üzerinde uygulanmasıyla elde edilen yöntemler ve sonuçlar ayrıntılı olarak açıklanmaktadır. Sonuç olarak, MTM metodolojisinin operatörlerin çalışma süreçlerinin planlanması ve düzenlenmesi için kullanışlı bir araç olduğu ve diğer uygulanan yöntemlerle birleştirildiğinde önemli bir üretkenlik artışı sağlayabileceği sonucuna varılmaktadır [2].

Tablo 1. MTM Hareket Kodları [9, 10]

Hareket Adı	Hareket Kodu	Hareket Adı	Hareket Kodu
Uzanmak	R	Ayak hareketi	FM
Kavramak	G	Bacak hareketi	LM
Taşımak	M	Yan adım	SS
Yerleştirmek	P	Vücudu döndürmek	TB
Bırakmak	RL	Yürümek	W
Bastırmak	AP	Eğilmek/Doğrulmak	B/AB
Ayırmak	D	Çömelmek/Doğrulmak	S/AS
Döndürmek	T	Diz Çökmek/Doğrulmak	KOK/AKOK
Göz Kaydırmak	ET	İki Diz Üzerine Çömelmek/Doğrulmak	KBK/AKBK
Kontrol Etmek	EF	Oturmak/Kalkmak	SIT/STD

Çolak vd. çalışmalarında, MTM yöntemi ile beyaz eşya yan sanayisinde faaliyet gösteren bir işletme için üretim sürelerinin iyileştirilmesi amaçlamıştır. Bu yöntem yardımıyla en küçük hareketler bile hassas bir şekilde incelendiğinden küçük iyileştirme fırsatları yakalanarak daha verimli çalışan bir üretim hattı elde edilmesi hedeflenmiştir. Çalışma sonucunda ele alınan ürün için iyileştirme öncesindeki üretim süresi ile iyileştirmeden sonraki üretim süresi karşılaştırılarak günlük üretim miktarında meydana gelen artış ortaya konulmuştur [1].

Kalkancı vd. çalışmalarında, bornoz üretiminde darboğaz oluşturabilecek bir faaliyet olarak yan birleştirme faaliyetini seçmişlerdir. Seçilen faaliyetin analizi kronometre ve MTM kullanılarak yapılmıştır. Bu iki yöntemle elde edilen veriler karşılaştırılarak işletme açısından verimliliği değerlendirilmiştir [3].

Demirci vd. çalışmalarında, tekstil endüstrisinin üretim sürecinde MTM-UAS (Metot Zaman Ölçümü Evrensel Analiz Sistemi) ile DAH (Değer Akış Haritalama) metotlarını birlikte kullanmışlardır. Müşterilere en iyi hizmeti vermek için geliştirilen yalın üretim sistemi hem israfların giderilmesini hem de teslimat ile ürün tasarım aşaması arasındaki süreyi minimuma indirmeyi amaçlamıştır. Bu çalışma kapsamında, yalın üretim araçlarından biri olan değer akışı haritalama yöntemiyle süreç akışında katma değer yaratmayan faaliyetleri ortadan kaldırarak, teslim süresi kısaltılmıştır [11].

Kirin ve Satovic çalışmalarında, Tekstil sektöründe muhtemel iş yöntemlerinin sistemli keşfi, standartlaştırılması ve MTM sistemi kullanarak temel hareketlerin kullanımı ile standart mantık setleri oluşturmuş, bunun da gerçek normların belirlenmesinde ve işçi iş yükünün azaltılmasında olanak tanıyan optimal iş yöntemini belirlemek için kullanılabilir olduğu sonucuna ulaşmışlardır [12].

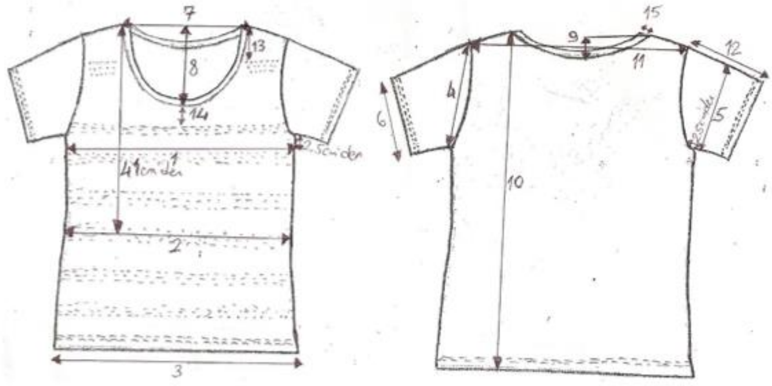
İşler vd. çalışmalarında, özellikle konfeksiyonda üretim optimizasyonunu sağlamak, geliştirmek ve eğitim yoluyla yaygınlaştırmak amacıyla iş akış sürelerini belirlemede çeşitli yöntemlerin mevcut olduğundan bahsetmişlerdir. Bu yöntemlerden biri MTM diğeri ise kronometraj yöntemidir. Bu çalışmada, MTM yönteminin konfeksiyon sektöründe özellikle üretim planlaması için öneminden bahsedilmiş ve bir uygulama üzerinden kronometraj yöntemi ile iş ölçümü karşılaştırması yapılmıştır [13].

Görüldüğü üzere MTM yöntemi farklı amaçlar için farklı sektörlerde uygulanmaktadır. Söz konusu çalışmanın gerçekleştirildiği bir işletmede hat dengeleme problemleri gözlemlenmiş ve bu problemin temel nedeninin hatalı standart süreler olduğu tespit edilmiştir. Mevcut sürelerin işletmenin kendi geliştirdiği bir Excel veri tabanından alındığı belirlenmiştir. Excel veri tabanı her operasyon için alınan 5 adet zaman etüdü ortalamasına bağlı olarak oluşturulmuş, üzerine %15 gibi bir pay eklenerek standart süreler elde edilmiştir. Ancak bu %15 payın neye göre hesaplandığı belli değildir. Bu çalışmanın amacı, literatürden farklı olarak işletmenin kabul ettiği operasyon süreleri ve gerçek standart süre değerleri arasındaki farkı belirlemek amacıyla MTM uygulaması gerçekleştirmektedir. Bu amaç doğrultusunda, tişört üretim bandında yapılan uygulama için, prosesler video ile incelenmiştir. Video çekimlerinden elde edilen görüntüler 1/8 hızda oynatılarak metne dökülmüş ardından MTM yöntemi yardımıyla analiz edilmiştir. MTM analiz süreleri ile operasyonların firma tarafından kabul edilen süreleri karşılaştırılmıştır.

2. MATERYAL VE METOT

Çalışmanın gerçekleştirildiği firma, büyük ölçekli olup hazır giyim ve konfeksiyon alanında faaliyet göstermekte ve %100 ihracat yapmaktadır. Avrupa'nın önde gelen markalarına kendi tasarımlarını sunmakta ve üretimlerini gerçekleştirmektedir. Kırklareli’nde yer alan ve aylık üretim kapasitesi yaklaşık 1000000 adet olan firma örme konfeksiyon üretimi yapmaktadır. Çalışmada MTM uygulamasının yapıldığı ürüne ait teknik çizim Şekil 1’de verilmektedir.

Dolaylı iş ölçüm tekniklerinden biri de önceden belirlenmiş zaman sistemleri veya diğer adıyla sentetik zaman sistemleridir. Önceden belirlenmiş zaman sistemleri, gelişmiş teknikler olup, doğrudan gözlemler ve ölçümlere dayanmadan, çeşitli hareketler için önceden belirlenmiş olan zaman standartlarından yararlanarak, çeşitli işlemlerin yapılması için gereken zamanı saptamak amacıyla uygulanmaktadır. Söz konusu sistemler, ortaya ilk çıkışlarından itibaren uzun yıllar boyunca oldukça kısıtlı bir kullanım alanına sahip olmuşlar ancak, zamanla sayılarının artması ve kullanıcıların bu sistemlerin getirdiği avantaj ile sahip oldukları sınırlamaları daha iyi kavramaları uygulama alanlarını genişletmiştir [14].



Şekil 1. MTM uygulaması yapılan tişörtün teknik çizimi

Önceden belirlenmiş zaman sistemleri içerisinde insan vücuduna ait temel hareketlerin hem yapısal açıdan hem de değişik koşullar altında gerçekleştirilmeleri bakımından bir sınıflandırması yapılmıştır ve ilgili zamanlar bu sınıflar çerçevesinde tespit edilmiştir. Böylece söz konusu zamanlar, işçinin herhangi bir işi tanımlanmış bir verimlilik düzeyinde bitirebilmesi için gerekli sürenin hesaplanmasında kullanılmaktadır [14].

Önceden belirlenmiş zaman sistemleri, temel hareketlere ilişkin standart süre verilerinden hareketle işlemin normal süresinin belirlenmesi esasına dayanır. Dolayısıyla, bu sistemde önemli olan sürenin tespiti değil, işleme ait hareketlerin belirlenmesidir. Hareketlerin belirlenmiş olması halinde, ilgili süre harekete ilişkin tablo değerinin okunması ile elde edilir. Bu nedenle, işleme ait hareketlerin tespiti bu konuda eğitimli iş etütçüleri tarafından yapılmaktadır [14]. Konuya uygun bir analiz tekniği uygulandığında bu yöntem, gerekli olan hareket öğelerini mantıksal biçimde sıralayarak insan emeğini biçimlendirip değerlendiren diğer yöntemlerden üstün gelmektedir. Böyle bir analitik değerlendirme çalışmasının mantıksal sonucu, verilen zaman değerleri biçiminde hazır bulunan zaman değerlerinin toplanmasıdır. Böylece temel zaman, kendiliğinden ortaya çıkmaktadır [15].

Günümüzde 200'ün üstünde sentetik zaman sistemi mevcut olup en çok uygulanan MTM önceden belirlenmiş zaman sistemidir. MTM yöntemi; insan tarafından yapılan herhangi bir işin ölçümüne esas olan, temel çalışma hareketlerini ve bu hareketlerin gerçekleştirilmesi için gerekli olan normal zaman değerlerini sağlamaktadır [14]. İnsan tarafından yapılan 19 temel hareketi esas alan MTM sisteminde kullanılan zaman birimi saatin yüz binde birini belirten TMU (Time Measurement Unit)'dur. 1 TMU = 0,00001 saat = 0,0006 dk = 0,036 sn'dir [3].

MTM yönteminin fabrika uygulamasında ilk olarak çalışmanın gerçekleştirildiği süreçte fabrikaya en sık gelen sipariş tespit edilmiştir. Ardından ilgili ürüne (tişörte) ait iş akışı çıkarılmış, operasyonlar bir kamera ile kaydedilmiştir. Kaydedilen görüntüler "Media Player Classic" yazılımıyla analiz edilerek metne dökülmüştür. Bu süreçte gerekli noktalarda video 1/8 hızda oynatılmıştır. Ardından metinde yazan hareketler MTM tabloları yardımıyla bir Excel dosyasında kodlara aktarılmış, ilgili kodlara denk gelen süreler TMU birimi olarak toplandıktan sonra saniyeye çevrilmiştir.

Tişört üretiminin operasyon isimleri Tablo 2'de verilmektedir.

Tablo 2. Tişört operasyon numaraları ve isimleri

Operasyon No	Operasyon Adı
T1	Sağ omuz çatma
T2	Yaka biye
T3	Sol Omuz Çatma
T4	Biye kapama, etiket
T5	Kol takma
T6	Yan çatma
T7	Kol kırım
T8	Etek Kırım
T9	Yaka Zikzak + Askılık takma
T10	İş çevirme
T11	Kalite kontrol

3. ARAŞTIRMA BULGULARI VE İRDELENMESİ

Tişört üretimine ait operasyonlar tespit edildikten sonra, tüm operasyonlar videoya kaydedilip izlenmiştir. Gerçekleştirilen incelemeler sonucunda operasyonlara ait MTM analizleri yapılmıştır. Örneğin, Tablo 4'ün ilk hareketi olan 60 cm'lik uzanma işlemi R60B olarak analiz edilmiştir. Söz konusu kodun "R" kısmı uzanma hareketini, "60" kısmı ise uzanma mesafesini, "B" kısmı ise hareketin durumunu ifade etmektedir. Konuya ilişkin Tablo 3'te gösterildiği üzere, R60B hareketinin süresi "21,2" TMU olarak hesaplanmıştır.

Çalışmada örnek olması amacıyla en uzun süreli operasyona (T5-kol takma) ait çalışan resmi (Şekil 2) ve ayrıntılı MTM analizi (Tablo 4) verilmektedir.

Tablo 3. Uzanma hareketinin MTM kodları ve TMU değerleri [16]

UZANMAK – R – (REACH)

Hareket Uz. (cm)	Norm zaman değeri TMU						Durumların Açıklanması
	R-A	R-B	R-C R-D	R-E	mR-A R-Am	mR-B R-Bm	
2 veya az	2.0	2.0	2.0	2.0	1.6	1.6	A. Yalnız duran, öbür elde olan ya da öbür elin altında bulunan nesnelere uzanmak
4	3.4	3.4	5.1	3.2	3.0	2.4	
6	4.5	4.5	6.5	4.4	3.9	3.1	
8	5.5	5.5	7.5	5.5	4.6	3.7	
10	6.1	6.3	8.4	6.8	4.9	4.3	
12	6.4	7.4	9.1	7.3	5.2	4.8	B. Bir iş akışından diğer iş akışına daima yer değiştiren ve yalnız başına duran bir nesneye uzanmak
14	6.8	8.2	9.7	7.8	5.5	5.4	
16	7.1	8.8	10.3	8.2	5.8	5.9	
18	7.5	9.4	10.8	8.7	6.1	6.5	
20	7.8	10.0	11.4	9.2	6.5	7.1	
22	8.1	10.5	11.9	9.7	6.8	7.7	C. Aynı türden veya benzeri nesnelerle birlikte karışık vaziyette duran ve seçilmesi gereken bir nesneye uzanmak
24	8.5	11.1	12.5	10.2	7.1	8.2	
26	8.8	11.7	13.0	10.7	7.4	8.8	
28	9.2	12.2	13.6	11.2	7.7	9.4	
30	9.5	12.8	14.1	11.7	8.0	9.9	
35	10.4	14.2	15.5	12.9	8.8	11.4	D. Ufak veya çok dikkatlice tutulması gereken bir nesneye uzanmak
40	11.3	15.6	16.8	14.1	9.6	12.8	
45	12.1	17.0	18.2	15.3	10.4	14.2	
50	13.0	18.4	19.6	16.5	11.2	15.7	
55	13.9	19.8	20.9	17.8	12.0	17.1	
60	14.7	21.2	22.3	19.0	12.8	18.5	E. Denge sağlamak, bir sonraki harekete hazırlanmak ya da çalışma yerinden çekmek için eli belirli olmayan bir duruma getirmek
65	15.6	22.6	23.6	20.2	13.5	19.9	
70	16.5	24.1	25.0	21.4	14.3	21.4	
75	17.3	25.5	26.4	22.6	15.1	22.8	
80	18.2	26.9	27.7	23.9	15.9	24.2	

Şekil 2. Kol Takma operasyonu video kesiti

Kol takma operasyonu videosunun metne çevrilmesi şu şekilde yapılmıştır: Operatör 60 cm uzaklıkta masada duran yarı mamullerin en üstünden bir parçayı iki eliyle alıyor ve mamulü 50 cm havaya kaldırarak sağ kol takılacak şekilde 50 cm uzaklıktaki makineye getiriyor ve yerleştiriyor. 20 cm uzaklıkta sağ tarafında duran kol parçasını iki eliyle alıyor ve doğru parçayı aldığını gözden geçirerek 30 cm uzaklıktaki dikiş makinesine getiriyor. Parçanın ucunu makineye tutturduktan sonra 20 cm arkada yer alan iki ucu bir araya getiriyor. Dikime başladıktan 2,75 sn sonra mamulü sol eliyle düzeltmek için mamulü tutarak 10 cm ileri götürerek bırakıyor. Bu düzeltme işlemi 2 defa tekrar ediyor. 2 sn'lik dikim işleminden sonra mamulün üzerindeki etiketi kontrol ettikten sonra sol el ile etiketi söküyor ve 20 cm uzaklıktaki yere etiketi yapıştırıyor. Mamulü 50 cm yukarı kaldırarak kendi ekseni etrafında döndürüp dikilecek olan sol tarafı 30 cm uzaklıktaki dikiş makinesine yerleştiriyor. Sağ eliyle 20 cm uzaklıkta (kucağındaki) parçayı alarak makine önüne getiriyor. Parçanın ucunu makineye tutturduktan sonra 20 cm arkada yer alan iki ucu bir araya getiriyor. Dikime başladıktan 2,75 sn sonra mamulü sol eliyle düzeltmek için mamulü tutarak 10 cm ileri götürerek bırakıyor. Bu düzeltme işlemi 2 defa tekrar ediyor. 2 sn'lik dikim işleminden sonra mamulün üzerindeki etiketi kontrol ettikten sonra sol el ile etiketi söküyor ve 20 cm uzaklıktaki yere etiketi yapıştırıyor. Dikim işleminden sonra mamulü gözüyle kontrol ediyor. Gözle kontrolden sonra mamulü düzeltmek için iki eliyle 50 cm havaya kaldırdıktan sonra 80 cm uzaklıktaki sepete bırakıyor.

Tablo 4. Kol Takma MTM Analizi

Sol El	TMU	Sağ EL	Hareket Açıklamaları
R60B G1B M50B M50B P1NSD FM RL1	21,2 3,5 18 18 16 2	R60B G1B M50B M50B P1NSD FM RL1	Operatörün 60 cm uzaklıkta masada duran yarı mamullerin en üstünden bir parçayı iki eliyle alması ve mamulü 50 cm havaya kaldırarak sağ kol takılacak şekilde 50 cm uzaklıktaki makineye getirmesi ve yerleştirmesi.
R20C G1B D1E EF M30C P1NSD RL2	11,4 3,5 4 7,3 15,1 16 0	R20C G1B M30C P1NSD RL2	20 cm uzaklıkta sağ tarafında duran kol parçasını iki eliyle alması ve doğru parçayı aldığını gözden geçirerek 30 cm uzaklıktaki dikiş makinesine getirmesi.
R20A	7,8	R20A	Parçanın ucunun makineye tutturulduktan sonra 20 cm arkada yer alan iki ucun bir araya getirilmesi.
PT	152,9	PT	Dikim işlemi. (2,75 sn)
G1A*2 R10B*2 RL2*2	4 12,6 0		Mamulü sol eliyle düzeltmek için mamulün tutularak 10 cm ileri götürülmesi bırakılması. Bu düzeltme işleminin 2 defa tekrar edilmesi.
PT	111,2	PT	Dikim işlemi. (2 sn)
EF	7,3		Mamulün üzerindeki etiketin kontrolünün yapılması.
D1E G1A M20B RL1	4 2 10,5 2		Elle etiketin sökülmesi ve 20 cm uzaklıktaki yere etiketin yapıştırılması.
R20E	9,2		Sol elin geri getirilmesi.
M50A S180˚ M30C P1NSD FM RL1	19 9,4 15,1 16 2	M50A S180˚ M30C P1NSD FM RL1	Mamulün 50 cm yukarı kaldırılarak kendi ekseni etrafında döndürülmesi ve dikilecek olan sol tarafın 30 cm uzaklıktaki dikiş makinesine yerleştirilmesi.
	10 2 11,7 16	R20B G1A M20C P1NSD	Sağ eliyle 20 cm uzaklıkta kucağında bulanan parçanın alınarak makine önüne getirilmesi.
 RL2	 0	FM RL2	Parça ucunun makineye tutturulması.
R20A	7,8	R20A	20 cm arkada yer alan iki ucun bir araya getirilmesi
PT	152,9	PT	Dikim işlemi (2,75 sn)
G1A*2 R10B*2 RL2*2	4 12,6 0		Mamulü sol elle düzeltmek için mamulün tutularak 10 cm ileri götürülmesi ve bırakılması.
PT	111,2	PT	Dikim işlemi (2 sn)
EF	7,3		Mamul üzerindeki etiketin kontrolü.
R20E G1A D1E M20B RL1 R20E	9,2 2 4 10,5 2 9,2		Sol el ile etiketin sökülmesi ve 20 cm uzaklıktaki yere etiketin yapıştırılması.
EF	7,3		Mamulün göz ile kontrolü.
G1A M50B M80B RL1	2 18 25,2 2	G1A M50B M80B RL1	Mamulü düzeltmek için iki elle 50 cm havaya kaldırıldıktan sonra 80 cm uzaklıktaki sepete bırakılması.
Toplam	947,9 TMU		

Çalışmanın devamında firmanın kendilerine özgü bir yöntemle hesapladıkları operasyon süreleri ve MTM verilerinin karşılaştırma sonuçları sunulmaktadır. Tişört üretimine ait operasyonların firma verileri ve MTM süreleri Şekil 3'te yer almaktadır. Görüldüğü üzere 10 farklı operasyonun süresi (saniye olarak) hesaplanmış MTM verileri gözlem verilerine oranla düşük çıkmıştır.

4. SONUÇ VE DEĞERLENDİRME

Bu çalışma işletmenin hat dengeleme problemlerinin nedeni olan, planlanan ve gerçekleşen operasyon sürelerinin uyumsuz-luğunu ortaya koymayı amaçlamıştır. Çalışmada, işletmenin kendi veri tabanından alınan süreler ile gerçekleşen operasyon süreleri arasındaki farkı belirlemek için MTM uygulaması gerçekleştirilmiştir. MTM yöntemi, üretim süreçlerinin planlanması, programlanması, malzeme taşıma sürelerinin ölçümü ve insan-makine etkileşimi gibi birçok alanda potansiyel taşımaktadır. Hızlı, güvenilir ve kabul edilebilir sonuçlar sunmasıyla, işletmelere operasyonel verimliliklerini artırma ve iş süreçlerini optimize etme imkânı sağlamaktadır.

Çalışma, üretim bandında yapılan uygulama üzerinden yürütülmüştür. Video görüntüleri alınan işlemlerin MTM analiziyle süreleri ölçülmüş ve firma tarafından kabul edilen sürelerle karşılaştırılmıştır. Sonuçlar, MTM verilerinin genellikle firma verilerinden düşük çıktığını göstermiştir. Özellikle bazı operasyonlarda 30 saniyeye varan farklıklar dikkat çekmektedir. Hat dengeleme hesaplanmalarında kullanılan algoritmaya göre 5 saniyelik bir sürenin bile tüm bandın verimliliği etkilediği düşünüldüğünde, söz konusu çalışmada gözlemlenen standart süre sapmaları son derece önemlidir.

MTM analizleri doğru standart zaman tespiti için yıllardır kullanılan bir tekniktir. Ancak, MTM yönteminin karşılaştığı zorluklara da dikkat çekilmelidir. Özellikle uygulanan metodun yazılı metne dönüştürülmesi ve kod atama işleminin yapılması gibi manuel çalışmaların zaman alıcı olması bir dezavantaj olarak göze çarpmaktadır. Bu noktada, otomatik metin analizi ve doğal dil işleme gibi tekniklerin kullanımı, bu süreçleri otomatikleştirme ve daha hızlı sonuçlara ulaşma potansiyeli sunmaktadır.

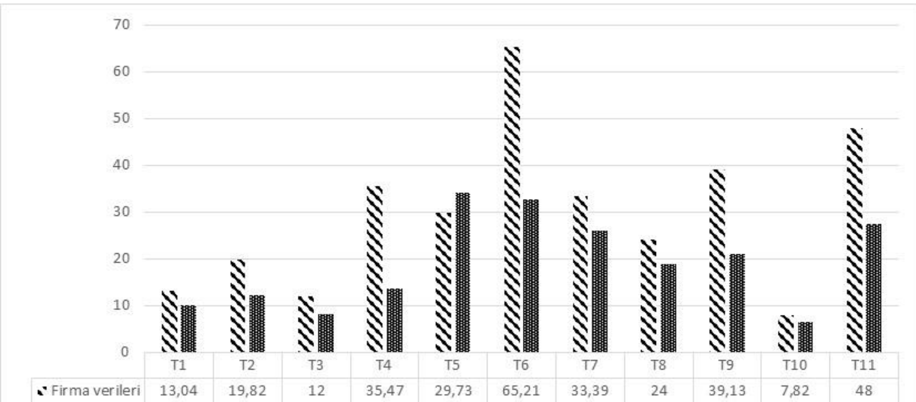
Sonuç olarak, MTM yöntemi işletmelerin operasyonel verimliliklerini artırmak ve hat dengeleme problemlerini çözmek için önemli bir araçtır. Bu çalışma, MTM yönteminin tekstil endüstrisindeki uygulamasına odaklanmış olsa da yöntemin farklı sektörlerde de başarıyla kullanılabileceğini göstermektedir. Ancak, yöntemin daha da geliştirilmesi ve zorlukların aşılması için ileri araştırmalara ihtiyaç vardır. Böylece işletmeler, doğru süre tahminleri yaparak verimliliklerini artırabilir ve hat dengelemeyi daha etkin bir şekilde gerçekleştirebilirler.

Gelecekte çalışma metodunun iyileştirilmesi üzerine çalışacak araştırmacılara, MTM yöntemini kullanarak gerekli iş yeri düzenlemelerinin yapılması tavsiye edilmektedir. Uygulaması uzun süren MTM analizinden sonra yapılacak en kolay metot değişiklikleri, hareket sınıfını olabildiğince "E" kodundan "A" koduna doğru (zordan kolaya doğru) geliştirmek olacaktır.

Çalışma üzerine yapılabilecek diğer bir öneri ise MTM yön-temini kullanarak çalışan performansının hesaplanmasıdır. Ancak böyle bir uygulama için aynı çalışanın farklı ürün gruplarına ait analizinin yapılması gerekmektedir. MTM metodu çalışanın %100 performansla yaptığı faaliyetlere göre oluşturul-duğu için, ilgili sürelerle MTM sonuçları karşılaştırıldığında çalışan performansı kolayca hesaplanabilir.

TEŞEKKÜR

Çalışmanın uygulanması sırasında, veri toplama aşamasında sağladığı destek için Ertuğrul Şüayip TEKEDERELİ'ye teşekkürü bir borç biliriz.



	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11
Firma verileri	13,04	19,82	12	35,47	29,73	65,21	33,39	24	39,13	7,82	48
MTM verileri	9,98	12,19	8,11	13,72	34,12	32,54	25,97	18,97	21,07	6,46	27,49

Şekil 3. Tişört üretimine ait operasyonların firma ve MTM süreleri

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INVESTIGATION OF TEXTILE BASED ELECTRODES FOR MONITORING sEMG MUSCLE SIGNAL

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***ABSTRACT*:** Wearable electronics are technological devices that are incorporated into garments with embedded systems and provide constant interaction with the user performing a specific task. This technology often focuses on devices to monitor physiological variables and seeks the most convenient and portable form for continuous monitoring. Although sEMG has emerged as a tool used in laboratory research for many years, with the development of technology in the fields of electricity, electronics, computers, and biomedicine, it has been used for different purposes in kinesiology (the branch of science dealing with human movements), rehabilitation, sports medicine, sports sciences, and many sports branches. In this study, textile based sEMG electrodes were produced by using knitting technology with silver plated polyamide conductive yarn with different densities. Then resistivity and sEMG signals of the produced samples and conventional disposable electrode were compared.

Key Words: Smart textile, textile-based electrode, medical textiles, sEMG signal, physiological monitoring

sEMG KAS SİNYALİNİN İZLENMESİ İÇİN TEKSTİL BAZLI ELEKTROTLARIN İNCELENMESİ

***ÖZ*:** Giyilebilir elektronikler, gömülü sistemlerle giysilere dahil edilen ve belirli bir görevi yerine getiren kullanıcı ile sürekli etkileşim sağlayan teknolojik cihazlardır. Bu teknoloji genellikle fizyolojik değişkenleri izlemek için cihazlara odaklanır ve sürekli izleme için en uygun ve taşınabilir biçimi arar. sEMG uzun yıllardır laboratuvar araştırmalarında kullanılan bir araç olarak ortaya çıkmış olsa da elektrik, elektronik, bilgisayar ve biyotıp alanlarında teknolojinin gelişmesiyle birlikte kinesiyoloji (insan hareketlerini inceleyen bilim dalı), rehabilitasyon, spor hekimliği, spor bilimleri ve birçok spor branşında farklı amaçlarla kullanılmaktadır. Bu çalışmada, farklı yoğunluklarda gümüş kaplı poliamid iletken iplik ile örme teknolojisi kullanılarak tekstil bazlı sEMG elektrotları üretilmiştir. Daha sonra üretilen numuneler ile konvansiyonel tek kullanımlık elektrotların özdirenç ve sEMG sinyalleri karşılaştırılmıştır.

Anahtar kelimeler: Akıllı tekstil, tekstil tabanlı elektrot, medikal tekstil, sEMG sinyali, fizyolojik izleme

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1. INTRODUCTION

The role of technology in healthcare is gaining importance day by day. The research and development studies on smart garments for monitoring physiological condition is growing very rapidly in scientific and technological areas. Such smart garments, popularly also known as electronic textiles, find applications in varied fields like civilian, medical, military etc.

Surface Electromyography (sEMG) is an assessment tool that is frequently used in many areas of medical science today and is used to analyze muscle function. With the help of this measurement technique, which contains important information about the contraction of our body muscles, it is determined which muscles are activated in which movement. sEMG provides information on which stage the muscles are active, especially in activities that contain important data such as walking movement. In addition, it allows evaluating muscle fatigue and making muscle strength estimates. Surface electromyography (sEMG) is one of the most common methods used to measure muscle activity in athletes and patients. Textile-based electrodes cover a larger area to acquire the sEMG signal, thus achieving muscle stimulation from all muscle groups. Real-time measurement of textile-embedded EMG electrodes has been shown to significantly improve clinical outcomes after rehabilitation. Scientific studies show that sEMG muscle signals can be obtained from muscle groups in the human body with conventional electrodes (Giggins et al.,2013; Pehlivan, 2006) or textile-based electrodes (Catarino et al., 2012; Pani et al., 2019; Colyer et al., 2018) integrated on a garment. When the studies in this field are examined, it is seen that textile-based electrodes can be created by various methods.

Biopotential monitoring has been greatly facilitated by advances in wearable technologies and textile electronics has become an important technology. The human body itself is a critical signal "source" in wearable applications. The material type and production technology have important effects on the performance and functionality of the textile-based electrodes. Textile-based electrode production is fundamentally based on the integration of conductive materials in the form of fabric. Commonly used conductive materials include metals and conductive polymers. With these materials, electrode fabric form is applied using knitting, weaving, embroidery techniques or using various other methods such as printing, electroplating, physical vapor deposition (PVD), chemical coating and chemical polymerization (Stoppa et al., 2014; Takamatsu et al., 2015).

Knitting, weaving, and embroidery technology are the most known and widely used techniques in wearable technology. Using various conductive fibers and yarns, electrode surfaces can be created by knitting, weaving and embroidery techniques directly. Woven textiles are produced by interlacing two perpendicular yarn groups. In contrast, the knitting technique uses a needle that constantly connects a series of thread chains. The embroidery method is a kind of decoration method for creating a pattern by including different sewing forms on a fabric surface. Among these methods, knitted fabrics, provide consumers skin comfort, low weight, and great flexibility, and the knitting process is a well-established approach that allows a whole garment to be made on a single machine (An et al., 2018; Xu et al., 2008). Electroless plating is a technique that involves spontaneous reactions in an aqueous solution without requiring the application of an external electric field, unlike galvanic plating, which uses an electrode current to reduce metal cations for plating (Mallory et al., 1990). Electrodeposition techniques and physical vapor deposition (PVD) are the most prominent techniques for metal coating on non-conductive yarns and textiles. PVD techniques such as thermal/e-beam evaporation and sputtering depend on the formation of conductive layer on the textile material, similar to electrodeposition in the microelectronic process industry. Metals are evaporated and deposited to form a thin film layer on various textile products (Mattox et al., 2010; Silva et al., 2012). Dip coating is one of the simplest methods of coating yarns or fabrics and is still used in the textile industry. Upon application of a conductive solution to textiles, excess material is removed, and a drying step known as curing is performed to evaporate the solvent and fix the conductive particles on the fiber surfaces (Shang et al., 2013; Garcia-Breijo et al., 2015). Printing techniques such as inkjet and screen printing are widely used to create conductive patterns on textile substrates and are already being used on a large scale to print stickers/images on textiles (Ujiie, 2006).

In the scope of this study, knitted fabric samples with different loop densities were produced using conductive yarn in order to obtain textile based sEMG electrodes. The effect of loop densities and so fabric tightness on resistivity and signal reception capability were investigated. Then, resistivity and signal reception capability of textile-based electrodes were inspected in comparison to conventional electrodes.

2. MATERIALS AND METHODS

A prototype vision inspection system is developed to acquire image frame of the yarn bobbin and fabric. In this study, it is aimed to produce a textile-based electrode samples for measuring sEMG signals. For this purpose, it is planned to produce electrode surface by using silver-coated polyamide yarns (Statex/Shildex Group, 117/17 dtex) via circular knitting technology. Since the conductivity and measurement accuracy of the produced textile-based electrodes is affected by the structural parameters, it is aimed to evaluate the textile-based electrode samples with different loop densities. The produced textile-based electrodes have a voluminous structure and form a surface area in contact with the body, conductivity levels were determined by resistivity measurements. The resistivity measurements were done by using a digital multimeter device. Three knitted fabric samples were produced with different levels of fabric density as loose, medium and tight, as single jersey structure. For this aim, a sample circular knitting machine with 3.5" gauge, 22 fein was used at 20±2 rev/min production speed. All fabric samples were conditioned according to TS EN ISO 139 before the tests and the tests were performed in the standard atmosphere of 20±2ºC and 65±4% relative humidity. Fabric mass, thickness, loop density and loop length properties of samples were determined according to TS EN 12127:1999, TS 7128 EN ISO 5048:1998, TS EN 14971:2006 and TS EN 14970:2006 respectively. All measurement results were given in Table 1. The produced fabric samples images were illustrated in Figure 1.

After the knitted fabric samples were produced and the necessary measurements were completed, the fabric samples were sewn on the torniquet in order to get the muscle signal. The knitted fabric samples with 1x1 cm size were prepared and sewn on the torniquet using conductive yarn. Arm muscle signals were obtained with the prepared torniquet as in Figure 2. Muscle signals captured using the Arduino sEMG sensor were displayed on the computer screen. Grove - EMG Detector was purchased for this investigation. Muscle and nerve EMG signals can be captured using sensors in the EMG measurement kit. Microcontrollers such as Arduino or other embedded systems might be used to implement the measurement kit. An Arduino-based EMG sensor serves as an interface between the electrical components and the physical body in this investigation. The sensor picks up twice-amplified and filtered electrical impulses from small muscles. The sensor output is detectable by Arduino. In standby mode, the sensor outputs 1.5V. Muscle contraction causes the output signal to increase to 3.3V.

Table 1. Structural properties fabric samples

Samples	Resistance, ohm/10 cm	Thickness, mm	Course density, course/cm	Wale density, wale/cm	Loop length, mm
Dense	1.4	0.34	11	16	2.9
Medium	1.4	0.35	10	14	2.7
Loose	1.5	0.36	9	12	2.5

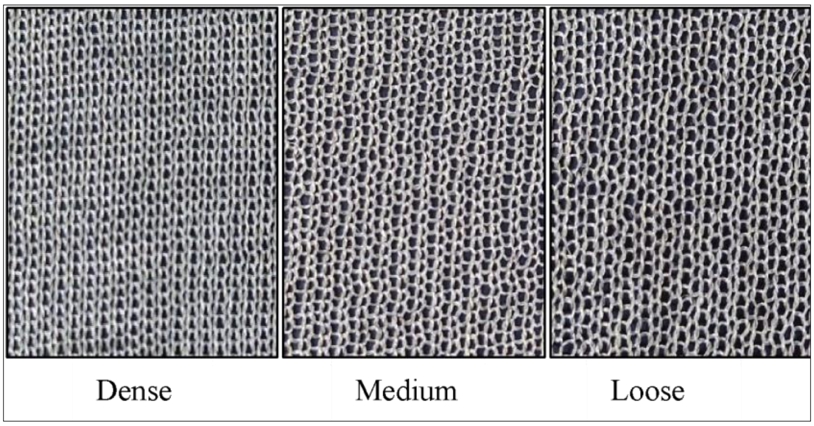

Figure 1. Knitted fabric images

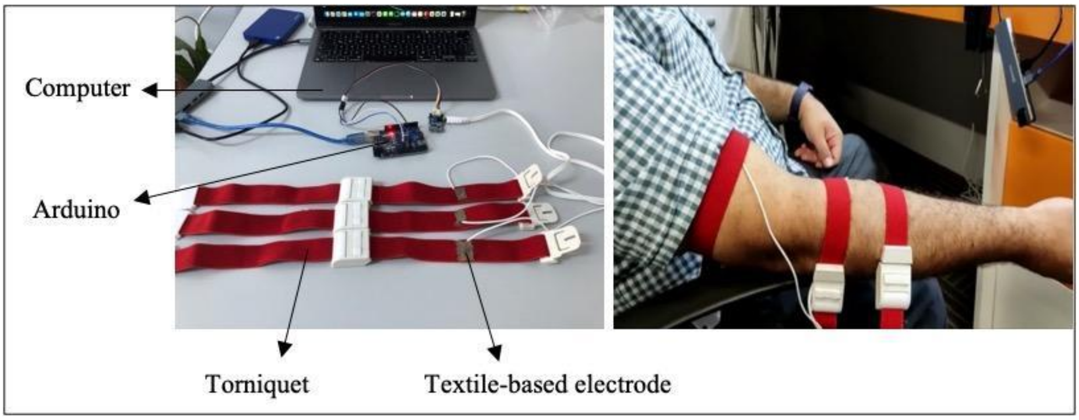

Figure 2. Conductive fabric placed on the torniquet

3. RESULT AND DISCUSSION

Surface resistivity measurements of the knitted fabric samples were carried out as shown in Figure 3. The fabric sample is placed in a hoop to keep the fabric tension constant and regular. The resistivity value of the fabric was measured at a certain distance by placing the probes of the digital multimeter device on the fabric surface. After that a square signal was created using Arduino and the characteristic of the signal transmitted through the fabric sample was analyzed via oscilloscope device. The signals acquired from each sample was compared. It was observed from the oscilloscope device that there was no loss in the generated square signal (Figure 4).

Muscle signals were acquired from three textile-based electrode samples and conventional disposable electrodes. In order to compare the signals, they were captured from the same person and same muscle group. The person made the same arm movement during the signal acquisition. When the muscle signals were analyzed, it was seen that all three fabric samples have similar results with disposable electrodes. It is clearly seen in Figure 5 that the signals received from the arm muscle have a similar characteristic. This result can be attributed to the close resistance values of the fabric samples. The disposable electrodes and all textile-based electrodes used in the experimental setup captured signals in the range of 200 to 800 millivolts. The obtained findings as a result of this study are also similar to the literature. It has also been stated in previous studies that textile-based electrodes and disposable electrodes perform similar measurements (Lee et al., 2018; Babusiak et al., 2018).

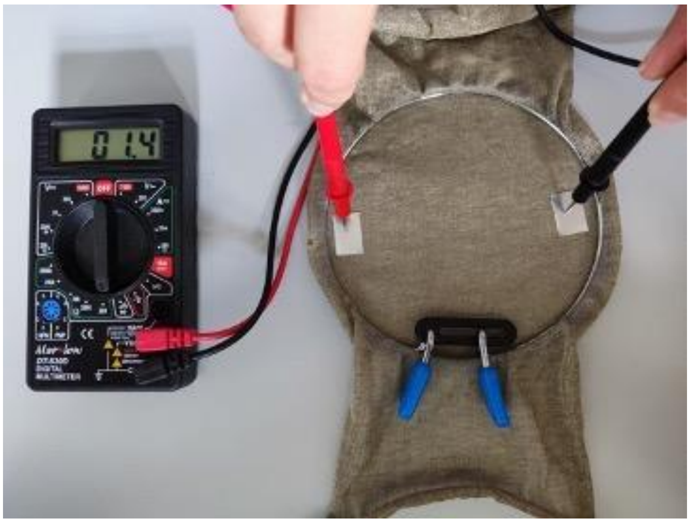

Figure 3. Surface resistivity measurement of knitted fabric sample

Figure 4. Signal measurement of knitted fabric sample

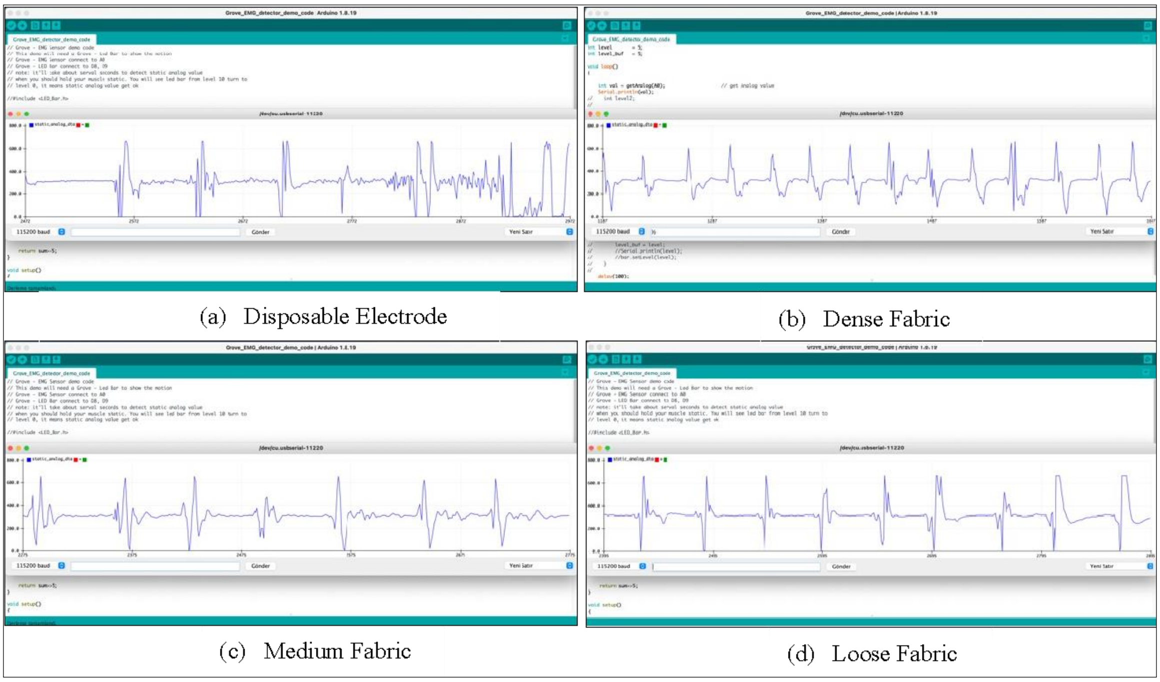

Figure 5. Comparison of sEMG signals captured from (a), (b), (c), (d) samples

4. CONCLUSION

In this work, it is aimed to submit information about textile-based electrode properties and to create textile-based electrode structures containing silver-plated polyamide conductive yarn. By producing knitted fabrics with three different densities with conductive yarn, textile based sEMG electrodes were produced. Then, surface resistivity and signal transmission levels of textile based and conventional sEMG electrodes were observed. It was seen that sEMG signals acquired from textile-based electrodes and conventional electrodes are very close to each other. It shows that the electrode structures produced by using conductive yarns, can be used in sEMG measurements. As a result, it is seen that textile-based electrodes can be used as an alternative to disposable electrodes. Thus, it can be concluded that the reliability of smart textiles to be used in the medical field is very high.

It is possible to collect clinical and behavioral data using wearable technology, which may be categorized under broad categories such real-time monitoring of health status in the medical area, diagnosis, and therapy. Numerous application examples highlight this benefit of wearable technology. As a result of this study, it can be demonstrated that smart clothing made with textile-based sEMG electrodes is adequately accurate for real time health monitoring. The smart clothes allow it to analyze muscle signals during active exercise, which is superior to measurements in medical environment. Smart clothes produced with textile electrodes provide comfort to the user in terms of both ease of measurement and comfort. As technology advances, consumers' perceptions of computers are changing from desktop computers to smart phones, tablets, and eventually wearable devices. According to market studies, this technology is becoming more and more prevalent in our daily lives. It has established itself as a significant player in the market with a wide range of products as a result of users' growing awareness of its benefits.

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Araştırma Makalesi / Research Article

ELECTROSPINNING OF PVP/CARVACROL/LANOLIN COMPOSITE NANOFIBERS

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ABSTRACT: In this study, it was aimed to produce and characterize various concentrations of carvacrol and lanolin loaded PVP nanofibers via electrospinning. Various concentrations of carvacrol: lanolin were added to the PVP polymer solutions such as 2.5, 5, 7.5, 10, 12.5 and 15 wt %. Solution properties such as viscosity, conductivity, and surface tension were measured. In terms of characterization studies, SEM, FT-IR, TGA and DSC analysis were carried out. According to the results of the study, viscosity increased and conductivity decreased with carvacrol: lanolin concentration increasement. However, surface tension was not affected from carvacrol: lanolin concentration. Nanowebs quality improved with carvacrol: lanolin concentrations. Generally, nanofibers are quite fine, smooth, and uniform. FT-IR spectrums verified that PVP, carvacrol and lanolin exist in the structure of nanofibers chemically. DSC and TGA results demonstrated that the thermal stability of carvacrol and lanolin, which have poor thermal stability, was enhanced by incorporating them into the PVP nanofiber structures. Considering antibacterial properties of carvacrol and wound healing properties of lanolin, these composite nanofiber surfaces have a high potential for use in the biomedical field, especially as a wound dressing.

Keywords: Polyvinylpyrrolidone, carvacrol, lanolin, electrospinning, nanofiber.

PVP/LANOLİN/KARVAKROL KOMPOZİT NANOLİFLERİN ELEKTRO LİF ÇEKİMİ

ÖZ: Bu çalışmada, elektro lif çekim yöntemi kullanılaarak çeşitli konsantrasyonlarda karvakrol ve lanolin yüklü PVP nanoliflerin üretilmesi ve karakterize edilmesi amaçlanmıştır. PVP polimer çözeltilerine ağırlıkça %2.5, 5, 7.5, 10, 12.5 ve 15 gibi çeşitli konsantrasyonlarda karvakrol:lanolin eklenmiştir. Hazırlanan çözeltilerin viskozite, iletkenlik ve yüzey gerilimi gibi çözelti özellikleri ölçülmüştür. Karakterizasyon çalışmaları açısından SEM, FT-IR, TGA ve DSC analizleri gerçekleştirilmiştir. Çalışmanın sonuçlarına göre, çözeltilerdeki karvakrol:lanolin konsantrasyonu arttıkça viskozite artmış, iletkenlik ise azalmıştır. Ancak, yüzey gerilimi karvakrol:lanolin konsantrasyonundan etkilenmemiştir. Nano ağların kalitesi, karvakrol:lanolin konsantrasyonu ile artmıştır. Genel olarak, oldukça ince, pürüzsüz ve üniform yapıda nanolifler elde edilmiştir. FT-IR spektrumları PVP, karvakrol ve lanolinin kimyasal olarak nanoliflerin yapısında bulunduğunu doğrulamıştır. DSC ve TGA sonuçları, zayıf termal stabiliteye sahip olan karvakrol ve lanolinin termal stabilitesinin, PVP nanolif yapılarına ilave edilmesiyle artırıldığını göstermiştir. Karvakrolün antibakteriyel özellikleri ve lanolinin yara iyileştirici özellikleri göz önünde bulundurulduğunda, bu kompozit nanolifli yüzeyler biyomedikal alanda, özellikle de yara örtüsü olarak kullanım için yüksek bir potansiyele sahiptir.

Anahtar Kelimeler: Polivinilpirolidon, karvakrol, lanolin, elektro lif çekim, nanolif.

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1. INTRODUCTION

Nanofibers have superior properties such as small fiber diameter (nm), small and open pores, high porosity, large specific surface area (m^2/g), and high loading capacity. With this high loading properties of nanofibers, different kinds of agents such as drugs, proteins, antibacterial agents, enzymes, and essential oils can be loaded nanofibers in terms of get much more functionally according to their end use application areas [1, 2]. In this study, carvacrol and lanolin were loaded to the biocompatible PVP nanofibers for their antibacterial and wound healing properties.

The main component of *Origanum minutiflorum* (O Schwarz and PH Davis), an endemic thyme species of the Lamiaceae family growing in Isparta/Sütçüler region, is carvacrol [3, 4]. Carvacrol is natural, inexpensive and easy to obtain. Both carvacrol and thyme essential oils have antibacterial, antifungal, odor, and pesticidal properties [5, 6]. In the literature, there are studies in which carvacrol is incorporated in the structure of nanofibers and nanofibers gain antibacterial properties. By using Zein/poly (lactic acid) [7], chitosan/poly(ethylene oxide) [8, 9], gelatin/ poly(vinyl pyrrolidone) (PVP) [10] polymers, and combinations, thyme essential oils loaded antibacterial nanofibers have been produced for different application areas such as food packaging and biomedical. Lanolin, an organic ester derived from sheep fleece after shearing, produces an air-permeable temporary barrier and promotes moist wound healing when applied to damaged skin. Actually, lanolin is a kind of wax formed which is also known as wool yolk, wool wax, or wool grease. It softens and treats dry skin on the lips and nipples. Generally, new mothers, breastfeeding mothers, chemotherapy patients with dry, cracked, and damaged skin, and those with burn wounds use products containing lanolin. Lanolin is commercially available in many medical such as ophthalmic eye drops, burn and wound healing creams, and cosmetic products such as lotions, makeup, sunscreen and shaving creams or gels [11, 12]. Studies on lanolin are quite new and limited in the literature. Akduman et al. [13] developed lanolin loaded cellulose acetate (CA), polyethylene oxide (PEO), polyethylene oxide/chitosan (PEO/chitosan) and thermoplastic polyurethane (TPU) based nanofibers which is used for nursing pads. The research group determined that lanolin loaded nanofibers can be used for nursing pads and CA nanofibrous surfaces could be preferred when better hydrophilicity and swelling are required. Another research group produced and characterized silk fibroin(SF)/poly (caprolactone) (PCL) blend nanofibers with various concentrations of lanolin. They indicated that smooth and fine nanofibers produced for all samples. However, as lanolin increased, the viability rate in the cell decreased. Because of this reason it is a solvent whose name is 1,1,1,3,3,3-hexafluoropropane-2-propanol(HFIP). They suggested that more suitable solvent should be used in terms of cell viability and antibacterial activity [14].

Poly(vinylpyrrolidone) (PVP) is not toxic polymer and environmental friendly [15], synthetic, hydrophilic [16], water-soluble [17], and biocompatible polymer [18]. PVP is chosen as the raw material for this study because of all of these features, which are important in biomedical and cosmetic applications [10, 19]. PVP polymer is widely used in the pharmaceutical industry [20] and biomedical applications [21, 22], such as medicine [23], drug delivery systems [24], wound dressing, tissue engineering [25], and the bioactive packaging industry [26].

Investigations on Carvacrol and Anhydrous Lanolin nanofibers have been published in the literature individually [7, 12, 27]. However, no study has been conducted on PVP/Carvacrol/ Lanolin nanofiber composites in combination. Therefore, the findings of this study are expected to be valuable in the literature.

2. MATERIALS AND METHODS

2.1 Materials

To produce nanofibers, PVP (360.000 g/mol) (Sigma–Aldrich (St. Louis, MO, USA)) was used as a polymer, Carvacrol (Süleyman Demirel University, Natural Products Application and Research Center, with 96 % purity) and Anhydrous Lanolin (Galenic Chemicals, İzmir, Turkey) were used as an additive, deionized water was used as a solvent and Cremophor RH 40 (Ersa Chemistry, İzmir, Turkey) was used as a surfactant.

2.2 Preparation and Characterization of Polymer Solutions

Various concentrations of carvacrol:lanolin added to the PVP polymer solutions (Table 1). According to our preliminary studies, optimum carvacrol:lanolin ratio was determined as 9:1. Then, solution properties such as viscosity, conductivity and surface tension were measured.

2.3 Production and Characterization of Nanofibers

Nanofiber productions were carried out by electrospinning set up under the optimum process parameters (Table 2).

After nanofibers production, characterization studies were achieved. In order to analyze nanofibers morphology, SEM images were taken with different magnifications. ImageJ software was used to measure the diameters of 100 fibers that were taken from different parts of the electrospun nanowebs. and in order to understand fiber diameter distribution, fiber diameter histograms curves were obtained via statistical analysis program. Then, average fiber diameter uniformity coefficient values were calculated using the formulas are given in below:

$$A_n = \frac{\sum n_i d_i}{\sum n_i} \ (number\ average) \quad (1)$$

$$A_w = \frac{\sum n_i d_i^2}{\sum n_i d_i} \ (weight\ average) \quad (2)$$

d_i: *fiber diameter* *ni: fiber number*

Table 1. Sample codes and composition of carvacrol:lanolin loaded PVP polymer solutions

Sample Codes	PVP Concentration (%)	Carvacrol:Lanolin Ratio	Carvacrol:Lanolin Concentration (%)
PVP0	12	9:1	0
PVP2.5	12	9:1	2.5
PVP5	12	9:1	5
PVP7.5	12	9:1	7.5
PVP10	12	9:1	10
PVP12.5	12	9:1	12.5
PVP15	12	9:1	15

Table 2. Process parameters of electrospinning

Voltage (kV)	Distance between electrodes (cm)	Feed Rate (mL/h)	Humidity (%)	Temperature (°C)	Needle Diameter (mm)
17	24.0	0.2	30-35	22-24	0.8

The ratio of A_w/A_n was used to calculate the fiber diameter uniformity coefficient. The closer the average fiber diameter uniformity coefficient value is to 1, the more uniform fibers can obtain [28]. FT-IR spectrums were carried out to understand chemical structure of PVP based nanofibers with Attenuated Total Reflection (ATR) technique between 4000 and 400 $cm^{-1.}$ Thermogravimetric analysis (TGA) was carried out with an Exstar SII TG DTA 7200 to analyze the thermal stability of PVP based nanofibers, polymer form of PVP, Carvacrol, and Anhydrous Lanolin in a nitrogen gas environment by increasing 10°C/min from room temperature to 600 °C. Differentiating Scanning Calorimetry (DSC) analysis was performed using a Perkin Elmer DSC 4000 in order to determine the glass transition, melting and decomposition temperatures, and enthalpies of PVP, lanolin, carvacrol, and nanofibers in a nitrogen gas environment from 24 °C to 600 °C, with a 10 °C/min temperature increase.

3. RESULTS AND DISCUSSION

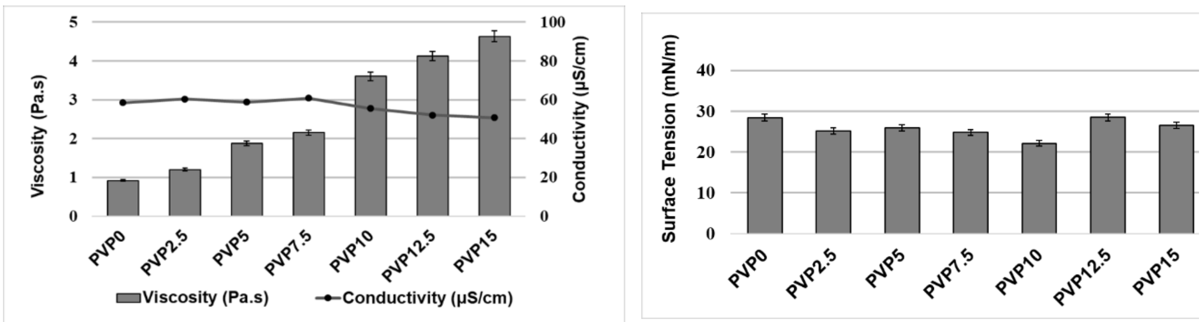
3.1 Solution Properties Results

The properties of polymer solutions, such as viscosity, electrical conductivity, and surface tension, all have an impact on the morphology of electrospun nanofibers. Therefore, within the scope of the study, the polymer solution properties were measured and the results are given in Figure 1.

According to Figure 1; viscosity increases and conductivity decreases while carvacrol:lanolin concentration increases. However, surface tension was not affected from carvacrol:lanolin concentration.

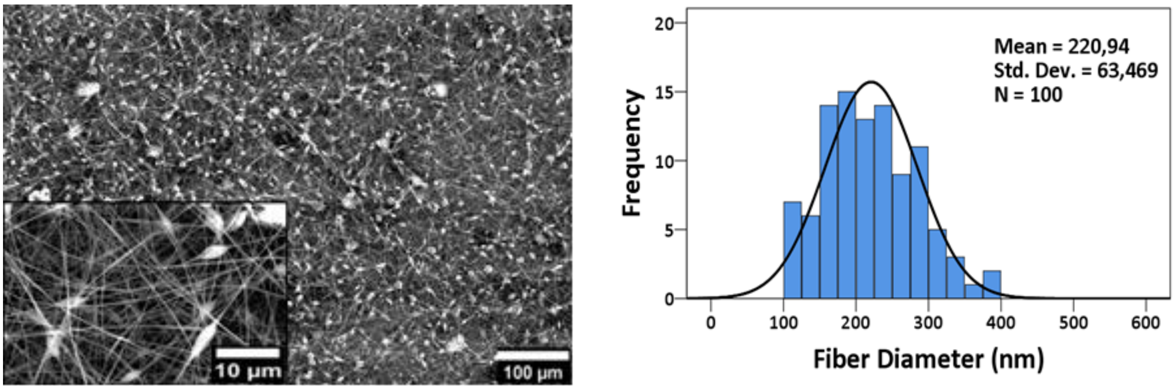
3.2 Fiber Morphology Results

SEM images of various concentrations of carvacrol:lanolin nanofibers are given in Figure 2.

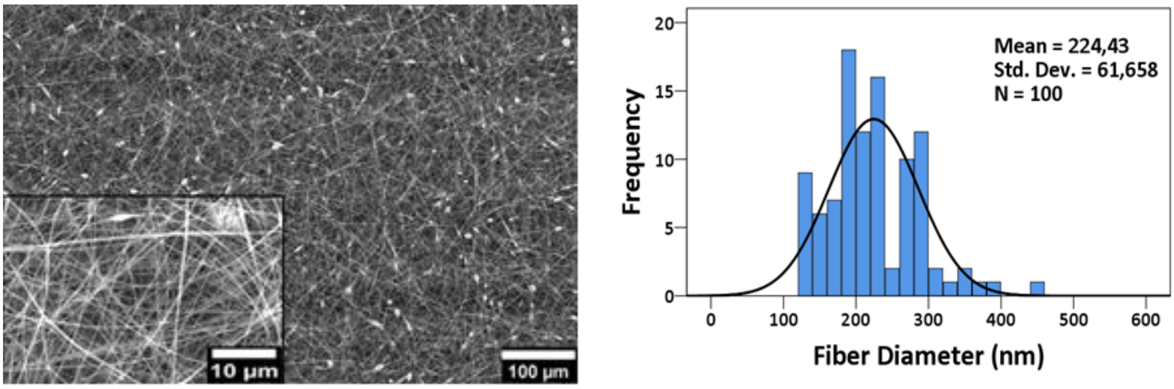


(a) (b)

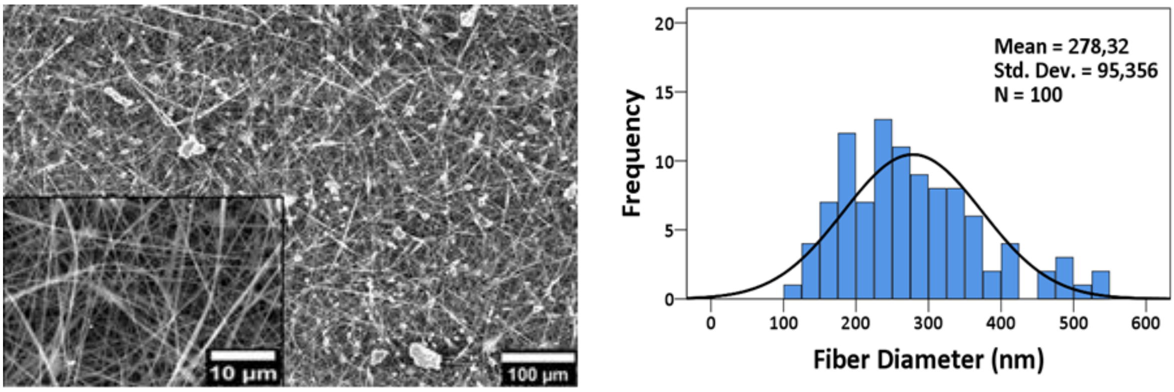
Figure 1. Solution properties results (a) viscosity and conductivity (b) surface tension



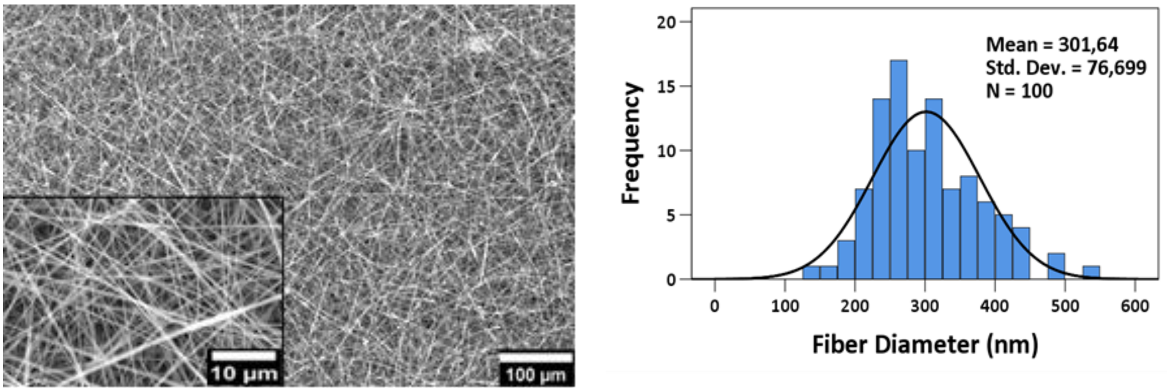
PVP0



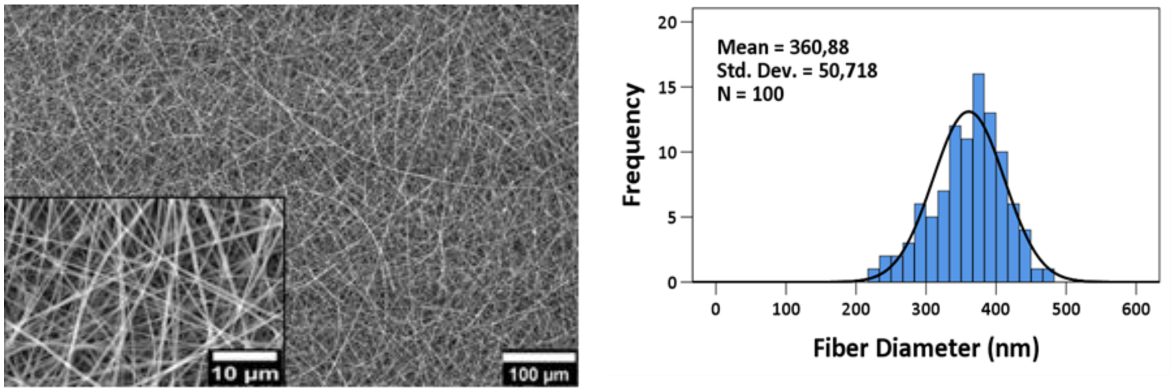
PVP2.5



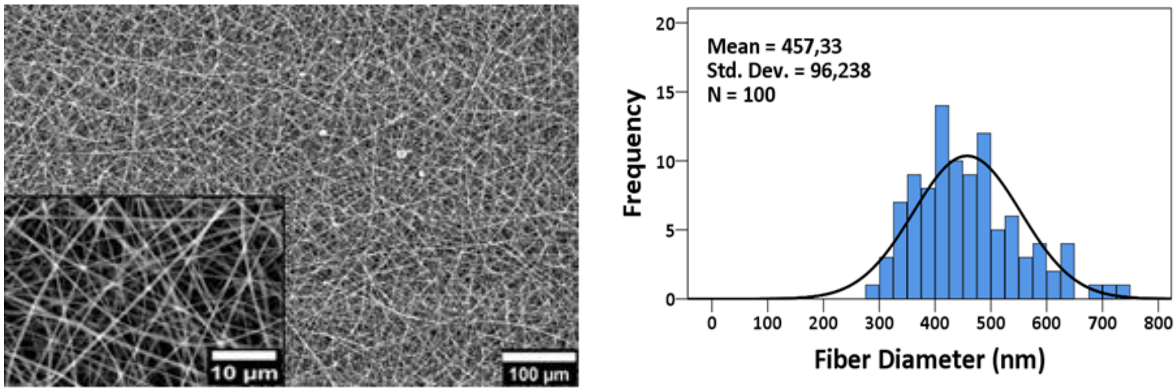
PVP5



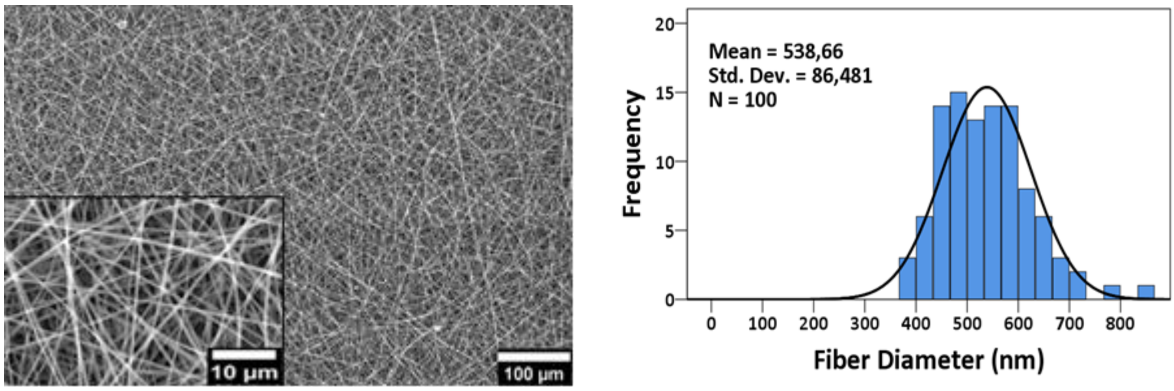
PVP7.5



PVP10



PVP12.5



PVP15

Figure 2. SEM images of PVP nanofibers with various concentrations of carvacrol:lanolin

It has been seen clearly that nanofiber morphology improved with carvacrol:lanolin concentrations. There are some bead defects in the nanoweb structure for concentrations of 0, 2.5, and 5 wt. % of carvacrol: lanolin. However, after these concentrations, nanoweb quality changed significantly. It is possible to say that nanofibers are quite fine, smooth and uniform for 7.5, 10, 12.5 and 15 wt % carvacrol:lanolin concentrations. Due to the fact that the interaction between macromolecules increased as solution viscosity increased, fiber spinning performance increased while beads decreased. Viscosity is known to influence the interaction between macromolecules [29]. In electrospinning, it is well known that higher viscosity and lower conductivity result in less stretching of the jet, therefore producing thicker nanofibers [1].

When the histograms are analyzed, it can be said that all samples have a single peaked and unimodal distribution. Average fiber diameter and fiber diameter uniformity coefficient graph is given in Figure 3.

According to Figure 3, it was determined that average fiber diameter increased and fiber diameter uniformity coefficient did not affect carvacrol:lanolin concentration. According to the viscosity results; it is expected that average fiber diameter increased from 220 (PVP0) to 538 (PVP15) nm with lanolin carvacrol concentrations. With 1.02, the most uniform nanofibers were obtained in the PVP10 sample. However, it is possible to say that the bead-free samples such as PVP7.5, PVP10, PVP12.5, and PVP15 are all uniform. As a nanofiber morphology results; it is possible to say that PVP10 were selected as the optimum sample in order to average fiber diameter, fiber diameter distribution, fiber uniformity and fiber morphology.

FT-IR spectrums of PVP, lanolin (LAN), carvacrol (CAR), and PVP10 nanofibers are given in Figure 4.

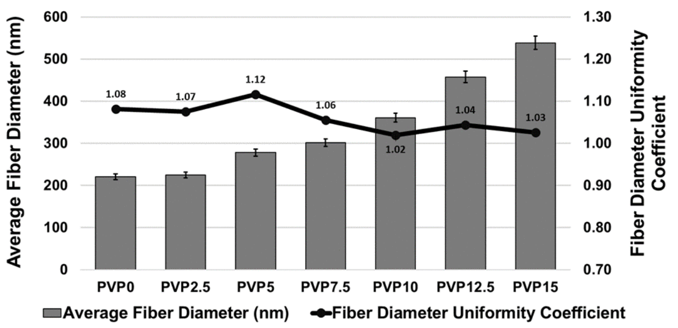


Figure 3. Average fiber diameter and fiber diameter uniformity coefficient of PVP nanofibers produced with various concentrations of carvacrol:lanolin

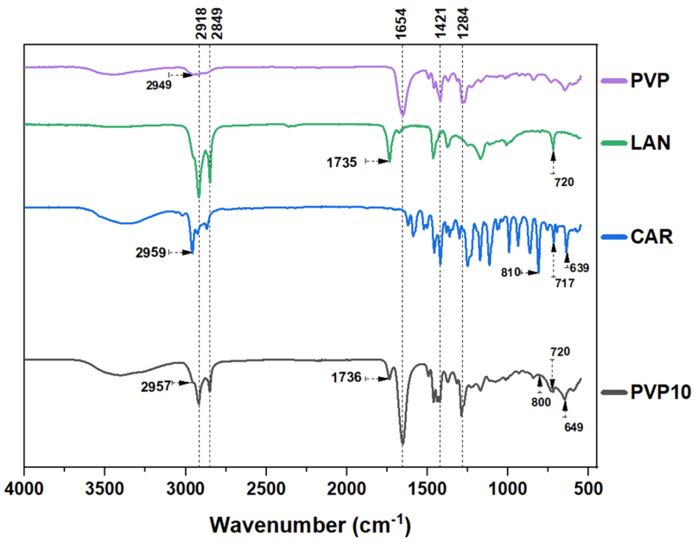


Figure 4. FT-IR spectra of PVP, LAN, CAR, and PVP10 nanofibers

FT-IR spectrums demonstrated that all characteristic peaks of PVP, lanolin and carvacrol arise in the spectra of the PVP10 nanofibers. This means, there were not undesirable reactions while preparing polymer solutions. In detail, there is a sharp peak at 3434 cm^{-1} in the spectra of PVP. The O-H peak can be attributed to the presence of water. The peak is determined at 3403 cm^{-1} in the PVP10 spectra with an increase of intensity. Because, at this wavelength, carvacrol also has a wide peak. Since these two peaks overlapped in the PVP10 sample, the intensity of the peak increased. Another strong peak at 1654 cm^{-1} identified the existence of heteroatomic molecules and carbonyl groups in the pyrrolidone ring of PVP as a sign of C=O stretching. The peak arises at the same wavelength in the spectra of PVP10 [26, 30, 31]. The most intense peak in the spectrum of carvacrol occurred at 811 cm^{-1} (C–H wagging vibrations). This peak also appears at 800 cm^{-1} in the spectra of PVP10. Additional peaks in the carvacrol spectrum at 639 cm^{-1} (C=C) and this peak also arise 649 cm^{-1} in the spectra of PVP10 [32, 33]. There are two characteristic absorption peaks at 2918 cm^{-1} and 2849 cm^{-1} could be attributed to $–CH_2–$ and $–CH_3$. Another characteristic two peaks are at 1735 cm^{-1} and 720 cm^{-1} namely cis-CH=CH and carbonyl compounds [34, 35]. All of these characteristic peaks also appeared in spectra of PVP10 nanofibers.

TGA thermograms of PVP based nanofibers, PVP polymer, Carvacrol, and Lanolin are given in Figure 5.

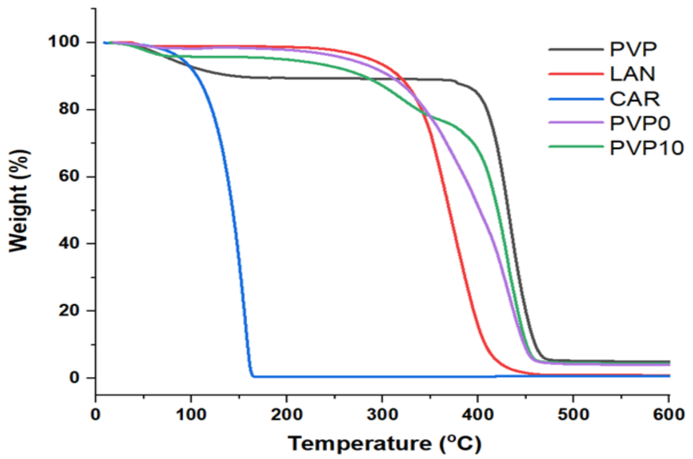


Figure 5. FT-IR spectra of PVP, LAN, CAR, and PVP based nanofibers

Carvacrol, known to be a volatile constituent, degraded between 44.43 and 164.52 degrees Celsius and left no residue, as expected. Anhydrous Lanolin, which is highly hydrophobic, undergoes almost no mass reduction up to 100 degrees Celsius. Lanolin, which started degradation at 231.72 degrees Celsius, completed degradation at 464.10 degrees Celsius and left a very small residue of 1.25%. PVP in polymer form lost 11.52% mass up to 100°C due to its hydrophilic structure, degraded between 354.6°C and 478.1°C and left 5.72% residue after degradation. When the thermograms of the nanofibers were examined, it was determined that the PVP0 coded nanofibers showed a thermal behavior similar to the PVP polymer in polymer form but degraded at lower temperatures (212-465 degrees) due to the rapid mass transfer due to the nanoscale fiber structure. The thermogram of carvacrol/lanolin-loaded and PVP-based nanofibers (PVP10) shows a two-step degradation. This is thought to be due to the fact that the starting temperatures of lanolin and PVP polymers are quite different from each other. While the first step degradation due to lanolin occurred between 204.74 and 377.43 degrees, the second step degradation due to PVP polymer occurred between 385.87 and 464.44 degrees. Both PVP0 and PVP10 coded nanofiber samples left 4.80% and 5.06% residue, respectively, similar to PVP in polymer form. In general, carvacrol and lanolin, which have very poor thermal stability, were incorporated into the structure of PVP nanofibers to increase their thermal stability.

DSC analysis of PVP polymer, Lanolin and PVP based nanofibers are shown in Figure 6.

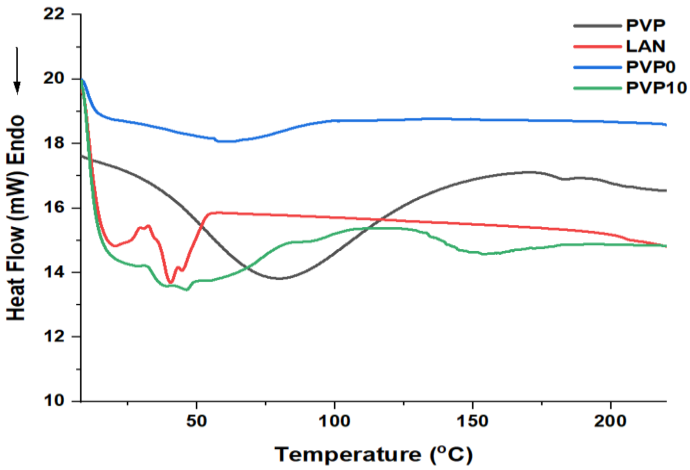


Figure 6. DSC thermograms of PVP, LAN and PVP based nanofibers

The thermal properties of PVP polymer, Lanolin, and PVP-based nanofibers were measured by DSC. Due to how volatile Carvcarol is, DSC measurements were unable to be performed effectively. According to the DSC thermograms in Figure 6, the PVP polymer did not exhibit any fusion peaks or phase transitions, similar to previous literature studies. Besides a wide endotherm brought on by dehydration, which takes place between 70 and 120 °C [36]. When the thermogram of PVP0 nanofibers was examined, it was observed that the endothermic peak width of the PVP0 nanofibers decreased compared to the thermogram of the PVP polymer. Additionally, in both nanofibers, the PVP polymer peak appeared at lower temperatures. This is assumed to be caused by a change in the chain structure of PVP polymers during the production of nanofibers. An exothermic peak was seen in the Anhydrous Lanolin thermogram between 25 and 35 °C, while an endothermic peak was seen between 45-50 °C [37]. According to the amount of lanolin it contains, as expected, the DSC thermogram of the lanolin-loaded PVP10 nanofibers was similar to the lanolin thermogram. But there was a slight increase in the degradation temperatures. The reason for this is that PVP nanofibers improve the low temperature stability of lanolin.

4. CONCLUSION

In this work, it is achieved to produce and characterize PVP based carvacrol and lanolin loaded composite nanofibers successfully. Pure PVP solution based nanofibers had a lot of bead defects but nanofibrous web quality was improved with addition of carvacrol:lanolin to the PVP polymer solutions with same PVP concentration. In this way, very smooth, fine, homogeneous, and uniform fibers were obtained without increasing the polymer concentration and without increasing the average fiber diameter prominently. In addition, the chemical structure of the nanowebs was investigated by FT-IR analysis. No undesirable reaction occurred between the components during the preparation of the polymer solution including many components, and all the components in the polymer solution in the produced nanowebs were chemically determined. In DSC and TGA analysis, it was determined that the thermal stability of carvacrol and lanolin increased with the inclusion of PVP nanofibers. Considering the properties of carvacrol and lanolin in the content of biocompatible nanofiber surfaces, it is thought that there is a potential for use in the medical application areas especially as a wound dressing.

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Araştırma Makalesi / Research Article

SMART TEXTILE pH SENSOR BASED ON CURCUMIN MICROCAPSULES

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ABSTRACT: In this study, pH-sensitive textile systems are developed for use in detecting alkaline media variations. The product is designed based on the surface functionalization of cotton fabric by semi-porous microcapsules containing curcumin. The capsules synthesized by interfacial polymerization from MDI and xylitol serve as micro-reactors where a modification of the chemical form of curcumin takes place, allowing observation of a change of color. This change of color is linked to the acidity constant of this molecule. The objective is also to correlate the visual observation to an evaluation of the color code via image capture by a smartphone of the textile structure and simplified processing of the image color. The analyses have shown that the product obtained is well-sensitive to pH variations and easy to use.

Keywords: Curcumin, microencapsulation, chemical grafting, smart textile, pH sensor

ZERDEÇAL MİKROKAPSÜL ESASLI AKILLI TEKSTİL pH SENSÖRÜ

ÖZ: Bu çalışmada, alkali ortam değişimlerinin tespitinde kullanılmak üzere pH'a duyarlı tekstil sistemleri geliştirilmiştir. Bu ürün ile pamuklu kumaşın yüzeyi zerdeçal içeren yarı gözenekli mikrokapsüller ile fonksiyonelleştirilmiştir. MDI ve ksilitolden ara yüzey polimerizasyonuyla sentezlenen kapsüller, zerdeçalın kimyasal formunun modifikasyonunun gerçekleştiği mikro reaktörler olarak hizmet ederek renk değişiminin gözlemlenmesine olanak tanımıştır. Bu renk değişimi, molekülün asitlik sabiti ile bağlantılıdır. Çalışmada tekstil yapısının bir akıllı telefon yardımıyla görüntülenmesi ve görüntü renginin basitleştirilmiş bir şekilde işlenmesiyle renk kodunun değerlendirilmesi de amaçlanmıştır. Analizler, elde edilen ürünün pH değişimlerine karşı oldukça duyarlı ve kullanımının kolay olduğunu göstermiştir.

Anahtar Kelimeler: Zerdeçal, mikrokapsülasyon, kimyasal aşılama, akıllı tekstil, pH sensörü

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1. INTRODUCTION

pH tests are commonly used in chemistry laboratories to measure the acidity or alkalinity levels of solutions. There are various technologies for measuring pH values, but the most accurate pH measurements can be obtained with a pH meter. For these reasons, many researchers have begun to look for new methods to determine pH values. With the help of computer technology, many processes can be simplified and performed in a shorter time. Today, digital image processing and analysis methods have gained popularity in these applications [1, 2].

The most common and convenient way to use pH paper is to measure acidity, basicity and pH concentration by changing the color. A pH paper is a paper made by infiltrating an indicator into a filter paper with a color change occurring as a result of the reaction depending on the hydrogen ion concentration of the solution. The pH of the solution can be determined by observing the color change and comparing it to the standard discoloration table. This method has the following advantages: simple and fast measurement Colorimetric indicators such as pH sensitive dyes provide visual information. The pH value is an important parameter in many circumstances and therefore a halochromic textile could be used for various applications [3]. In this context, the textile structure can also be used to detect the pH of an environment [4].

Curcumin (1,7-bis(4-hydroxy-3-methoxyphenyl)-1,6-heptadiene-3,5-dione) is a bioactive component and a low molecular weight polyphenol of turmeric (*Curcuma longa L.)* which is widely used as a food colorant [5]. Curcumin has a yellow color, and the chemical structure presents two o-methoxy phenols attached symmetrically through α, β-unsaturated β-diketone linker, which also induces keto-enol tautomerism [6]. This compound is practically insoluble in water at acidic and neutral pH, and this stability is attributed to its conjugated diene structure. Furthermore, curcumin has three ionizable protons, one from the enolic proton and the two last from the two phenolic OH groups. The pKa values for dissociating the three acid protons have been estimated from 7.7 to 8.5, 8.5 to 10.4, and 9.5 to 10.7, respectively [7]. Thus, when the pH increases to neutral-basic conditions, a proton is removed from the enolic form and afterward from the phenolic group leading to the destabilization of the structure. Even if the solubility can be enhanced under alkaline conditions resulting in a color change of the chromophore groups to deep red, the pH modification caries to the instability and the destruction of this structure [8].

This paper studies the conventional finishing method to as possible approaches to obtain textile pH-sensors. Since curcumin can interact with the environment, it is necessary to protect it with a semi-porous polymeric membrane allowing the diffusion of the liquid into the core of the capsule to modify its chemical form, while ensuring the reversibility of the effect [9]. In addition, the chemical grafting method of the microcapsules was preferred to ensure the permeation of the membrane. The objective of this study is to investigate the influence of the rate of microcapsules required for pH detection, and to couple the visual measurement with simple image processing from capturing the functionalized media with a smartphone to edit the color code, as a simple alternative approach to determine pH values of different, was investigated.

2. MATERIAL AND METHOD

2.1 Reagents and Materials

1,7-Bis(4-hydroxy-3-methoxyphenyl)-1,6-heptadiene-3,5-dione (curcumin) was purchased from Aldrich (France) and used as core material. Diphenyl methylene diisocyanate (MDI) (Suprasec 2030, Hüntsman ICI), and xylitol (Roquette Frères, content >99%) ($C_5H_{12}O_5$), a polyhydric alcohol, were employed as shell-forming monomers for the interfacial polycondensation. Ethyl acetate (EtAc) (Fluka, France) and acetone (Merville, France) were used as solvents. Nonionic surfactant, Tween® 20 (Polyethylene glycol sorbitan monolaurate) was purchased from Aldrich and used as emulsifier. Sodium Dodecyl Sulfate (SDS) purchased from Aldrich (France) was used as surfactant. A 100% cotton twill fabric (TDV Industries, France) (296 g/m^2, air permeabilty 156 $L/m^2/s$, thickness 0.67 mm) was used as textile substrate.

2.2 Preparation of Curcumin Microcapsules

Curcumin microparticles were prepared by emulsion–diffusion technique, which is divided in four steps, i.e. mutual saturation, emulsification, diffusion and purification [10]. First, continuous (distilled water) and dispersed (ethyl acetate, EtAc) phases (2:1 v/v) were mutually saturated for 24 h to ensure thermodynamical equilibrium. The obtained solutions, aqueous and organic phases, contain 8.7% w/v of EtAc and 3% of water, respectively. Second, for the emulsification step, 0.5 g of curcumin and 2.9 g of MDI were dissolved in 30 ml of a binary mixture of acetone/ethyl acetate (1/2 v/v) saturated with water, and then this phase was emulsified with 60 ml of the aqueous phase containing 1.5 wt.% of Tween 20 at 4 °C, with the use of a high-speed homogenizer (Ultra-Turrax® T25 basic, Germany) at 6500 rpm during 50 min. After 25 min, when the expected droplet size of the emulsion was reached, the polymerization reaction was carried out by drop-wise addition of 10 ml of aqueous solution containing xylitol. The xylitol concentration was adjusted to obtain an NCO/OH mole ratio about 0.28, 0.138, 0.092, 0.069 and 0.0555. Third, to induce the formation of polymeric shell, the solution was transferred into a double walled four-necked vessel, the microparticles were maintained in suspension under a stirring speed of 500 rpm for 3 h. A large quantity of distilled water was subsequently added to the microemulsion inducing the diffusion of EtAc from the inner to the outer phase for the microsuspension. A volume equal to twice the volume of the emulsion was used for dilution. Finally, the resultant microparticles were recovered by filtration and washed twice with water, and then dried at 50 °C overnight, before being redispersed in water for further uses.

2.3 Preparation of Textile Based Curcumin Microparticles

In order to obtain the textile-based curcumin microparticles, microcapsules were applied to the surface of the fabric by bath exhaustion with a liquor ratio about 1:20, during one hour at 70°C before being dried in an oven at 130°C for 3 minutes. The solutions were prepared with different concentration of the microencapsulated curcumin, 60 g/L of Mikracat B and 10g/L of Mikrafix (obtained from Devan Chemicals, Belgium).

2.4 Characterization

2.4.1 Infrared spectra analyses

The chemical structure of the samples was analysed by infrared spectra in an absorbance mode, and recorded using Nicolet Nexus, connected to a PC, in which the number of scans was 256 and the resolution was 0.5 cm^{-1}. Samples were ground and mixed with KBr to make pellets. To put an interpretation on a more quantitative basis, we performed the de-convolution of the spectra using peakfit 4.0 software (Jandel, San Rafael, CA) in the 1575 - 1800 cm^{-1} region into Gaussian peaks. These wavenumbers were used as initial parameters for curve fitting with Gaussian component peaks. Position, bandwidths, and amplitudes of the peaks were varied until: (i) the resulting bands shifted by no more than 4 cm^{-1} from the initial parameters, (ii) all the peaks had reasonable half-widths (< 20-25 cm^{-1}), and (iii) good agreement between the calculated sum of all components and the experimental spectra was achieved ($r^2 > 0.99$). The results of four independent experiments were averaged.

2.4.2 Morphology of the particles

The microscopic aspects of the particles were observed by scanning electron microscopy (SEM) (Philips XL30 ESEM/EDAX – SAPPHIRE).

2.4.3 Thermal stability of the particles

The thermogravimetric analysis (TGA) was carried out using a TA Instrument TGA2950 apparatus under an inert atmosphere at a 50 ml/min purge rate. The heating rate of 10°C/min was used from 25 to 700 °C. For each experiment, approximately a 10.0 mg sample was used in the TGA test. TGA experiments were used to evaluate the thermal stability of the microcapsules shell, and they can also provide indirect information on shell structure and encapsulation yield.

2.4.4 pH Response of fabric sample

Functionalized textile fabrics were cut into squares (5 cm × 5 cm) and introduced into individual buffered solutions (20 mL, pH = 4, 5, 6, 7, 8, 9, 10, and 11) for 5 minutes, then removed with tweezers. The color changes of the textile-based pH sensors were captured and extracted using a spectrophotometer, Datacolor International SF 600 plus, interfaced with a personal computer. 10 detections were performed for each sample. A photographic image was captured using a smartphone camera at a distance of 10 cm from a designated angle. Because the color from a sensor is influenced by the angle owing to the nature of diffraction, the initial angle was fixed at 90°. Image treatment was realized to extracted in a simple way the values of Red, Blue and Green. The data obtained from these two ways were transformed to Y-greyscale values for comparison (greyscale=0.299*R + 0.587*G + 0.114 *B) [2].

3. RESULTS AND DISCUSSION

3.1 Formation and structure of the microparticles

Curcuminoids are readily soluble in polar organic solvents, but are sparingly soluble in water or hydrocarbons. Curcumin's 1,3-diketone group has keto-enol tautomerism, and thus exists in the tautomeric keto and enol forms. The keto form predominates in curcumin crystals or in acidic and neutral solutions, while the keto-enol form is exclusively present under alkaline conditions. Under acidic and neutral conditions, curcumin was relatively stable, with no change in color. Under alkaline conditions, the color changes from yellow to orange-brown. At pH 2-7, curcumin was stable and yellow in color, while at pH 8-13, it turned orange-brown. Consequently, as water solubility increases under alkaline conditions, this compound must be protected before use.

Curcumin microencapsulation was achieved by an emulsion solvent diffusion process, in which shell formation was promoted by the interfacial polycondensation of diisocyanate and xylitol (Figure 1). The process used was based on several consecutive steps, namely (i) the formation of a stable emulsion governing droplet size, (ii) a dilution step to induce ethyl acetate diffusion from the inner core of the droplet to the continuous governed by thermodynamic equilibrium, (iii) the interfacial reaction of the two monomers to promote polymeric shell formation. Diffusion of ethyl acetate changes the solvency of the reaction medium, of a solid shell entrapping curcumin.

The choice of solvents to form curcumin-containing microparticles was based on the physicochemical characteristics of curcumin and the polymeric shell to ensure emulsion establishment, followed by precipitation/formation of the polymeric shell at the interface. Shell formation during polycondensation requires precipitation of the oligomers initially formed to cover the droplets by modifying the solvency of the medium [11]. As the growth of this shell is achieved by the diffusion of one of the monomers through it, the formulation of the dispersed phase plays an important role. Based on the determination of the solubility parameters of curcumin (δ_d=17.4, δ_p=6.0 and δ_h=10.9 $MPa^{½}$) [12], acetone (δ_d=15.5, δ_p=10. 4 and δ_h=6.9 $MPa^{½}$) and ethyl acetate (δ_d=15.8, δ_p=5.3 and δ_h=7.2 $MPa^{½}$) were chosen as suitable solvents, and MDI as the fat-soluble monomer. Acetone is more polar than ethyl acetate, and the interactions of these solvents with water can be considered similar.

Dropwise, the addition of xylitol leads to the formation of insoluble oligomers in the droplets, which diffuse to the organic side of the interface to form a primary shell around the droplets. Membrane growth is based on further cross-linking reactions by monomer diffusion. Nevertheless, shell thickness increases slowly due to the restricted diffusion of starting monomers, inducing layer morphology and roughness changes. Capsule porosity increases with polymer precipitation at the interface and diffusion of solvent molecules through the wall. Solid membrane formation is linked to precipitation of the polymers formed due to non-solubility in the selected solvent media (polyurethane (δ_d=20.5, δ_p=6.4 and δ_h=13.0 MPa^{½})).

The chemical reactions during membrane formation are illustrated in Figure 2. MDI monomers are slowly hydrolyzed on the organic side of the interface to form an unstable amino acid group, which dissociates into an amine end group and carbon dioxide. This reaction is initiated by the diffusion of water molecules through the polymer shell network. The formation and release of CO_2 contribute to an increase in particle porosity. In the second reaction, the amine end group reacts with the isocyanate end group to form a urea bond. In the third reaction, the diisocyanate or isocyanate end groups react with the hydroxyl groups of xylitol to form a urethane bond. Other secondary reactions are likely to occur during this step, forming an allophanate or biuret bridging the macromolecular chains.

An example of the FTIR absorption spectrum of the microcapsules is presented in Figure 3 (a), and the absence of a typical stretching absorption band at 2270 cm^{-1}, and the presence of the C O vibration between 1770 and 1600 cm^{-1} reveal that −NCO groups have reacted completely with the -OH group of xylitol. The absorption peaks corresponding to poly(urea-urethane) shell can be observed at around 3300 cm^{-1} (-OH and -NH stretching vibration), between 2920 and 2870 cm^{-1} for the C–H asymmetrical and symmetrical stretchings due to the methyl and methylene groups. C-O-C stretching at 1110 cm^{-1} and =C-H bending at 820 cm^{-1} are also present. N-H bending and C-N stretching at 1540 and 1236 cm^{-1} are also observed. The 1600, 1410, and 820 cm^{-1} peaks are assigned to the C=C stretching, C-C stretching, and C-H bending in aromatic groups, respectively. Since curcumin has many chemical similarities with the polymeric shell, confirmation of its entrapment can be confirmed by the presence of two thin shoulders at 1630 and 1280 cm^{-1}, assigned to the enol carbonyl stretching vibration and the C-O stretching, respectively. The C-O stretching is also present at 1160 cm^{-1} and 1031 cm^{-1}.

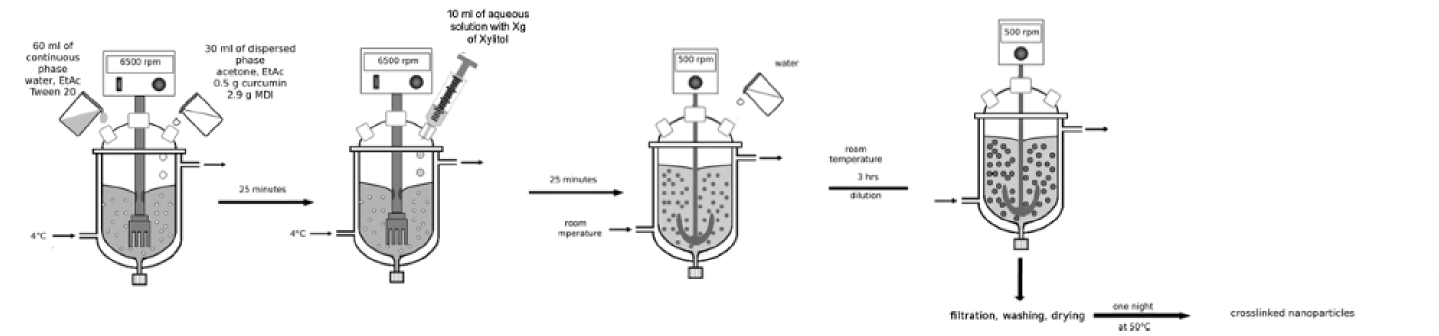

Figure 1. Schematic representation of the various stages of the microencapsulation process by the emulsion solvent diffusion method

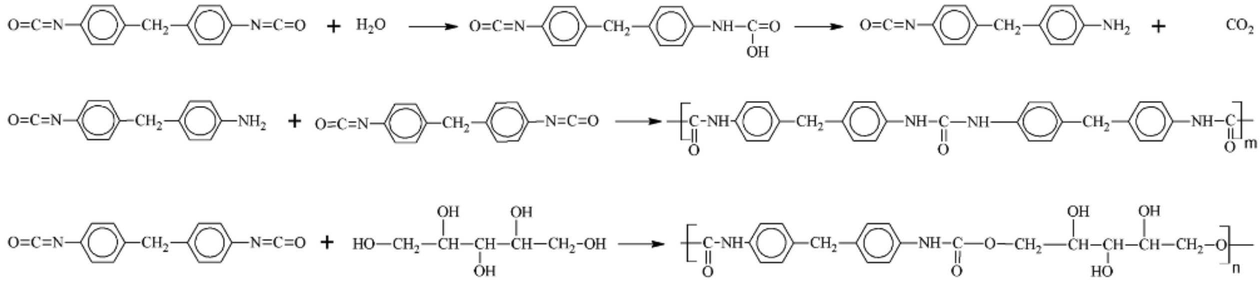

Figure 2. Chemical reactions leading to the formation of the microcapsule shell

3.2 Influence of the NCO/OH ratio on the structure of the microparticles

During shell formation, xylitol diffuses into the dispersed phase to react with MDI. Both the di-isocyanate and the amino oligomer formed are fat-soluble, which affects the course of polycondensation due to specific changes in phase composition. Formation of the swelling primary shell facilitates diffusion of xylitol and water molecules at the interface. It favors urea and urethane bonding, illustrated by the presence in the carbonyl region of a relatively sharp peak with a maximum at 1640 cm^{-1} and a thin shoulder at 1730 cm^{-1}, corresponding to C=O stretching of the free and bonded urea and urethane groups, respectively.

The formation of tinier particles during emulsification coupled with the diffusion of ethyl acetate leads to an increase in the surface area of the dispersed phase, favoring the hydrolysis of the isocyanate group at the interface and thus the formation of urea bonds to the detriment of urethane bonds. The formation of these oligomers at the interface contributes to an increase in interface viscosity, which delays the diffusion of xylitol molecules through the shell, and therefore the formation of urethane bonds decreases as NCO/OH ratio (Figure 3).

The microencapsulation process and the NCO/OH ratio influence the particle size and their morphology (Figure 4). A high NCO/OH ratio leads to the formation of nanoparticles due to the spontaneous emulsion, allowing them to maintain the spherical shape during the first step of the polymerization course. The excess of xylitol promotes aggregation of the tiny particles, which collapse together to form irregular, rough microparticles. A slight decrease of xylitol limits the aggregation. The increase of xylitol induces changes in the formed particles' shape. The formation of more hydrophilic oligomers increases in the particle-to-particle interaction, which leads to the formation of aggregated submicronic particles to form irregular microparticles from 10 to 50 µm due to the macromolecular chain entanglements during the various steps of the process. Only at low ratios are spherical particles obtained. They have a rough surface, but closer examination revealed that the particles with broken membranes were hollow. This is due to the rapid polycondensation between the diisocyanate monomers and the small number of hydroxide functions, coupled with the diffusion of organic solvents in the aqueous medium.

The effect of the NCO/OH ratio on the thermal stability of the microparticles was also investigated. The TG curves of all samples have similar shapes. Degradation of the polyurea-urethane shell occurs in two consecutive stages, i.e. (i) from 200 to 340°C, linked to depolymerization of polyurethane units and oligomers leading to the formation of units cross-linked with urea groups; and (ii) from 340 to 700°C, there is initially recombination of urea oligomers up to 440°C and their degradation in a subsequent stage. The temperature corresponding to a 5% weight loss is the initial sample degradation temperature. The weight loss during the two degradation stages and the temperature at which degradation begins are correlated with the quantities of urethane and urea in the polymeric shell. Thus, the thermal stability of microparticles decreases with increasing urethane groups.

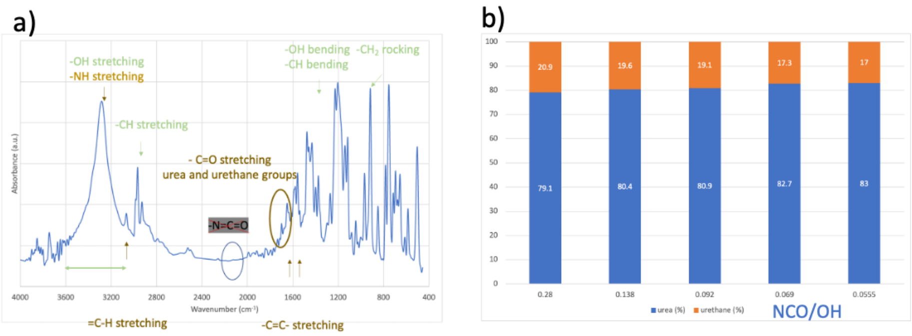

Figure 3. FTIR spectrum of curcumin microcapsules (NCO/OH=0.069) (a), and quantitative analysis of the urea–urethane region of FTIR spectra by peak deconvolution (b)

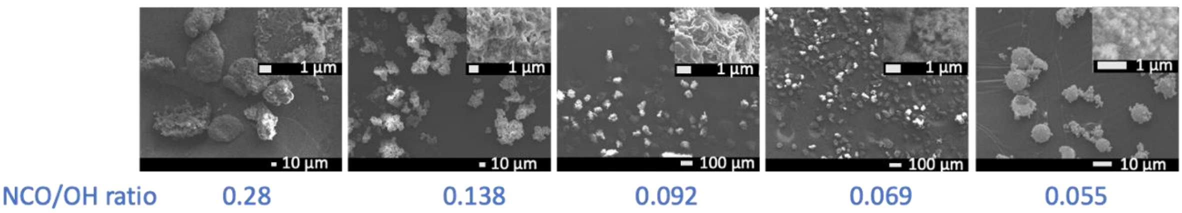

Figure 4. Influence of the NCO/OH ratio on the particles size and morphology.

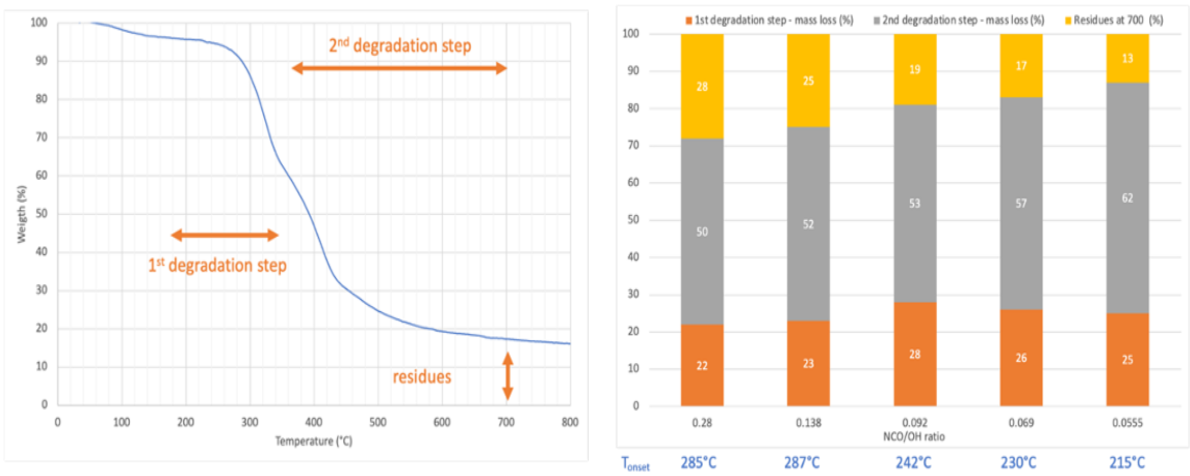

Figure 5. TG curve of microcapsule sample with an NCO/OH ratio of about 0.092 (left), and thermal stability data for different formulations (right).

The NCO/OH ratio when formulating the microparticle membrane influences the chemical structure of the membrane, with a modification of the urea and urethane functions. The number of hydroxyl functions modifies the polymerization kinetics, leading to different morphologies and hollow particles in the least favourable case. The thermal stability of the microparticles means they can be functionalized on textile substrates. Based on these results, an NCO/OH ratio of 0.092 was chosen for the rest of the study.

3.3 pH sensitive textile fabrics

3.3.1 Characteristics of pH sensor fabric at different pH values

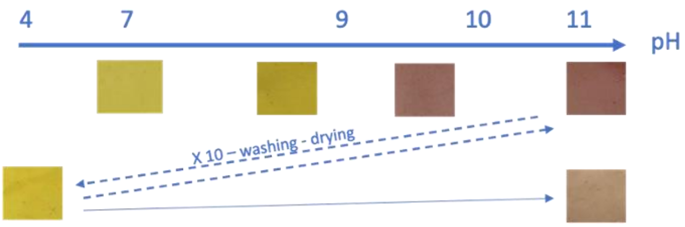

Figure 6. Color changes of test zones for the first test, and after 10 repetitions of pH tests and wash/dry cycles.

The pH dependence of the fabric-based microencapsulated curcumin was investigated by changing the pH of the solution from 4 to 11. Due to the porosity of the particle shell, the microcapsules act as a micro-reactor, allowing the diffusion of the aqueous solution in the inner core of the particles to react with curcumin molecules. At pH between 4 and 7, curcumin acts as a H-atom donor due to its keto form. From pH 8, curcumin acts as an electron donor since its enolate form predominates. Thus, a color change was observed from yellow to darker yellow until red at pH 9 and brown at pH 10 (Figure 6). All these color changes are also related to the pKa values: pKa_1 = 7.7-8.5, pKa_2 = 8.5-10.4, and pKa_3 = 9.5-10.7. After 10 repetitions of pH tests (from 4 to 11) and wash/dry cycles, the samples have the same initial color at low pH and a slight change at higher pH. The slight divergence underlines the stability of the pH-sensitive fabric's color change, with little degradation probably due to a hydrolysis reaction.

3.3.2 Influence of the amount of microcapsules on pH sensor fabric at pH = 7

The influence of the content of deposited microcapsules onto the textile fabric was studied to determine the most suitable amount for pH detection. The color of the samples at neutral pH (7.0) was used as a set point to establish the parameters for total variation in the fabric's color. The measured values of ⊗E do not allow us to distinguish between all the treated samples subjected to a neutral environment. All the calculated values range between 28 and 35 without being correlated to the microcapsule content. The samples became drastically darker (values of CIE L* are lower), less green (value of CIE a* increased), and no slight change was observed for the yellow since the values of CIE b* were positive and in the same range. The content of microparticles slightly influences the color of the textile support; the more microparticles there are, the more yellow predominates, and this in a uniform way on the surface of the samples at neutral pH. Figure 7 shows the RGB ratio according to the microcapsule concentration. The ratio of R is relatively high and reaches 40% from 3 wt.%, and the ratios of G and B do not vary much. Nevertheless, it was observed that the standard deviation decreased when the microcapsule content increased due to a better homogeneity of the finishing treatment. Thus, considering the reproducibility of the color change and the color homogeneity, surface treatment required 4 wt.% of microcapsules.

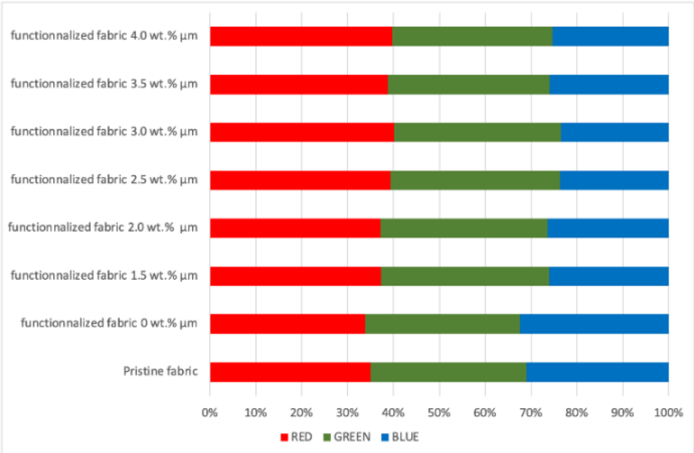

Figure 7. Influence of the amount of microcapsules at pH=7 on the RED, Blue and Green color ratio in the RGB space.

3.3.3 Characteristics of pH sensor fabric at different pH values

The pH-sensitive color change of the textile samples with 4 wt.% of microcapsules was also analytically assessed by analyzing the ⊗E values of the Datacolor spectrophotometer. The response of treated fabric to different pH solutions was examined for a functionalized fabric without microcapsules (i.e., control sample). The ⊗E values vary from 25 to 37, but only the L* value is correlated to the pH (R^2=0.88). The ratio of RGB was used to observe the color change. Until pH 6, no modification was observed; when the pH of the solution reached the pKa_1 of the curcumin, the ratio of B was increased, and the ratio of G was decreased. The ratio of R decreased only for pH close to the pKa_2 of curcumin, and the ratio of B was higher for pH in the range of pKa_3. Thus, it confirms the possibility of using the ratio of RGB to monitor color change versus the pH.

The changes in pH can be displayed visually in the numerical pH values with grey values data. This has the advantages of understanding the information intuitively and accessing it in a user-friendly way. Therefore, data will be readily understood, and trends will be identified easily (Figure 9). Through this method, a regression equation with a similar tendency to the original data was obtained from the two measurement ways, and the most appropriate formula was detected by comparing values of the coefficient of determination (R^2). The results show that both methods are correlated, and the data can be divided into three main ranges, i.e., (i) pH 4 to 6, (ii) pH 6 to 9, and (iii) pH higher than 9. Each inflection point corresponds to the pKa range.

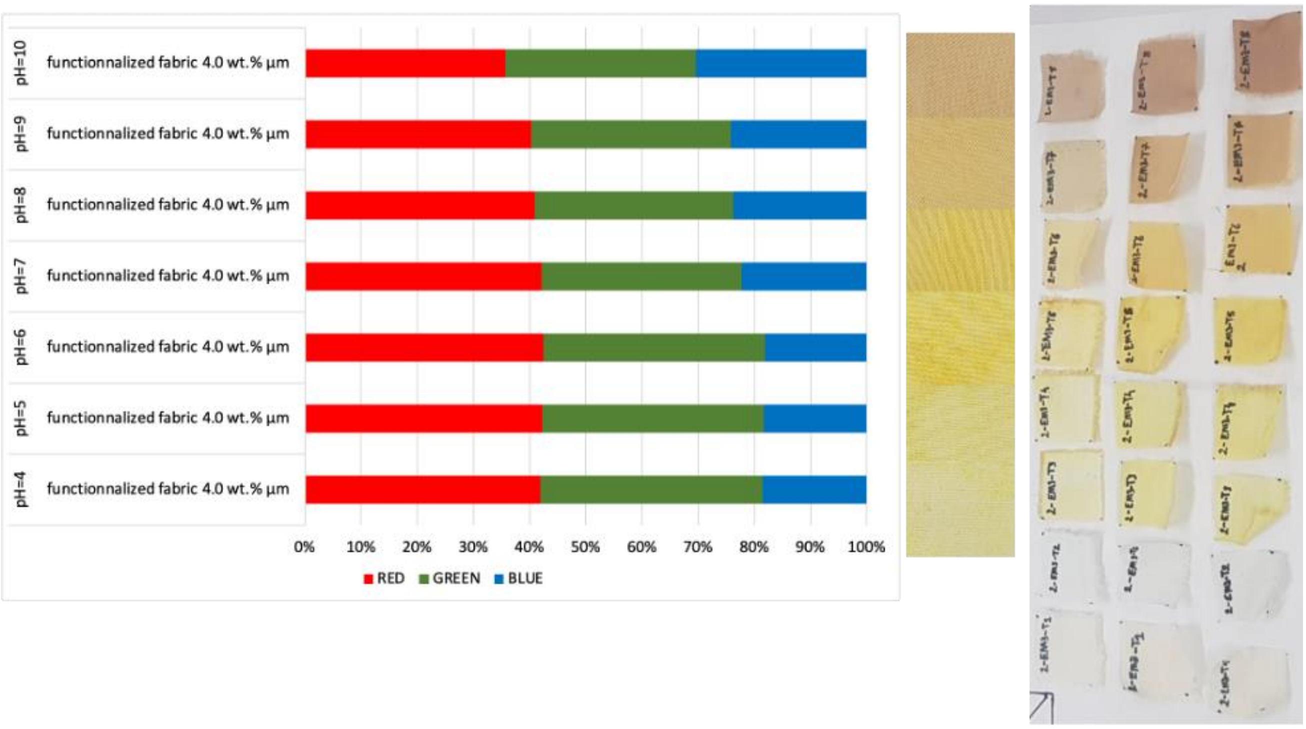

Figure 8. Influence of the pH on the color change of the fabric in the RBG color space (left), and images of the various samples (right).

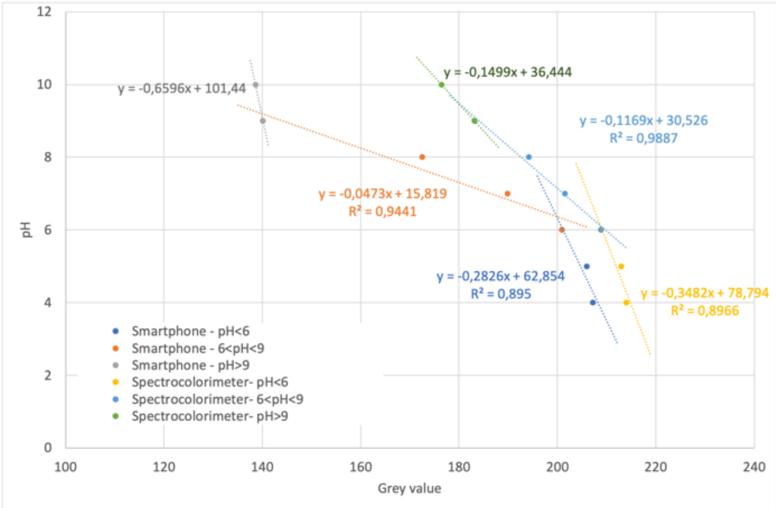

Figure 9. Relation between the grey value determined from the Red, Green and Blue values (smartphone and spectrocolorimeter) and pH.

4. CONCLUSION

This study suggests a new possibility of estimating pH by analyzing the color of pH-sensitive textiles, which is not a subjective method of visually assessing the degree of pH but quantitative data based on determining the color code of textile photographs. Curcumin was microencapsulated in a semi-porous polyurethane membrane. The influence of formulation parameters was used to provide information on the synthesis mechanism and to optimize the proportions of the two monomers. The capsules were then chemically grafted onto a textile substrate. Optimization of the rate of microcapsule deposition was based on the colorimetric response of the substrates, as well as their sensitivity to pH. The results showed that the textile support had become sensitive to pH and that it was possible to determine the pH of solutions using this material. The pH sensor developed has the advantage of being environmentally friendly thanks to using curcumin and textile microcapsules for sensor manufacture, requiring only a minimum of reagents and samples and not sophisticated instrumentation. What is more, it can be used up to 10 times. Evaluation of the results shows that the products have sufficient activity and sensitivity to detect the pH of the surrounding liquid medium. Exploiting the photographic images is a simple means of determining the pH value since these data correlate well with the data obtained by the spectrophotometer. In the later stages of the study, improving the system's sensitivity will be investigated to improve the performance.

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Araştırma Makalesi / Research Article

LAYER-BY-LAYER SELF-ASSEMBLY APPROACH IN THE UV PROTECTIVE MODIFICATION OF ARAMID-BASED MATERIALS

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ABSTRACT: This paper presents the Layer by Layer self-assembly (LbL) approach for developing the UV resistance of aramid yarns. Initially, a pretreatment was achieved by polyethyleneimine to obtain cationic surface charges on aramid yarns. Then zinc oxide and titanium dioxide nanoparticles were self-assembled on these yarns by the LbL process. The findings revealed that the LbL nano coatings significantly improved the UV resistance and tensile properties of the aramid yarns. This study highlights the unique opportunities offered by the LbL methodology to both modify aramid-based materials in mild conditions and provide an effective UV protection.

Keywords: Aramid, UV resistance, Layer by Layer self-assembly, nanocoating

ARAMİD ESASLI MATERYALLERİN UV KORUYUCU MODİFİKASYONUNDA ÇOK TABAKALI KENDİLİĞİNDEN DÜZENLENME YAKLAŞIMI

ÖZ: Bu makale, aramid ipliklerin UV dayanımını geliştirmek üzere çok tabakalı kendiliğinden düzenlenme (LbL) yaklaşımını sunmaktadır. Başlangıçta, aramid iplikler üzerinde katyonik yüzey yükleri elde etmek için polietilenimin ile bir ön işlem gerçekleştirilmiş ve daha sonra bu iplikler üzerinde LbL prosesi ile çinko oksit ve titanyum dioksit nano parçacıkları kendiliğinden düzenlenmiştir. Bulgular, LbL nano kaplamaların aramid ipliklerin UV direncini ve çekme özelliklerini önemli ölçüde artırdığını ortaya koymuştur. Bu çalışma, LbL metodolojisinin hem aramid esaslı materyalleri ılıman koşullarda modifiye etme hem de etkili bir UV koruması sağlama konusunda sunduğu benzersiz fırsatları vurgulamaktadır.

Anahtar Kelimeler: Aramid, UV dayanımı, Çok tabakalı kendiliğinden düzenlenme, nano kaplama

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1. INTRODUCTION

Aramid fibers possess many superior properties like ultra-high strength and modulus, lightweight, good thermal and chemical resistance; and their outstanding integrated performances render them one of the best competitors meeting harsh requirements in numerous cutting-edge fields like space and aviation, defense, and electronics [1-5]. However, when exposed to UV light, aramid fibers undergo rapidly evolving photolytic/ photooxidative reactions, which result in wear, discoloration, and loss of thermal and mechanical properties [6-11]. The poor UV resistance shortens the outdoor service life of aramid fibers and greatly restricts their applications [12, 13]. Moreover, considering it is an indispensable strategic material for national security, construction, and scientific and technological progress [13], UV-induced strength losses are unacceptable. Therefore, eliminating or minimizing these damages with UV protective coatings is of great interest both in academia and industry.

Nevertheless, the main problem of coating aramid fibers is their chemically inert surface, originating from strong conjugation and steric hindrance within the molecular chain [14]. This critical drawback transforms even an ordinary coating process into a significantly challenging task and also limits the effectiveness of UV protective coatings on these fibers [14-16.] Hence, aramid fibers are pretreated with mostly acid or alkali prior to any surface treatment [1, 2, 4]. In fact, any attempt to modify aramid fibers entails highly demanding operational requirements including high temperature and/or pressure, prolonged and complicated processes, and the necessity for exploiting specific machinery depending on the modification method [4, 12-18]. However, it is essential to note that abrasive pretreatments destroy the structural integrity and tensile properties of aramid fibers [5]. Therefore, the real challenge lies not only in developing an effective UV protective coating but also in seamlessly integrating it without compromising the intrinsic properties of aramid fibers.

In this regard, the Layer by Layer (LbL) self-assembly approach offers a promising solution to these challenges as an easy, efficient, reproducible, robust, and versatile bottom-up strategy to modify surfaces and prepare functional coatings [19]. LbL self-assembly, particularly driven by electrostatic interactions, is by far the most extensive and powerful way of constructing LbL films; it relies solely on the alternating adsorption of oppositely charged particles and enables the use of a wide range of materials [19]. Upon its exceptional versatility, LbL methodology holds the great potential to surpass restrictions related to substrate properties or even render them inconsequential. Notably, the pioneering works by Uğur and co-workers on the application of LbL for textile surfaces, particularly utilizing nanoparticles, have revealed unexplored potential [20-23]. Although LbL offers a valuable opportunity to tailor the surface properties of textile fibers, its utilization in modifying aramid fibers remains surprisingly scarce [24-28], with only two studies focusing on UV protection [4, 29].

Concerning the limited use of LbL, it can be addressed that inorganic one-dimensional UV absorbers, such as TiO_2 and ZnO nanoparticles, may not be suitable for modifying aramid fibers due to their (i) photocatalytic activities and (ii) limited surface coatings [4]. The first point seems plausible, indeed semiconductors pose a risk of damaging the substrate itself [30, 31]. As for the second point, the relatively limited surface area of nanoparticles could be quite discouraging for adopting LbL in UV protection as it is a surface phenomenon, and effective coverage of the fiber surface is crucial. As a result, the risks and difficulties in coating aramid fibers, coupled with the fact that LbL is mainly applied to relatively easy-to-process fibers such as cotton and polyester [32], may have created a prevailing notion over time that LbL is an unsuitable method for modifying aramid fibers. Taken together, solid reasoning for the limited use of LbL becomes evident.

Discussing UV protection, it is essential to consider the UV aging treatments as they reveal the effectiveness of the coatings. While UV protection is mainly developed against UVA and/or UVB rays, certain applications like aviation and welding operations [33, 34] require protection against UVC rays as well. Besides, UVC irradiation has gained great interest in neutralizing biological threats, such as coronaviruses [35-37]. Due to the rising demand for disinfection and sterilization, UVC technology has been integrated into various devices and everyday objects, becoming ubiquitous. Thus, accounting for UVC light in the assessment of UV protective coatings can become necessary in the near future, and in certain fields, it could be imperative. However, protective additives against UVC radiation and their effects on materials in our daily lives remain largely unknown [38].

This study was carried out to explore the possibilities of the Layer by Layer self-assembly approach in UV protective modifications of aramid-based materials. Overcoming existing limitations, we aimed to establish an effective and simple coating process. To achieve this, we conducted a mild pretreatment using polyethyleneimine to introduce cationic charges on the fiber surface. This allowed us to overcome the chemically inert surface of aramid fibers and create an appropriate sublayer for the subsequent LbL self-assemblies. Harnessing the charged surface, we successfully coated aramid fibers with TiO_2 and ZnO nanoparticles. Advanced protection in a harsh environment of highly energetic UVC rays validated the effectiveness of LbL coatings. This research uncovered the strong potential of LbL technology to overcome limitations in the UV protective modifications of aramid-based materials and establish a sustainable alternative to current practices.

2. MATERIAL AND METHOD

2.1. Material

Para-aramid (Kevlar 49) staple yarns (60/1 Nm, Z twist) were kindly supplied by Kipaş Textiles. Polyethylenimine (branched, average Mw ~25,000) and TiO_2 and ZnO nanoparticles were purchased from Sigma-Aldrich. Sodium hydroxide (NaOH) and hydrochloric acid (HCl) were used for pH adjustment.

2.2. Method

2.2.1. Pretreatment

Polyethyleneimine (PEI) is a common cationic polyelectrolyte in electrostatic self-assembly with strong adhesion, and recent applications have shown that it can serve as a suitable template to overcome chemically inert surfaces [32, 39, 40]. Based on this, pretreatment was carried out using PEI to obtain cationic charges on aramid yarns. Aramid yarns were immersed in the PEI solution (1 g/L) for 20 min and then dried without any heat treatment.

2.2.2. UV Protective LbL Coatings

Aqueous anionic and cationic dispersions of ZnO and TiO_2 (1 g/L) were prepared using an ultrasonic homogenizer (Hielchier, 40 W, 26 kHz) and adjusting pH with NaOH and HCl, respectively. After the pretreatment with PEI, aramid yarns were dipped first into anionic dispersions of ZnO or TiO_2 (20 minutes) and then into cationic dispersions, and washed in each sequential step (5 minutes). At the end of this cycle, a bilayer of ZnO or TiO_2 nanocoating was obtained. Ten layers of LbL nanocoating were obtained by repeating this cycle five times at room temperature for each and then drying at 105 °C for 5 minutes. The entire process is depicted in Figure 1.

2.2.3. Accelerated UV Aging

Regarding UVC aging, test method development at global standards organizations, such as ASTM and ISO, is still in its early stages, and commercial UVC testing instruments are relatively new [38]. Therefore, without relying on a standard like others [41, 42], we conducted accelerated UV aging in a self-designed box (60 cm x 60 cm x 60 cm) using three Philips TUV series 253.7 nm UVC lamps (model: 15W15G8T, 41 cm long) for 168 hours.

2.2.4. Characterizations and Tests of UV Protective LbL Coatings

The morphologies of the aramid yarns were observed using a Carl Zeiss 300VP Scanning Electron Microscope (SEM). The aramid yarns were tested in Attenuated Total Reflection Infrared (ATR-FTIR) mode using a Thermo Scientific Nicolet iS50 FTIR Spectrometer, with a wave number range of 400 ~ 4000 cm^{-1}. To assess the UV protection efficiency of LbL nanocoatings, tensile strength, and break extension were measured according to TS EN ISO 2062 before and after UV aging.

3. RESULTS AND DISCUSSION

3.1. SEM Observation

SEM images of the aramid yarns taken at ×2500 and ×5000 magnifications are displayed in Figure 2 for a-b) untreated, c-d) PEI pretreatment, e-f) ZnO nanocoating, and g-h) TiO_2 nanocoating. The average diameter of the aramid fiber was approximately 12 µm. Some narrow grooves are uniformly distributed in the longitudinal direction of the fiber, indicating axial orientation [43, 44]. The punctiform stains generated during the production of fibers are also observed [40]. Additionally, there are some fibrillar structures misaligning to the fiber axis with diameters mostly below 1 µm, and some appear to be roughly 200-400 nm in size. It was observed that some fibrillar structures seemed to peel off of the fiber's skin layer in the longitudinal direction, while others appeared as a single solid piece (Figure 2a). Furthermore, some formed continuous ribbons that coiled into helices (clearly visible in Figure 2e, f) [43]. The presence of these separated fibrillar structures in SEM images suggests that certain microfibrils may have become detached from the fiber structure during the manufacturing process. The fibrous form consisting of staple fibers might have contributed to these splittings, as they presumably tended to create broken fiber ends and separate into microfibrils [44, 45]. Yet, further analysis, such as advanced microscopy techniques and material testing, would be required to study the exact nature and implications of these microfibril observations in Kevlar fibers. These observations thus need to be interpreted with caution and closer inspection.

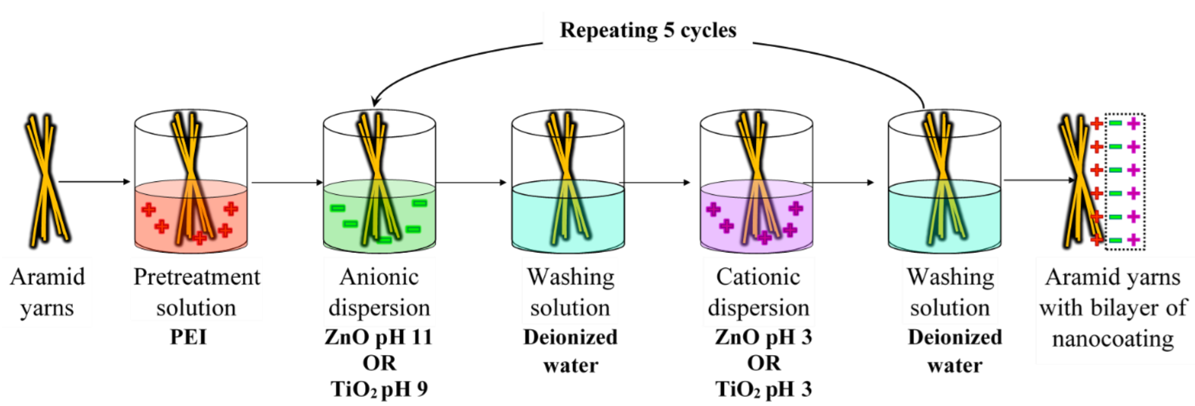

Figure 1. Pretreatment and LbL nanocoatings of aramid yarns

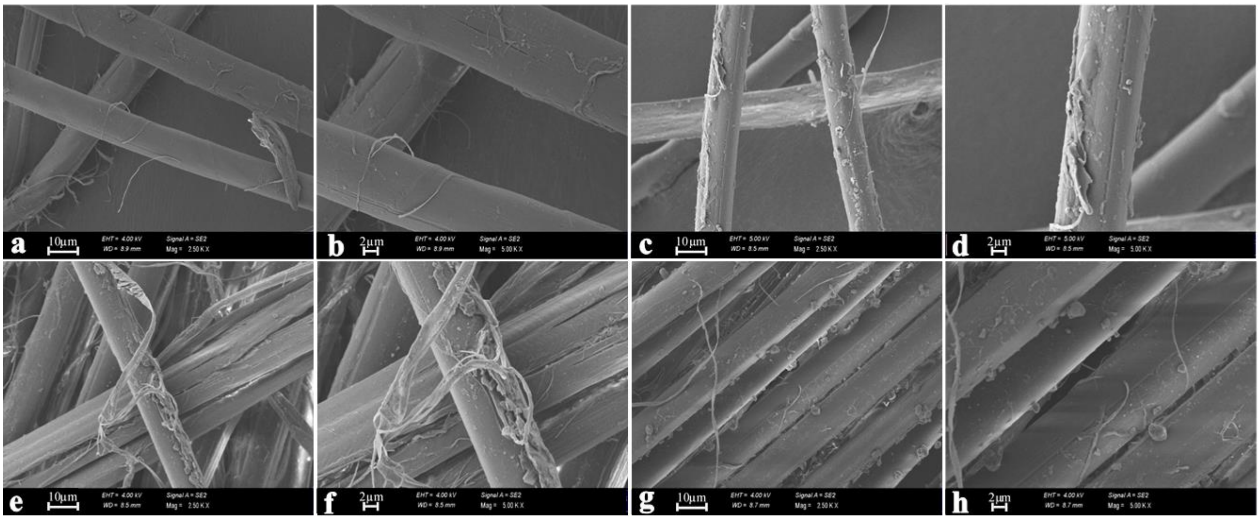

Figure 2. SEM micrographs of aramid yarns; a,b) untreated, c,d) PEI pretreatment, e,f) ZnO nanocoating, g,h) TiO_2 nanocoating (In the ordered pair, the first letters represent x2500, while the latter ones represent x5000)

Apart from the fibrillar structure, the untreated fiber surface appeared smooth and clean, whereas an attached dense coating layer was observed after the PEI pretreatment (Figure 2c, 2d). However, the PEI coating exhibited uneven distribution, with some regions showing abundance (Figure 2e, 2f), while others had a relatively thin and uniform layer (Figure 2g, 2h). The non-uniformity of the PEI coating appeared to affect the distribution of nanoparticles, as well. ZnO nanoparticles tended to agglomerate, whereas TiO_2 nanoparticles were smaller, evenly distributed, and separated. While it was not expected to achieve full coverage of fibers with LbL coatings, as in the case of atomic layer deposition [12, 14], it was also not predicted that the PEI coating would show relatively moderate to high levels of differences in region to region. These observations imply two points about exploiting a strong adhesive material serving as a charged sublayer for subsequent LbL coatings. This surface strategy might be more effective in the implementation of nanoparticles in case: providing a uniform and widely spread sublayer coating, which would enable well-manipulated and controlled distributions of particles, or simply using UV absorbers with a larger surface area, as suggested [4].

Regarding the fact that this was only a preliminary attempt to coat aramid fibers with a simple and easy approach, it is hardly surprising that LbL coatings were imperfectly distributed along the fiber. It should be reminded that no chemicals other than PEI were exploited, and even heat treatments were not applied after PEI coating. Likewise, LbL coatings were carried out without drying between each self-assembly deposition, contrary to previous studies [4, 27, 29]. Although the surface coverage performance appeared to be not ideal, we nevertheless believe that LbL has strong potential for the deposition of nanocoatings with the right material combination, and provides a unique opportunity to tailor the surface of fibers, even inert ones like aramid.

3.2 ATR-FTIR Analysis

Figure 3 displays the ATR-FTIR measurement results of untreated and LbL-coated aramid yarns before and after UV aging. The FTIR spectra show specific amide-related peaks at certain wavenumbers: 3308 cm^{-1} (amide A), 1642 cm^{-1} (amide I), 1537 cm^{-1} (amide II), 1298 cm^{-1} and 1223 cm^{-1} (amide III), and 721 cm^{-1} (amide IV) [11, 27, 46-49]. Additionally, bands at 817 cm^{-1} indicate out-of-plane C-H vibrations of two adjacent hydrogens in an aromatic ring, while 521 cm^{-1}, 720 cm^{-1}, and 805 cm^{-1} bands suggest out-of-plane N-H deformation modes, indicating para disubstitution in the aromatic ring [50, 51]. The absorption bands at 1510 cm^{-1}, 1014 cm^{-1}, and 817 cm^{-1} are attributed to the C–H deformation of the aromatic ring [52], and the band at 1605 cm^{-1} is related to the C=C tensile vibration of the benzene ring [12, 50, 53].

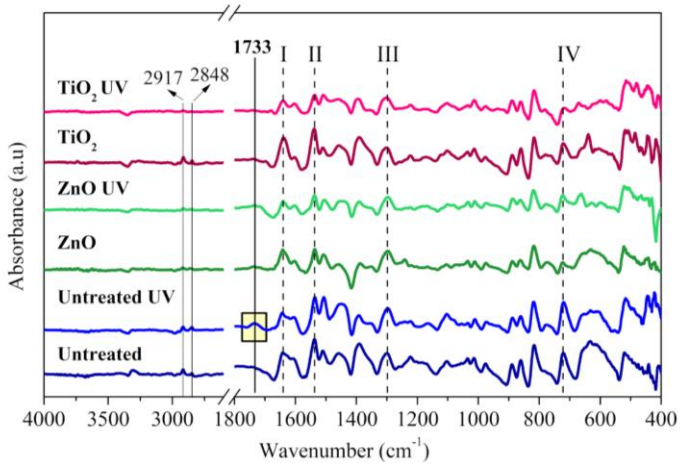

Figure 3. ATR-FTIR analysis of aramid yarns

The bands at 2917 cm^{-1} and 2848 cm^{-1} are associated with the stretching of C–H groups, as well as aldehyde groups [54]. Previous studies have linked these bands to the incorporation of PEI [27, 55], indicating effective PEI coating on TiO_2-coated yarns, as evidenced by strong peaks. However, in the spectrum of ZnO-coated yarns, these bands appear weak, possibly due to the nonuniform PEI coating mentioned in SEM. Normally, these peaks could indeed be observed [13, 54, 56]. Nevertheless, their unusually high intensity in our study raises the possibility that they may result from the residual sizing agent used in the manufacturing process. It is worth considering that aramid yarns were not thoroughly cleaned in a harsh medium containing acid [57], which might explain the observed peak intensity. Despite this, we successfully achieved our goal of avoiding the use of harsh treatments and directly coated the aramid fibers.

In the case of ZnO-coated samples, specific peaks at 425 cm^{-1}, 450 cm^{-1}, and 570 cm^{-1} are associated with the characteristic Zn-O stretching vibration [58-60]. Furthermore, the peaks observed at 1242 cm^{-1}, 1350 cm^{-1}, and 1736 cm^{-1} might suggest the presence of ZnO coating on aramid yarns, as they are specifically detected in the FTIR spectra of ZnO-coated samples. In the case of TiO_2-coated yarns, a broad absorption band observed roughly at 400-700 cm^{-1} is attributed to the bending vibrations of the Ti-O and -O-Ti-O groups, which is clearly visible in the figure. Additionally, there are distinct peaks at 417 cm^{-1} (in-plane TiOH bending) and 485 cm^{-1} (out-of-plane TiOH bending), as well as 639 cm^{-1} (sym-TiOH stretching), all of which are related to $OTi(OH)_2$ [61]. Moreover, the peak at 1123 cm^{-1} can be linked to the formation of amide linkages between aramid yarns and TiO_2.

After UV irradiation, changes in intensities were observed in the IR spectra. Reduction in the intensities of the Amide I, II, and III peaks was noticed, indicating potential damage to the polymer backbone and the formation of carboxylic acids and other oxidized species, likely due to photo-oxidation [11, 62]. Furthermore, shouldering peaks at 1605 cm^{-1} and 1510 cm^{-1} tended to converge with amide I and II, respectively. After UV aging, the peak at 1350 cm^{-1} remains, while the other peaks that presumably indicate the amide-ZnO linkage (1242 cm^{-1} and 1736 cm^{-1}) disappear. This observation may suggest the degradation of the amide-related bonds in the aramid yarns due to UV exposure. The increase in the intensity of the C=O stretch peak (1102 cm^{-1}) suggests the oxidation of amide groups in the aramid yarns [63]. The peak at 1123 cm^{-1}combined with the 1102 cm^{-1} peak after UV aging, indicating possible UV-induced damage for TiO_2-coated yarns.

Additionally, after accelerated UV aging, a new peak at 1733 cm^{-1} appeared in the untreated samples ("untreated UV" indicated in a rectangular yellow box"), which is attributed to the breaking of the amide bond and the formation of a carboxylic acid group [4, 11, 12, 53, 64]. However, no strong peak corresponding to the cleavage of the amide bond was observed in ZnO and TiO_2-coated samples after UV aging. This suggests that the coatings may have provided some protection against UV-induced degradation of the amide bonds in the aramid yarns.

The presence of additional ZnO and TiO_2 related peaks in the spectrum of coated samples indicates the successful achievement of LbL nanocoatings. The FTIR spectrum showed that UVC aging conditions led to the formation of new functional groups and changes in the intensity of main wave numbers with slight shifts after aging. Despite the somewhat disappointing coating performance, it is surprising that ZnO and TiO_2 nanoparticles demonstrated a significant ability to prevent chain scission, especially at 1733 cm^{-1}. This finding suggests that the LbL self-assembly of nanoparticles can be highly effective for UV protection modification of aramid yarns

3.3. Tensile Strength and Break Extension Tests

The tensile strength and break extension of aramid yarns before and after UV aging are presented in Figure 4a and 4b, respectively. The tensile properties of the bare para-aramid staple yarn were lower (9.7 cN/dtex; 4.4%) compared to values reported in the literature (20.8 cN/dtex; 2.4%) [44]. As previously observed in the SEM micrographs, the presence of detached fibrillar structures, which are assumed to result from the manufacturing process, might have contributed to the lower tensile properties. Ultimately, these defects could have led to failure by axial splitting, possibly triggered by the shear stresses in a twisted fiber [45]. However, it is worth noting that the coatings were applied to the same yarns, ensuring a consistent assessment of the coatings' effects on the tensile properties.

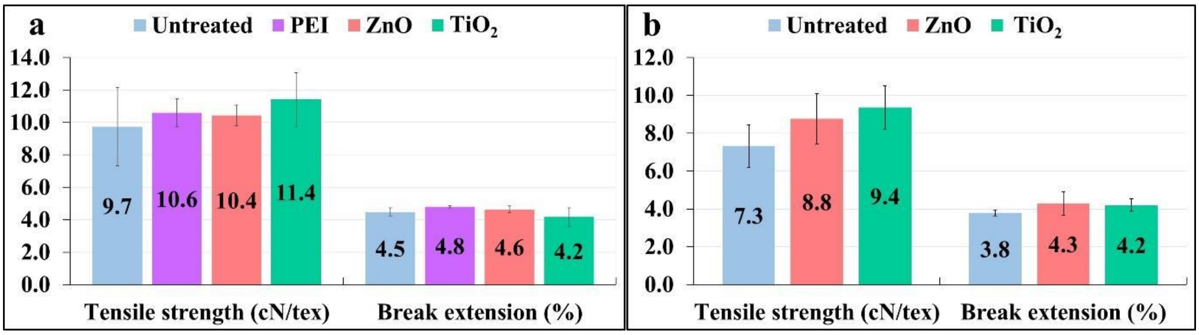

Figure 4. Tensile strength and break extension of aramid yarns a) before UV aging b) After UV aging

The tensile strength of the untreated aramid yarn increased by 9%, 7%, and 17% with PEI, ZnO, and TiO_2 coatings, respectively. This improvement can be attributed to the beneficial effects of the PEI polymer layer, which introduces active sites to the fiber surface through nondestructive functionalization and helps to repair defects on the fiber surface [55]. It is reasonable to assume that TiO_2 performed better than ZnO due to possibly achieving a more uniform coating, as mentioned in the previous subsection. In contrast to some studies that reported only minor changes in tensile strength for ZnO and TiO_2-modified fibers [42, 58, 65], our results are quite satisfactory, showing a significant increase in tensile strength. This improvement is particularly notable as previous studies have indicated a decrease in tensile strength for ZnO and TiO_2-modified fibers [18, 66-68]. It is worth mentioning that achieving an enhanced tensile strength of aramid fibers after modification is a rare finding [12, 14]. Regarding the break extension, there was a slight decrease observed in TiO_2-coated fibers, while the other coatings showed a slight increase. However, these fluctuations can be considered as insignificant since they resulted in an extension of less than 5% [44].

The tensile strength of all aramid yarns decreased after accelerated UV aging (Figure 4b), with untreated yarns showing the most severe decline. It is reasonable to observe a decrease in the break extension of untreated and ZnO-coated yarns, as UV aging may have made the fibers more brittle. However, the break extension of TiO_2 nanocoating showed no change. It is important to remind that this preliminary study conducted UV aging solely with a UVC lamp, without considering the additional effects of temperature and moisture. For more realistic simulations, temperature and humidity should be included as essential parameters, as previous studies have shown that UV aging can become extremely severe under such conditions [12, 14, 56]. Although our test conditions were not severely harsh, UVC light energy is higher than UVA and UVB. Therefore, these findings are not unexpected, given the high sensitivity of aramid fibers to UV light.

To assess the UV protection efficiency of LbL nanocoatings more clearly, examining the retention rates of the yarns is beneficial. Tensile strength retentions and break extensions (%) of aramid yarns after 168 hours of UV irradiation were evaluated both individually and in comparison to the untreated yarn, as presented in Figure 5. The break extension retentions of ZnO and TiO_2 modified yarns were found to be 92-100% individually or compared to the untreated sample 96-95%, respectively. These findings suggest that the LbL nanocoatings preserved the break extension properties of the aramid yarns after UV aging.

The untreated aramid yarn retained only 75% of its original tensile strength, which is typical for Kevlar49 fibers. In contrast, aramid yarns with ZnO and TiO_2 LbL nanocoatings maintained at least 84% and 82% of their original values, respectively. These retention values were obviously higher compared to the untreated sample. It is essential to note that retention rates should be given with reference to the initial values of both the original fiber and the modified fiber; otherwise, the interpretation could be misleading. For instance, the tensile strength of TiO_2-coated yarns before and after UV aging was 11.4 cN/tex and 9.4 cN/tex, respectively, resulting in tensile strength retention of 82%. However, when compared to the untreated para-aramid yarns before UV aging (9.7 cN/tex), this value (9.4 cN/tex) corresponds to 96%, which is significantly higher than the 75% retention of the uncoated yarns (7.3 cN/tex), indicating remarkable UV protection.

In previous studies [1-5, 17, 66] that used Kevlar49 fibers and conducted UV aging for 168 hours, the reported UV protection rates ranged from 82% to 97%. Our findings demonstrate that LbL nanocoatings considerably retain the tensile strength of aramid fibers, whether considered individually (82-84%) or compared to the untreated sample (90-96%). This is quite surprising, given the observed incomplete coverage of the fiber surface and the photocatalytic nature of ZnO and TiO_2 nanoparticles.

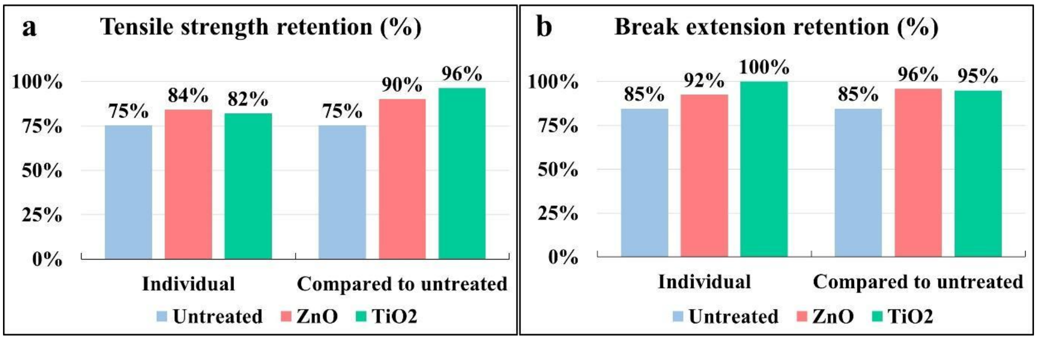

Figure 5. Tensile strength (a) and break extension (b) retentions of aramid yarns after UV aging

4. CONCLUSION

This paper presents the Layer by Layer self-assembly approach for assessing its potential in the UV protective modifications of aramid-based materials. Prior to the application of LbL nanocoatings, a PEI coating was carried out to create a charged sublayer. This approach facilitated overcoming the inert nature of aramid fibers while circumventing the need for abrasive pretreatments. The findings showed that the LbL technique enables the self-assembly of ZnO and TiO_2 nanoparticles on PEI-coated aramid yarns. Tensile strength values of aramid yarns were considerably increased by both PEI pretreatment and LbL nanocoatings. This suggests that it is quite possible to build up nano coatings without compromising the tensile properties of aramid fibers using the LbL approach. Furthermore, LbL nanocoated yarns have significantly preserved their tensile properties after accelerated UVC aging. It was concluded that the LbL self-assembly approach may well overcome the limitations of the current coating practices and is highly suitable for achieving high protection rates in the UV protective modification of aramid-based materials. Indeed, comprehensive investigations need to be conducted to broaden the opportunities offered by LbL and to develop a robust and sustainable UV protection system for aramid fibers. Further LbL applications providing protection against the entire UV spectral range are currently in the development stage, and we hope to share them soon.

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Araştırma Makalesi / Research Article

TEMPERATURE REGULATING POLYESTER SHORT STAPLE RING SPUN YARNS BY PCM NANOCAPSULE APPLICATION

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ABSTRACT: Phase change materials (PCMs) are thermal energy storage materials and therefore they are used for the manufacturing of heat-storage and thermo-regulated textiles. In this study, it was aimed to produce polyester spun yarns with thermo-regulation function via an alternative capsule application method. In the study, PMMA-co-MAA walled nanocapsules were synthesized by emulsion polymerization method and an alternative capsule application method was used to apply PCM nanocapsules into the staple polyester yarn structure during the yarn production process. Ne 30/1 polyester ring spun yarns with knitted twist were produced and some of the PCM nanocapsule and produced yarn properties were analyzed. According to the results, PCM nanocapsules had dimensions around 200-400 nm, uniform size distribution and spherical morphology. They could store approximately 100 j/g heat and had sufficient thermal resistance. With the developed capsule application method, nanocapsules were successfully applied to spun yarn structure and produced polyester yarns exhibited temperature differences in the range of 2-5 °C compared with undoped reference ring spun yarns. The results of the study indicated that this application method could be an alternative to fabricate thermo-regulating fabric surfaces and such integrated yarn materials have demonstrated promising potential for the production of thermoregulating textile material.

Keywords: Functional textiles, ring spinning, microcapsule, phase change materials (PCM), polyester yarn.

FDM NANOKAPSÜL UYGULAMASI İLE SICAKLIK DÜZENLEME ÖZELLİĞİNE SAHİP EĞRİLMİŞ POLYESTER RİNG İPLİK ÜRETİMİ

ÖZ: Faz değiştiren malzemeler (FDM'ler), termal enerji depolama özelliğine sahip malzemelerdir ve bu nedenle ısı depolama ve ısı düzenleme özellikli tekstillerin üretiminde kullanılmaktadır. Bu çalışmada, alternatif bir kapsül aplikasyon yöntemi ile termoregülasyon fonksiyonlu polyester eğrilmiş ipliklerin üretilmesi amaçlanmıştır. Çalışmada, PMMA-ko-MAA duvar nanokapsüller emülsiyon polimerizasyon yöntemiyle sentezlenmiş ve alternatif bir kapsül uygulama yöntemi, iplik üretim sürecinde kesikli polyester iplik yapısına FDM nanokapsülleri aplike etmek için kullanılmıştır. Örme bükümüne sahip Ne 30/1 polyester ring iplikler üretilmiş ve FDM nanokapsül ve üretilen ipliklerin bazı özellikleri çalışmada incelenmiştir. Sonuçlara göre, FDM nanokapsülleri 200-400 nm civarında boyutlara, düzgün boyut dağılımına ve küresel morfolojiye sahiptir. Nanokapsüllerin yaklaşık 100 j/g ısı depolayabildiği ve yeterli termal dirence sahip oldukları tespit edilmiştir. Geliştirilen kapsül uygulama yöntemi ile nanokapsüller eğrilmiş iplik yapısına başarıyla uygulanmış ve üretilen polyester iplikler katkısız referans ring ipliklere göre 2-5 °C aralığında sıcaklık farklılıkları sergilemiştir. Elde edilen sonuçlar doğrultusunda, bu uygulama yönteminin sıcaklık düzenleyici kumaş yüzeyleri elde etmek için bir alternatif olabileceği ve bu tür entegre iplik malzemelerinin, sıcaklık düzenleyici tekstil malzemelerinin üretimi için umut verici bir potansiyel sergilediği sonucuna ulaşılmıştır.

Anahtar Kelimer: Fonksiyonel tekstiller, ring iplikçiliği, mikrokapsül, faz değiştiren malzemeler (FDM), polyester iplik.

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1. INTRODUCTION

Phase change materials (PCMs) are among the smart materials. PCMs can store and release high latent heat energy as their physical state changes under the nearly isothermal condition and therefore show a temperature regulation effect by absorbing and emitting heat energy in a certain temperature range depending on the changes in ambient temperature. Thanks to the heat exchange properties of PCMs, it is possible to improve thermal comfort in clothes and to provide heating and cooling effects [1-3]. Textile materials containing PCMs not only provide dynamic insulation properties (buffering effect against temperature change) in clothing fabrics, but also provide heating or cooling effects in different environmental conditions, in case of sudden temperature changes. Today, the use of PCMs in the textile industry is becoming increasingly important to improve the thermal comfort of clothing and to eliminate the effects such as sweating and sudden changes in body temperature as a heat regulator. Furthermore, the usage of PCMs has gained importance for the protection in extreme conditions and for the performance increase of professional athletes. The majority of PCMs, particularly paraffinic solid-liquid phase change PCMs, are used after microencapsulation. Encapsulation is a packaging technology that a tiny particle or droplet is enveloped by an organic or inorganic wall in order to develop micro or nano-sized capsules. Microencapsulation is an effective method in terms of reducing the interaction of the PCMs with the environment, preventing its separation from the textile structure by flowing when it enters the liquid phase, increasing its permanence in the textile structure, increasing its heat transmission surface and providing a constant volume [4-5].

The application of PCMs to textile structures focuses on synthetic fiber production and fabric finishing. However, the methods used in the current microcapsule application have some important disadvantages. They can be summarized as reduced thermal conductivity, softness, flexibility, strength, breathability or moisture transport capability of textiles, and non-durable thermal properties in the final products [6-12]. In this study, different from present application methods, it is aimed to produce innovative yarns that can offer latent heat storage/dissipation and heat regulation (thermoregulation) properties by applying PCM nanocapsules to the yarns obtained from staple fibers. In literature, Zhang et al. (2006) [13] and Gao et al. (2009) [14] stated that the incorporation of microencapsulated PCM during fiber spinning process is a promising approach which can enhance the life time of the thermo-regulating effect of the woven or knitted fabrics made of such filament. From this point of view, in the study, PCM nanocapsules were applied to polyester staple fibers with an alternative method and ring spun yarns with Ne 30/1 yarn count (knitted twist) were produced. To the best of our knowledge, no article has, to date, focused on integration of the PCMs to the spun yarns from polyester staple fibres and this application is a new method for the thermo-regulating functional yarn production.

2. MATERIALS AND METHODS

2.1. Microcapsules Preparation and Characterization

Emulsion polymerization method was performed to synthesize nanocapsules. In nanocapsule production, wall polymer was synthesized with methyl methacrylate (MMA, Sigma-Aldrich) monomer and methacrylic acid (MAA, Sigma-Aldrich) comonomer. 1-tetradecanol (Alfa Aesar, %97+) was used as the core phase change material (PCM) of the nanocapsules. PEG 1000 (Sigma Aldrich; Merck) was used as emulsifier and ethylene glycol dimethacrylate (EGDM, Sigma-Aldrich; Merck) was used as cross-linker. 2,2-Azobis(2-methyl-propionamidine) dihydrochloride (Acros Organics) was used as initiator in order to form free radicals and initiate addition polymerization via monomeric radicals. In the production of nanocapsules, the wall/core ratio was used as 1/1. In the first stage of production, 32.5 g of 1-tetradecanol was added in a 500 ml of deionized water heated to 50 °C and mixed at 1000 rpm for about 20 minutes. In order to emulsify 1-tetradecanol in the water phase, 10 g of PEG1000 was added to mixture and the emulsion was prepared by stirring at 1000 rpm for 30 minutes. A 29 g of MMA and a 3.5 g of MAA (approximately 12% by weight of comonomer) monomers, a 6.75 g of EGDM cross-linker and a 5 g of initiator were added to the emulsion. After the addition of each component, mixing was done for 5 minutes and finally the temperature was increased to 80 °C. The nanocapsule production process was completed after the reaction, which was carried out at 1000 rpm, at 80 °C for 3 hours. The produced nanocapsules were washed several times with hot water at 70 °C, then rinsed, filtered and stored in a refrigerator (+8 °C).

2.2. Method

In this study, an alternative method was used to impart the microcapsules into the staple polyester fiber bundle before the yarn formation. An alternative application method developed in previous study of the authors was used for production of the PCM nanocapsule doped composite ring yarns [15-16]. The method based on integrating the PCM nanocapsules into the open fibre bundle before yarn twisting during the ring spinning process and hence trapping the capsules in the twisted yarn structure. In the study, yarn production was carried out on a conventional ring spinning machine (Rieter G10 model) due to its widely usage in the spun yarn production and also superior yarn properties. In the method, a dispersion including PCM nanocapsules was prepared and then applied to the polyester fibres during the yarn spinning process via a special apparatus. Nanocapsule dispersion contained surfactant (S), defoamer (D), water and also PMMA-co-MAA/1-tetradecanol nanocapsules. Mechanical homogenizer (IKA ULTRA-TURRAX® T 18 basic) and sonic mixer (BANDELIN SONOPULS HD 4200) devices were used to disperse nanocapsules in the water homogeneously. Nanocapsule concentration was determined by Alay Aksoy et al. as 6% based on their previous findings [17]. After the preparation of microcapsule dispersion, the mixtures were applied to staple fibres by the developed alternative method. In the study, Ne 30/1 polyester ring spun yarns were produced by using four different feeding rate values from 62.5 mL/h to 77.5 mL/h. Yarn production parameters such as draft and spindle speed were kept constant during the yarn production.

2.3. Test and analysis

The morphological properties of the produced PCM nanocapsules were studied by SEM images taken with LEO 440 Computer Controlled Digital Scanning Electron Microscope (SEM). The nanocapsules' average particle size and particle size distribution diagrams were determined by the particle size analysis device (Malvern MS2000E). The nanocapsules were washed and filtered before measurement and then they were subjected to additional mixing with a homogeniser at a speed of 10000 rpm for 45 minutes. The thermal properties of the produced nanocapsules were investigated by Differential Scanning Calorimetry (DSC) and Thermogravimetric Analysis (TGA) methods. Phase change temperatures and heat storage and dissipation capacities of the nanocapsules were analysed by DSC. The analyses were carried out in nitrogen (N2) atmosphere at a heating/cooling rate of 10 °C/min between -5 °C – +80 °C using the Perkin-Elmer Jade DSC device. TGA analysis was carried out to examine the thermal stability of the produced nanocapsules for possible subsequent textile processes such as washing, finishing. The analyses were carried out in the nitrogen gas environment, at a heating rate of 10 °C/min, in the range of 0-500 °C, using the Perkin Elmer TGA7 device. Chemical structure of PCM nanocapsules were analysed by Fourier Transform Infrared (FT-IR) Spectrometer analysis.

In the study, morphological, thermal and physical properties of the produced polyester yarns were analysed. The yarn samples without nanocapsules were named as a reference or undoped while the samples comprising nanocapsules were called as a doped or composite yarn. At first, yarn images were taken with LEO 440 Computer Controlled Digital Scanning Electron Microscopy (SEM) in order to determine the morphological properties of the nanocapsule doped and undoped reference yarn structure. Thermal History (T-History) test method was used to determine the changes in surface temperatures of yarn samples resulting from absorbed latent heat by the nanoencapsulated PCMs in their structure in variable temperature environments. Yarn unevenness, imperfections (thin-thick places and neps) and hairiness were tested on Uster Tester 3 device at 400 m/min test speed while yarn strength and breaking elongation properties of the yarn samples were tested by Mesdan Lab tensile tester according to ASTM D 2256. Test length was 500 mm and the test speed was 5000 mm/min and 3 tests were carried out for nanocapsule doped and undoped reference yarns.

3. RESULTS AND DISCUSSION

3.1. PCM Nanocapsule Properties

In this section, morphological, thermal and chemical properties of the PCM nanocapsules are discussed.

<u>*Morphological properties of PCM nanocapsules*</u>

According to the SEM images (Figure 1), it was determined that capsules had nano dimensions and their sizes ranged from approximately 150 nm to 400 nm. The particle sizes and size distributions of the prepared nanocapsules were calculated using particle sizer. The mean and coefficient of variation (CV%) values of capsule diameter values were determined as 78.45 µm and 31.7%, respectively. According to the particle size distribution diagram given in Figure 2, it was determined that capsules exhibited a wide range but a unimodal distribution. The particle size distribution uniformity value was determined as 0.317. The average particle size of 98% of the particles was 127.2 µm. Compared to the SEM images, the particle size measured with the particle size analyzer was found to be higher. This case resulted from different measurement principle of SEM and particle sizer. SEM images show the actual size of the capsules while the particle size analyser measures the clustered capsules as a single capsule. As can be seen from the SEM images, produced capsules had nanoparticle sizes. However, they bonded to each other and formed aggregates after these ultra-small particles were mixed in an aqueous medium.

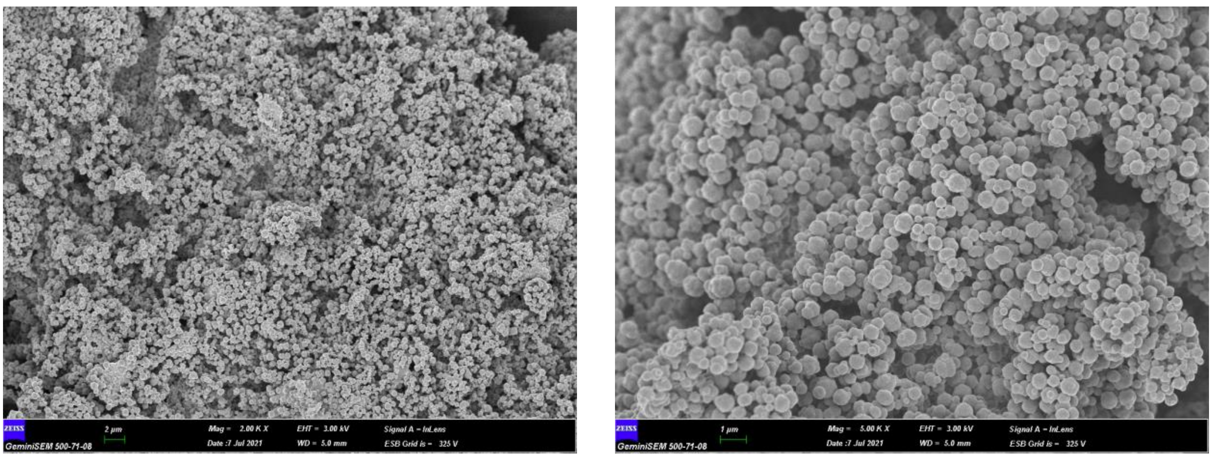

Figure 1. SEM images of the PMMA-co-MAA walled nanocapsules (A: 2000x, B: 5000x)

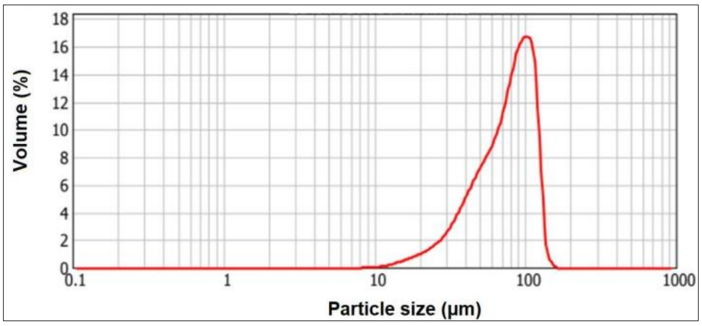

Figure 2. Particle size distribution of PMMA-co-MAA walled nanocapsules

Thermal properties

The curve obtained from the DSC analysis used to determine the thermal energy storage properties of nanocapsules are given in Figure 3. According to the DSC curve given in Figure 3, PMMA-co-MAA walled 1-tetradecanol core microcapsules absorbed 101.7 j/g heat energy at 34 °C. Two solidification peaks occurred during the cooling processes of these nanocapsules. This is a characteristic behaviour of fatty alcohols. Fatty alcohols exhibit two phase transitions during the solidification process, first the liquid-solid phase transition and then the solid-solid phase transition [18]. The liquid-solid and solid-solid transition temperatures during the cooling of nanocapsules were 35 °C and 26 °C, respectively. The total enthalpy of crystallisation for liquid-solid and solid-solid phase transitions was -101.2 j/g. The findings propounded that the produced nanocapsules have transition temperatures suitable for the manufacture of textile-based thermal energy storage materials and these materials can be used in the household or clothing industry due to their sufficient high thermal energy storage capacity.

The curve obtained as a result of the TG analysis performed to determine the thermal resistance of nanocapsules are shown in Figure 4. According to TGA curves, the nanocapsules exhibited two-stage thermal degradation behaviour. The first decomposition step started at 206 °C and ended with a mass loss of 60.3% at 252 °C. This mass loss seen in capsules was due to the thermal breakdown of 1-tetradecanol, which forms the microcapsule core material, due to the increase in temperature and its removal from the capsule wall structure. Pure n-tetradecanol undergoes one-step thermal decomposition, starting at around 135 °C and ending at about 260 °C [19]. Nanoencapsulation into the PMMA-co-MAA wall delayed the thermal degradation of n-tetradecanol and increased its thermal resistance. The second thermal decomposition of the nanocapsules, which started at about 352 °C, was due to the thermal decomposition of the cross-linked PMMA-co-MAA copolymer structure forming the wall structure. Decomposition of encapsulated 1-tetradecanol was delayed due to the presence and thermal resistance of the microcapsule wall structure (decomposition at 206 °C and above). The mass loss values in this step were determined as 31.2% (Table 1). In summary, PMMA-co-MAA walled nanocapsules were found to be suitable for textile processes in terms of thermal resistance.

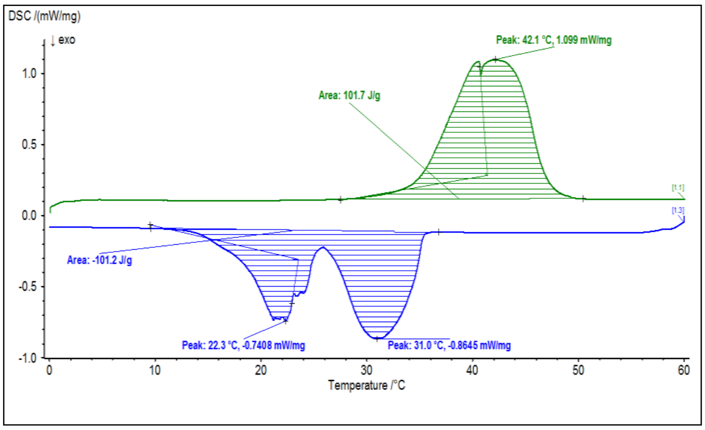

Figure 3. DSC curve of 1-tetradacanol core microcapsules with PMMA-co-MAA wall produced by emulsion polymerization method

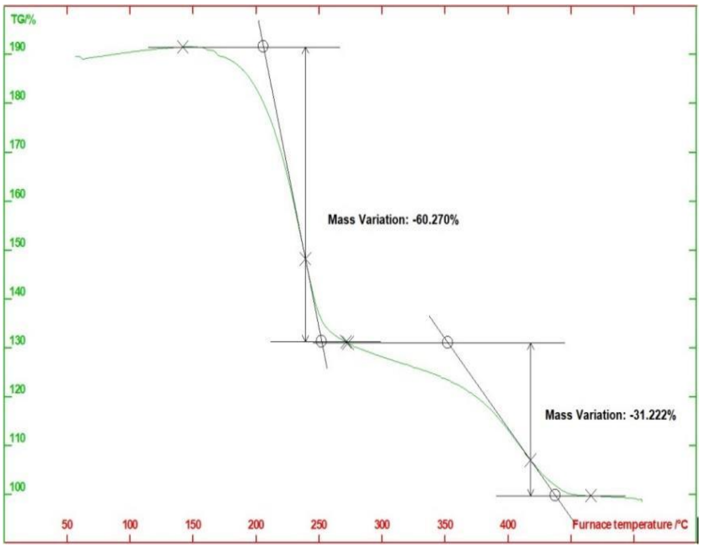

Figure 4. TGA curve of 1-tetradecanol core microcapsules with PMMA-co-MAA walls

Table 1. TGA results of PCM nanocapsules

Material	**1. step**				**2. step**			
	T1	**Tinflexion**	**T2**	**Mass loss (%)**	**T1**	**Tinflexion**	**T2**	**Mass loss (%)**
PMMA-ko-MAA/1-tetradecanol	206.1	239.3	252.3	60.3	352.5	417.9	437.8	31.2

Fourier Transform Infrared (FT-IR) Spectrometer analysis

In this section, the results of FT-IR spectroscopy analysis performed to define the chemical structures of the produced nanocapsules are given. The presence of wall and core materials in the structure of nanocapsules was investigated.

In Figure 5, the FT-IR spectrum of PMMA-co-MAA walls/1-tetradecanol core nanocapsules produced by emulsion polymerization method is given. In the spectrum of 1-tetradecanol, which forms the core material of the nanocapsules, the peak at 3330 cm^{-1} wavelength belonged to the -O-H stretch, the triple peaks at 2962-2922-2850 cm^{-1} and the peak at 1467 cm^{-1} belonged to the C-H stretch. In the same spectrum, the peak at a wavelength of 725 cm^{-1} was the characteristic peak of 1-tetradecanol. In the spectrum of the methyl methacrylate monomer, the peak at 1741 cm^{-1} was the stress peak belonging to the carbonyl group. The small peak at 1635 cm^{-1} in the spectrum was the C=C bond stretch peak in the monomer. The peaks between 1100-1300 cm^{-1} belonged to the –C-O stretching vibration in the ester structure. The broad band at 2979 cm^{-1} in the spectrum of the methacrylic acid monomer belonged to the H-bonded –OH stretch of the carboxylic acid group. The peak at 1698 cm^{-1} belonged to the carbonyl group in the carboxylic acid group. The peak at 1625 cm^{-1} was the peak of vinyl group (C=C) stretching. The peak at 1440 cm^{-1} was the -OH bending peak of the carboxylic acid group. The peaks at 1307 and 1211 cm^{-1} wavelengths were carboxylic acid –C-O stretching peaks.

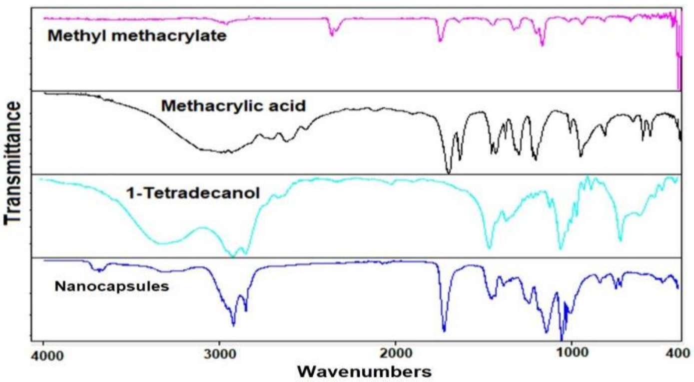

Figure 5. FT-IR spectrum of PMMA-co-MAA walled, 1-tetradacanol core nanocapsules produced by emulsion polymerisation method and materials used in nanocapsule production

When the FT-IR spectrum of the nanocapsules was examined, the peaks at 2953 cm^{-1}, 2919 cm^{-1} and 2849 cm^{-1} wavelengths were the characteristic C-H stretching peaks of 1-tetradecanol fatty alcohol. The peaks at 1461 cm^{-1}, 1456 cm^{-1} and 1435 cm^{-1} were C-H stretching peaks and belonged to the C-H stretching peaks of tetradecanol and methacrylic acid monomers in the structure of nanocapsules. In the spectrum, the sharp peak at a wavelength of 1724 cm^{-1} was the peak belonging to the carbonyl (C=O) group in the nanocapsule wall copolymer structure and was formed by the combination of the carbonyl peaks in the MMA and MAA monomers. The peaks of 1635 cm^{-1} and 1625 cm^{-1} wavelengths, respectively, in the spectra of MMA and MAA monomers were vinyl group (C=C) stretching peaks of methyl methacrylate and methacrylic acid monomers, but they did not appear in the spectra of nanocapsules. This case showed that the polymerization between methyl methacrylate and methacrylic acid monomers took place and the predicted copolymer wall structure (PMMA-co-MAA) was synthesized.

3.2. Yarn properties

In this section, morphological, thermal and physical properties of the PCM nanocapsule applied yarns were analysed. The yarn samples without nanocapsules were named as a reference or undoped while the samples comprising nanocapsules were called as a doped or composite yarn.

Yarn images

When the longitudinal views of the yarns were examined, PCM nanocapsules were easily observed on the surface of all polyester fibers (Figure 6). In the cross-sectional images of the yarns, it was seen that the nanocapsules were attached to the fiber surfaces (Figure 7). In particular, presence of capsule in the yarn structure was getting higher as the feeding rate values were increased from 62.5 mL/h to 77.5 mL/h (Figure 6B). It was determined that the capsules agglomerated, and settled on the surface of the fibers in the capsule cluster form with the increase of the feeding rate values. Capsule clusters were clearly seen on the fibre surfaces and between the fibres for 77.5 mL/h feeding rate. The agglomeration tendency of the capsules is an inevitable problem especially in applications in the form of dispersion in aqueous media. Particularly, decreasing particle size and size distribution homogeneity increases the aggregation tendency. The capsules produced in this study showed a clustering tendency due to their nano size. In short, SEM images showed that PCM nanocapsules could be integrated into polyester ring yarns.

Thermal properties

Thermal properties of undoped and PCM nanocapsule doped polyester ring spun yarns were analysed by Thermal History (T-History) test method. The changes in surface temperatures of yarn samples in variable temperature environments were determined. Undoped and nanocapsule doped yarn samples were firstly conditioned and then temperature changes on the yarn surface were measured with a thermal camera (Fluke TX 500) during the heating of the sample in a warm insulated box. The time-dependent graphs (T-history graphs) of the temperatures measured every 30 seconds with a thermal camera were drawn. In T-History graphs, y-axis shows the temperature measured on the surface of the yarn sample while x-axis shows the measurement time. In the T-history test, the differences on the surface temperatures of the undoped and PCM nanocapsule doped yarns were compared for determination of thermo-regulating effect of the PCM in the yarn structure.

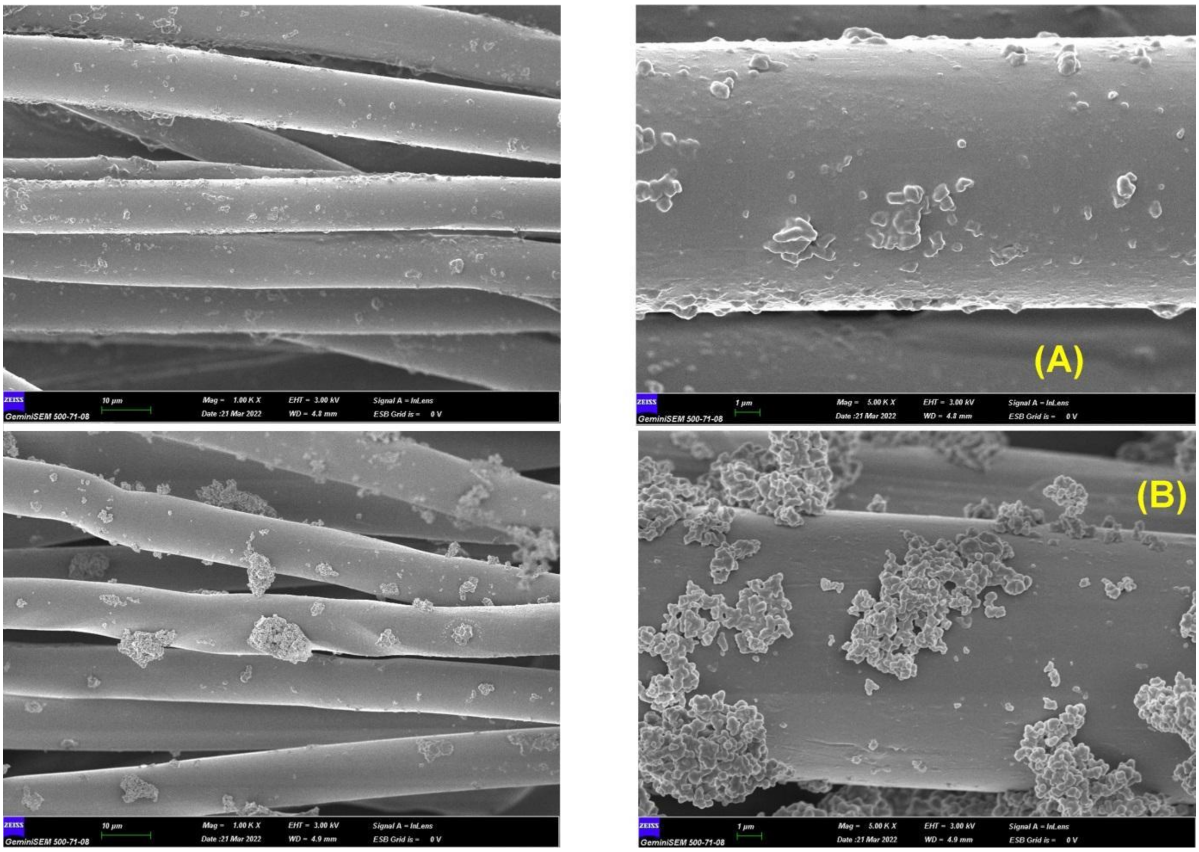

Figure 6. Longitudinal views of PCM nanocapsule loaded Ne 30/1 polyester ring spun yarns
(A: 62.5 mL/h, B: 77.5 mL/h feeding rates)

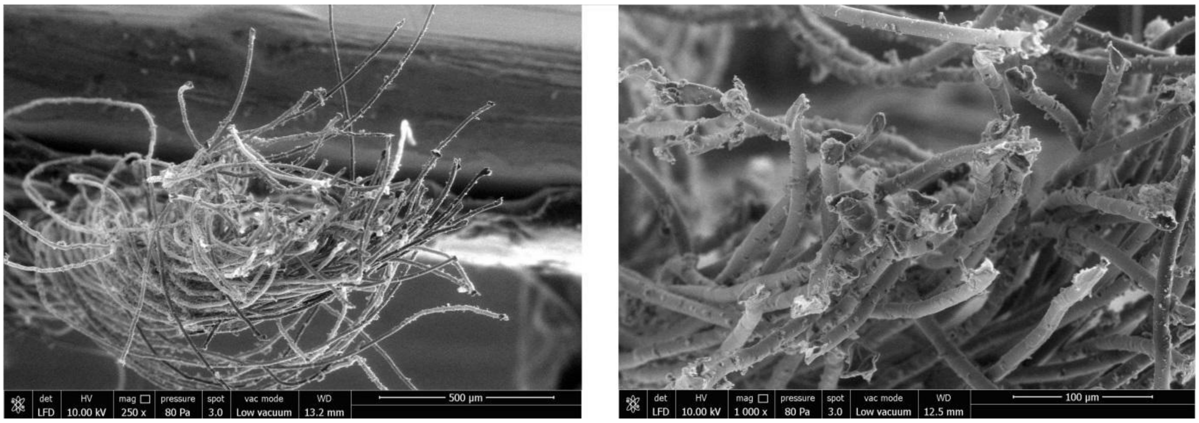

Figure 7. Cross-sectional images of PCM nanocapsule loaded Ne 30/1 polyester ring spun yarns produced at 77.5 mL/h feeding rate

When the undoped and PCM nanocapsule applied yarns were placed in a warm insulated box after the conditioning in a cold environment, their temperatures increased by the time. This case was named as warming-up period. After this point, the rate of increase tended to slow and surface temperature reached to a maximum value at the end of the measurement period. This period was named as saturated surface temperature region. During the warming-up period, surface temperature of the undoped yarn increased rapidly to 21.2 °C in the first 10 minutes while the temperatures were 13.5-17.4°C °C for PCM nanocapsule doped yarns depending on the feeding rates. After this point, the rate of increase tended to slow and saturated surface temperature peaked at 38.1 °C at the end of the measurement period (77th minute) for undoped yarns. As to PCM nanocapsule doped yarns, 32.7-35.5 °C maximum surface temperatures were determined at the end of the measurement period (Figure 8). It was determined that there was a significant difference in the surface temperatures of undoped and PCM nanocapsule yarns. Polyester yarns having PCM nanocapsules had lower surface temperatures during all the measurement process. Temperature differences might be resulted from PCM in the structure. PCM could absorb latent heat from the environment during its melting process in a high temperature environment and this feature of PCMs provided lower surface temperature values.

In the study, temperature difference value between undoped and PCMs doped yarns was calculated for certain measurement time. As seen in Table 2, at the end of the measurement period, the temperature difference values change between 2.6-4.0 ºC at the feeding rates below 70 mL/h while they were about 4.8-5.4°C at the feeding rates above 70 mL/h. The lowest mean temperature difference value was determined as 2.3° at 62.5 mL/h feeding rate while the highest temperature difference value was determined as 5.5°C at 77.5 mL/h feeding rate.

Table 2. Differences in surface temperatures of virgin and PCM nanocapsule incorporated polyester yarns at different feeding rates for 6% capsule concentration (ºC)

Time (min.)	62.5 mL/h	67.5 mL/h	72.5 mL/h	77.5 mL/h
05:00	1.00	2.20	3.40	1.90
15:00	3.60	7.40	8.00	6.70
30:00	2.90	5.30	5.50	6.20
45:00	2.00	4.30	5.10	5.50
60:00	0.90	4.00	4.80	5.40
75:00	2.30	4.00	4.80	5.40
77:30	2.60	4.00	4.80	5.40

Yarn physical properties

In order to determine the effect of PCM nanocapsule presence on yarn properties, yarn physical properties were investigated. In line with the results obtained in this section, it was also aimed to obtain an idea about the use of the yarns for the production of woven and knitted fabrics. According to the results given in Table 3, it was observed that PCM nanocapsule doped polyester ring spun yarns had higher yarn unevenness and yarn imperfection values. When the tensile properties were examined, it was determined that polyester yarns having PCMs had lower yarn tenacity and slightly higher breaking elongation values compared to undoped polyester yarns. Similar to the results observed in viscose yarns, it was determined that yarn unevenness and faults increased, and yarn strength decreased after capsule application to viscose fibers. In nanocapsule doped yarns, nanocapsule presence and also agglomeration in the nanocapsules might be a reason for the deterioration in yarn unevenness, imperfections and tenacity values [16]. SEM images showed the presence of capsules on the surface of the fibers and capsule aggregation. Therefore, PCM nanocapsule clusters might cause a negative effect of yarn properties. On the other hand, surfactant used for nanocapsule dispersion might reduce fiber-fiber friction and this case might deteriorate the yarn unevenness and tenacity properties [16]. Lord (2003) reported that yarn strength for a staple yarn varies from about 10 cN/tex for the weakest yarns to 30 cN/tex for the best ones [20]. Therefore, the tenacity of PCM doped polyester ring yarns was between 10 and 30 cN/tex and it was evaluated that PCM doped yarns had properties that can be used in weaving and knitting processes.

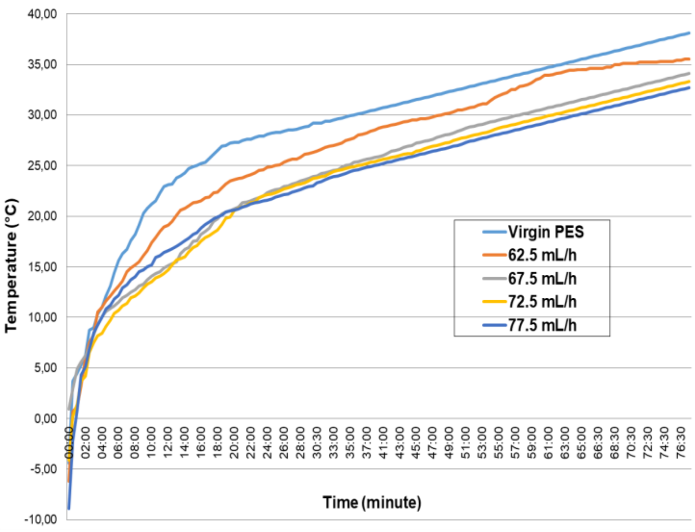

Figure 8. T-history curves of virgin and PCM nanocapsule incorporated polyester ring spun yarns for 6% capsule concentration

Table 3. Yarn properties of undoped and PCM nanocapsule doped polyester ring spun yarns

Feeding rate (mL/h)	CVm (%)	Thin places (-50%)	Thick places (+50%)	Neps (+200%)	Total IPI	H	Tenacity (cN/tex)	Breaking elongation (%)
0 (Undoped)	11.07	0	25	32	57	5.1	26.53	11.58
62.5	12.62	0	70	40	110	5.81	19.58	12.25
67.5	13.07	3.3	56.7	43.3	103.3	5.83	18.49	12.03
72.5	11.78	0	33.3	26.7	60	5.86	20.73	12.45
77.5	11.56	0	50	40	90	5.48	19.86	12.37

4. CONCLUSION

This study focused on the integration of PCM nanocapsules into the polyester staple open fiber bundle during the short staple yarn spinning process via an alternative nanocapsule application method in order to fabricate thermo-regulating polyester surfaces. SEM images indicated the presence of nanocapsules in yarn structure and time-dependent surface temperature (Thermal-history test) measurements showed that PCM nanocapsules incorporated yarns exhibit temperature differences about 2-5 °C compared to undoped yarns during all the measurement period. Cooling effect of PCM in yarn structure provides nanocapsule-doped composite yarns heat up less in high temperature environment compared to undoped polyester yarns. Alternative application method and the produced spun yarns from staple fibres can be a potential to rival the thermally adaptive textile products produced from specially designed synthetic fibers. Such integrated yarn materials have demonstrated promising potential to be used as thermo-regulating textile material.

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SUSTAINABILITY APPROACHES IN DENIM PRODUCTS AND PRODUCTION PROCESSES

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ABSTRACT: Sustainability in denim refers to the practices implemented to reduce the environmental, economic and social impacts of the denim production process and these practices are divided into two as product and production process. Sustainable denim product practices include various approaches such as using environmentally friendly, organic materials and recycled denim. In the sustainable production process, there are more sustainable alternatives such as desizing with amylase enzyme, mercerization with the best available techniques, bleaching with enzyme, ozone and laser technologies, washing with natural resources and water reduction technologies. This study aims to explain the sustainable product and production process that can reduce waste, water and energy consumption, using environmentally friendly raw materials, recycling and reuse.

Keywords: Sustainable, denim production, recycled denim, denim fading, denim washing

DENİM ÜRÜNLERİNDE VE ÜRETİM SÜREÇLERİNDE SÜRDÜRÜLEBİLİRLİK YAKLAŞIMLARI

ÖZ*:* Denimde sürdürülebilirlik, denim üretim sürecinin çevresel, ekonomik ve sosyal etkilerini azaltmak için uygulanan uygulamaları ifade eder ve bu uygulamalar ürün ve üretim süreci olarak ikiye ayrılmaktadır. Sürdürülebilir denim ürün uygulamaları, çevre dostu, organik malzemeler ve geri dönüştürülmüş denim kullanmak gibi çeşitli yaklaşımları içermektedir. Sürdürülebilir üretim sürecinde amilaz enzimi ile haşıl sökme, mevcut en iyi tekniklerle merserizasyon, enzim, ozon ve lazer teknolojileri ile ağartma, doğal kaynaklarla yıkama ve su indirgeme teknolojileri gibi daha sürdürülebilir alternatifler bulunmaktadır. Bu çalışma, atık, su ve enerji tüketimini azaltabilecek, çevre dostu hammaddeler kullanarak, geri dönüşüm ve yeniden kullanıma sunabilecek sürdürülebilir ürün ve üretim sürecini açıklamayı amaçlamaktadır.

Anahtar Kelimeler: Sürdürülebilirlik, denim üretimi, geri dönüştürülmüş denim, denim ağartma, denim yıkama

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1. INTRODUCTION

Sustainability, which means continuity, is based on the principle of utilizing renewable resources by meeting human needs without harming nature or with minimal harm. Sustainability creates a healthy ecosystem by aiming for the continuity of natural and economic resources and the progress of humanity. Rapidly increasing human population, non-renewable energy use with the effect of developing technology, unconscious use of limited natural resources and increasing environmental pollution are among the important factors that emphasize the necessity of the emergence of sustainability. Sustainability involves recognizing the interconnectedness of economic, social, and environmental systems, and working to address the challenges that arise when these systems come into conflict. It requires considering the full lifecycle of products and services, from production and consumption to disposal and recycling, and striving to minimize negative impacts on people and the planet.

Sustainability in the denim industry refers to the environmentally and socially responsible production of denim garments, which minimizes negative impacts and maximizes positive contributions to society and the planet. While evaluating the effects of denim production on the environment, society and economy, all activities related to denim production such as raw materials, production, transportation, use and disposal should be evaluated, and all factors should be considered. These activities are included waste, water, and energy consumption, using eco-friendly raw materials, improving worker conditions and labour practices, and recycling and repurposing.

In this study, sustainability approaches that are frequently applied in terms of raw materials and production in the denim sector are examined. Firstly, the three main components of sustainability, namely environment, economy and social, are discussed. Then, the denim production process, eco-friendly denim and recycled denim products used in denim production and sustainability practices applied in dyeing, desizing, mercerization, fading and washing processes are explained. In order to reduce the environmental, economic and social impacts of the denim industry, sustainability practices are an important issue that should not be ignored.

2. SUSTAINABILITY

The concept of sustainability that emerged from forestry means never harvesting more than a newly growing forest produces. It was formed with the belief of protecting natural resources, traditional beliefs from our ancestors and concern for the future [1]. However, sustainability means more than forest protection rules. Sustainability means not using more resources than can be reproduced in the same period [2].

In its most basic form, sustainability means the capacity to be permanent. For something to be sustainable, it must be used for a long time. It is based on the principle of transferring the world we live into the next generations without harming them or with the least damage. It is to reconstruct the waste material, turn it into a product, and ensure its long-term use. Sustainability, one of the new elements of the scientific revolution, is a concept aimed at ensuring the continuity of natural and economic resources and the progress of humanity [3]. New technologies bring side effects as well as advantages. Sustainable development is a social task and is associated with the use of technology. In the absence of technological advances, societies can collapse. It is necessary to maintain the balance between technology and sustainability in order to develop societies. Therefore, in order to comply with the principle of sustainable technology, the concepts of “human”, “profit” and “planet” should be given priority [4].

The understanding that environmental pollution, especially encountered in industrialized regions of the world, began to threaten our future, gained an international character with the "United Nations Human Environment Declaration" published in Stockholm in 1972 for the first time. At the conference, attention was drawn to the carrying capacity of the environment, the use of resources, the main problems created by economic and social developments, and the foundations of the idea of sustainability were revealed [5]. The World Commission on Environment and Development, also known as the Brundtland Commission, in 1987, reconsidered sustainable development as the broad political vision. Sustainability has been defined as the viability of natural resources and ecosystems over time and the preservation of human living standards and economic growth [6]. The term sustainability was later discussed extensively at the United Nations Conference on Environment and Development (UNCED) held in Rio in 1992. At the Rio conference, sustainable development goals were set on environmental issues on climate change, biodiversity, and desertification [7]. In 2002, the World Sustainable Development Summit was held in Johannesburg. As a result of the summit, two documents, “Johannesburg Declaration for Sustainable Development” and “Johannesburg Implementation Plan” were presented. As a result of the summit, the objectives of the “Implementation Plan” such as eradicating poverty, changing unsustainable production and consumption patterns and sustainable development in the globalizing world were revealed [8].

2.1. Environmental Approaches

Problems such as global warming, depletion of natural resources, climate change, and depletion of the ozone layer, acid rain and air pollution are increasing day by day. These problems may affect many areas, especially human health, and become unavoidable problems for future generations in the end. Solution methods that can be applied in this sense; It is seen as the use of renewable energy and substances, the prevention of air pollution and ozone depletion, and the use of sustainable resources. With environmental sustainability approaches, it is aimed to use the air, water, and land resources of people in an economical way. Increasing environmental pollution as a result of production and consumption brought about by overconsumption with population growth causes depletion and destruction of natural resources.

Environmental sustainability is a universal issue that many countries should consider. The balance between production and consumption activities that will be needed for all countries differs. Some countries need to focus more on controlling pollution, while others need more to reduce harvest rates of renewable sources to regeneration rates or reduce per capita consumption [9]. For example, in countries with intensive agricultural production, it is possible to encounter problems such as deterioration of soil health and land when environmental sustainability is not taken into account. In addition, there are problems such as the extinction of large whales and the decline of many fish and tropical timber stocks below harvestable levels. In this sense, it will be a solution for OECD (Organisation for Economic Co-operation and Development) countries to take action and lead the way compared to developing countries. Some measures can be taken, such as implementing environmental sustainability policies and reducing excessive consumption and waste [10].

Within the scope of the environmental sustainability principle, industrial ecology and green chemistry applications such as wastewater management, energy management, and reduction of CO2 emissions are included. In this sense, applications that can significantly reduce the high energy consumed in the cement production process and environmental impacts [11], the use of wastewater streams as a potentially valuable resource [12], applications such as industrial monitoring and control systems aimed at reducing energy consumption in building energy management systems [13] can be given.

The most important issue to be considered in sustainability practices is the carbon footprint. Carbon footprint (CFP) is defined as the measure of the damage caused by human activities to the environment in terms of the amount of greenhouse gas produced and measured in units of carbon dioxide [14]. CFP originates from the global warming potential (GWP) and was first included in the scientific literature by Høgevold in 2003 [15]. The effects of climate change cause carbon footprints to be seen widely. CFP carries risks of chemical pollution or depletion of natural resources [16]. For example, for a T-shirt in the textile industry, the CFP calculation covers the time from cotton planting to the final finishing of the T-shirt. [17]. Another concept, water footprint (WF), is defined as the total volume of fresh water used, consumed, and polluted. WF is measured by calculating the volumes of polluted water per unit time or functional unit during evaporation, incorporation into the product [18]. Cotton fiber is one of the most used fibers to create fabrics in the world textile industry. In the production of cotton fabrics, a water footprint is created for the agricultural process, such as the production and harvesting of cotton, and for the industrial process, such as turning the fibers into fabrics. Cotton's WF consists of three water footprints: green, blue, and gray. Evaporation of infiltrated rainwater represents the green WF, while surface or groundwater extracted for irrigation represents the blue water footprint [19]. Gray WF identifies copper and silver contaminants. The woven fabric sizing process has the greatest variation in high gray WF contaminants, followed by stock and yarn processing and simple knit fabric processes [20].

Life cycle assessment (LCA) is often used to assess the environmental impacts of a product. LCA is a multi-step assessment method for calculating environmental impacts, such as CFP, over the life of a product [21]. LCA is defined by ISO 14040 as "compilation of life cycle assessment (LCA) principles, framework and environmental impacts" [22].

2.2. Economical Approaches

Developing countries need land for food, rivers for water, and forests for fuel. For this reason, the consumption of natural resources and environmental destruction are increasing. Economic growth should be less energy consuming and environmentally friendly potential for environmental development. A balance must be struck between economic growth and environmental destruction. The gains of less developed countries compared to developed countries are decreasing day by day. In this sense, industrialized countries should develop new policies [23]. For countries to provide economic sustainability approaches correctly, cost and performance factors should be considered. Production costs and life cycle costs are considered for economic evaluation [21]. It is important to intervene in the circular economy and the textile industry while making this assessment. The circular economy (CE) business model has a structure that aims to prevent resource depletion and close the energy and material cycles. For the correct implementation of the CE business model, an organizational transformation is necessary to reveal the current cyclical state of the supply chain and identify challenges and opportunities [24].

The textile sector has an important place in economic development with factors such as industrial production and employment. For this reason, sustainable efforts are made at every stage in the textile industry, from fiber production to the production of textile products, and are encouraged to make higher profits. Within the scope of economic sustainability, an economic sustainability radar such as partnership or cooperation, profitability, added value, new market position and competitiveness development and long-term business development is created [25-27]. Achieving a sustainable economy in the textile sector can be achieved by achieving high profitability with minimal environmental damage and resource use. For this reason, determining factors such as management of intangible assets of enterprises, energy and raw material cycle, market competitiveness and country policies should be taken into consideration.

2.3. Social Approaches

Social sustainability focuses on meeting the basic needs of individuals as a complement to environmental and economic sustainability. It includes equality, welfare and balance between socio-cultural groups and legal entities [28]. For example, factors such as social homogeneity, fair incomes, equal access of people to goods, services and employment ensure social sustainability and holistic development in a society [29]. Creating an environment that is compatible with fair social, economic, and environmental conditions among people, regardless of race, religion, language, gender, culture, or socio-economic status, constitutes the vision of social sustainability. This idea is capable of creating radical new form and value in the future [30]. One of the sectors with the highest human employment is the textile sector. Social sustainability in the textile sector should be developed through improvements in the quality of life such as good working conditions in the business environment, fair wages, raw material production that does not harm human health, equality between men and women, and appropriate working hours. There is no doubt that social sustainability will support stability in these areas, people working in harmony and welfare as well as economic development.

3. DENIM INDUSTRIES AND DENIM FABRIC PRODUCTION

Denim is a type of cotton fabric in which the weft thread goes under two or more warp threads. The most widely known type of denim is the indigo colored twill weave, in which the twist yarn is left blue and the weft yarn white [31]. Generally, denim fabrics are 3/1 twill cotton fabric and having weights of 14½ ounces per square yard. The most frequently used denim fabric structures are 2/1 and 3/1 different combination twill structures (Figure 1.) [32]. The name ‘denim’ is thought to have originated from the French serge de Nimes. Denim firstly was a durability fabric especially in the manufacture of overalls and trousers for hard labour but now denim products are used in extremely popular for leisure wear [33].

The denim industry, which constitutes a significant percentage of the textile industry, maintains its superiority in imports and exports in the world clothing market. The USA and the European Union (EU), as the top developed countries, import most of the denim textile and apparel products. Mexico, the most important supplier of denim pants, is followed by China and Bangladesh. These three countries account for more than 66% of raw denim imported into the USA [33]. Denim consumers worldwide differ between Europe, the USA and Asia. While European consumers demand high-priced fashion denim, American consumers are generally willing to pay less than international consumers [34]. Consumer preferences are a factor that differs according to geography, culture, and demographic structures.

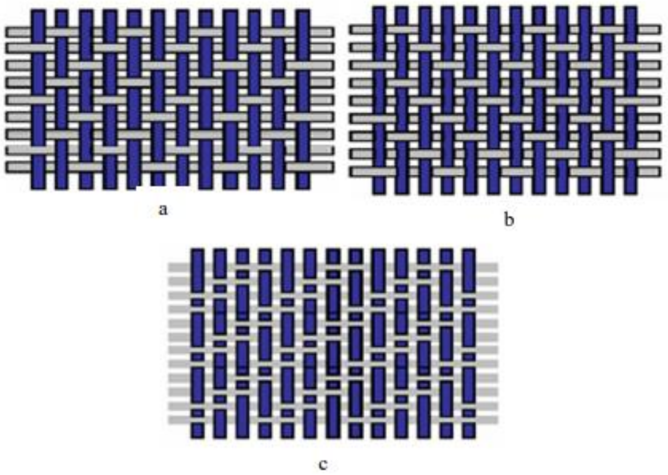

Figure 1. Common weaving construction types used at denim fabric types a) 2/1 Z Twill, b) 2/1 S Twill, c) 2/2 Z Twill [32]

Denim fabrics have some general features. The warp thread of denim fabrics is cotton thread dyed with indigo dye or sulphur dyes, and the weft thread is white cotton thread. The front and back faces are different due to the fabric weave. White weft threads are prominent on the reverse, and dyed warp threads are evident on the front. Warp yarn is thinner and more tightly twisted than weft yarn. The pH value of denim fabrics should be between 8-10. Light fastness is expected to be 4, sweat fastness to 5, friction fastness to maximum 3 for dyestuffs [35].

The process flow chart of denim fabric production, which includes spinning, warp preparation, fabric production and finishing processes, is shown in figure 2. The first stage in denim production starts with spinning the yarn in either a ring spinning or rotor spinning system. The conversion from fiber to yarn consists of various processes such as opening and cleaning, carding, drawing, roving, and spinning. In second step, warp yarns are dyed by the loop dyeing, rope dyeing or slash dyeing method with indigo. Synthetic indigo dyestuff is widely used in denim dyeing as it imparts the characteristic natural indigo blue color to denim [36] In loop dyeing, the yarns are dipped several times in the same bath. The second method is slash dyeing method. In the sizing procedure with slasher dyeing, 12 to 16 tension-controlled warp beams consisting of 350 to 400 threads of 50.000 m length are placed in front of the Slasher line. The Slasher line provides continuous dyeing, drying, sizing and warping in a single process cycle [37]. Third method is the rope dyeing technique, the rope wrapping process is done first in this. Approximately 350-400 threads are combined and made into ropes. At this point, it is important that the yarn tensions in the rope are equal or very close to each other. Around 12-14 ropes are passed through the dyeing machine. After dyeing, the ropes are dried in the drying cylinders, and the worker beam is prepared in the last step [38].

In denim production, after dyeing, sizing is used to increase the strength of the yarns during weaving. Indigo sizing is preferred for easy dissolution in hot water for washing after denim weaving [37].

In another step is the weaving process, which has shuttle- less, shuttle weaving and air system weaving machines [31, 37]. For the finishing processes, denim fabric goes through a singeing, brushing, washing, and drying. With these processes, it is aimed to provide the fabric with a smoother, non-rolling, soft, shiny, and slippery appearance. After the finishing processes, the denim fabric is inspected for defects such as uneven dyeing, bleaching and dyeing defects, oil stains, patches. Thus, denim fabrics could be categorized according to the quality. Last step of denim production is garment manufacturing, which have several operations such as pattern making, spreading, cutting, sewing, pressing, inspecting, and packaging [31, 38].

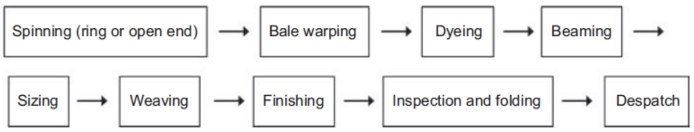

Figure 2. Warp yarn production flowchart of denim fabric [39]

Denim washing is an aesthetic finishing applied to the fabric to improve and improve the softness and comfort of the fabric. Chemicals and stones are used largely to achieve the softening and discoloration effects of denim garment washing [36]. There are two types of washing processes: dry and wet processes. Dry processes include eight different mechanical processes: scarping, sandblasting, manual damage, tagging, laser, resin, ironing-creases and flat press, print. Wet treatments are listed as desizing, stonewash, enzyme wash, bleaching, tinting – overdyeing, softening, rinse, rubber balls. While the aim in dry processes is abrasion, the purpose in wet processes is to give an appearance effect [37].

4. SUSTAINABLE DENIM PRODUCT APPLICATIONS

Sustainability can be evaluated based on a product/process, project, sector, and country. When this evaluation is examined in general terms, we come across as life-cycle evaluation or life-cycle thinking. Life cycle assessment (LCA) is a scientific method or tool for identifying, measuring, and evaluating all environmental impacts of a product, service, or activity throughout its entire life cycle [21]. It is used effectively to calculate the effects of the product, service, or activity on the environment, to identify the problematic points of production and to get down to the source of the problems. LCA, which also deals with the relationships between companies, suppliers, and customers, thus provides a total analysis of the environmental effects of a product from the cradle to the grave.

LCA for the denim industry can be divided into four phases. The first stage includes defining the objectives of the study and defining the denim product. The second stage is the collection and processing of data from all processes of the product life cycle, from the acquisition of raw materials used in denim to the development of the final product. At this stage, energy, raw material requirements, environmental emissions and discharges related to the denim product can be calculated and presented. This data can be used to calculate discharge from all processes of the product lifecycle. The third phase is called the "impact assessment phase", where the collected data is translated into its effects on human health, ecological health, and resource consumption. The final stage of the LCA process can be termed 'recommendations' based on the analysis of the impact assessment results [40]. LCA is a system that analyzes the entire process, from raw material to final product. Thanks to the special software developed for this system, many environmental effects can be demonstrated with numerical data. It has a very important place in the denim industry, which is one of the textile production areas where waste management and resource consumption are the highest.

It is a progression in the denim production cycle, starting with natural resources cultivation and extraction and continuing with consumer use and care. In this progress, reuse and recycling of denim products is an approach that completes the cycle. In this section, the raw materials of sustainable denim products will be examined under three main headings: eco-friendly denim, recycled denim and eco labels for denim production (Figure 3.).

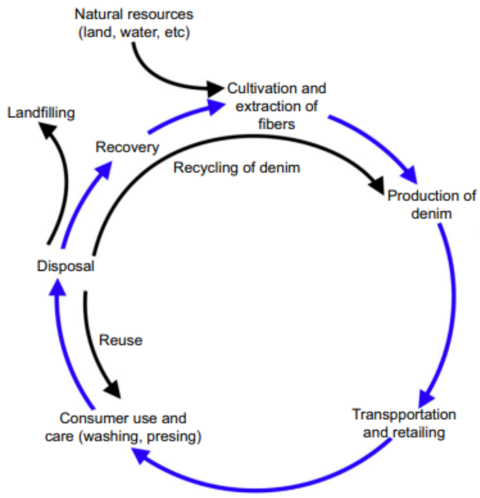

Figure 3. Phases of a product's life cycle (for denim). [40]

4.1. Eco-Friendly Materials in Denim Fabrics

Organic cotton, alternative natural fibers or recycle fibers materials are used to reducing the environmental effect of denim production. The use of these eco-friendly materials helps to create more environmentally responsible denim products that are healthier for both people and the planet.

One of the most used fibers is cotton in the textile industry. Preparing cotton raw material 1 kg organic cotton requires 7 to 29 tons of water. Cotton is the most toxic crop in the world [41]. Cotton uses more than 25% of all insecticides and 12% of all pesticides in the world. These insecticides are known as the most toxic chemicals in the world. Pesticide exposure poses many health risks, including birth defects, reproductive disorders, and immune system damage [40]. One of the most important property is tensile strength for denim fabrics. The tensile strength of denim fabrics must be maintained in the final product because the strength has a very important effect on the service life of the garment [42]. The fuzzy logic model was evaluated by Sarkar et al. [42] and the average relative error for tensile strength in warp and weft directions was found to be 2.82 and 3.92, respectively. In addition, the fixation coefficient for the tensile strengths in both the warp and weft directions was determined as 0.99. In the research, it was concluded that the tensile strength of 10 denim fabrics was compatible with the tensile strength found by fuzzy logic. With this model, it was possible to predict the tensile strength of denim clothes washed with bleach. Additionally, it was concluded that the environmental footprint of the applied model was positive in terms of material and process. Tarhan and Sarıışık (2009) [43] in their study, seen that fading methods decreased tensile strength and weight values, and color abrasion values of the fabrics was changed to due to the intensity and the pressure. Cotton fiber is used in the denim industry in different forms as organic cotton and recycled cotton. The use of recycled cotton has a positive effect on the environment and has good physical performance properties [44]. In the use of organic cotton, in order to reduce environmental impacts in the denim sector, regulations such as limiting or prohibiting the use of fertilizers and pesticides in organic cotton are made. Denim fabrics produced using organic cotton are seen as a more sustainable alternative to denim fabric produced with conventional cotton in the entire environmental impact process. The environmental damages and health hazards caused by cotton fiber have caused the denim industry to turn to alternative ecological fibers other than cotton. When the studies conducted in recent years are examined, it is seen that the amount of cotton in denim has decreased and ecological fiber blends for green denim such as hemp, bamboo, tencel, linen, soybean, viscose, and ramie are used. Physical and mechanical properties of some eco-friendly fibers in denim fabric are given in Table 1.

Hemp fiber, which is notable for its rapid growth compared to cotton, has very little water consumption and the need for herbicides or pesticides. The carbon footprint of cotton is 4.2 tons per ton, while that of hemp is 1.9 tons per ton. In addition, hemp fiber has moisture retention, breathability, UV resistance, antistatic, antibacterial, and hypoallergenic properties (Figure 4 [a]) [45]. Denim fabric containing bamboo viscose fiber has high air, and moisture permeability, elastic structure, antibacterial properties and soft-touch. Being a new kind of regenerated cellulosic fiber, bamboo viscose fiber, it is thought that its applications in the field of denim will increase due to its high tensile and tear strength properties (Figure 4 [b]) [46]. Tencel, the only man-made cellulosic fiber that performs relative to cotton, is a silky and shiny fabric. Tencel ™ denim, which contains at least 40% lyocell, is extremely durable and extremely comfortable compared to cotton denims. Tencel ™ is extremely breathable, absorbs moisture and has better performance characteristics compared to cotton [47]. Linen is a natural fiber made from the flax plant that is grown with minimal pesticides and water usage. Linen is a cellulosic fiber and its chemical treatment is similar to cotton properties (Figure 4 [c]) [48]. Chun et al. [49] observed that although linen denim showed antibacterial properties, the addition of flax did not increase its antibacterial properties. Soybean fibers have a soft and silky texture, providing a comfortable feel to denim garments and strong and durable, long-lasting, and hard-wearing material. Uzun [50] studied in her thesis, it was seen that soy protein fiber can be used in denim fabrics and sportswear fabrics with or without elastane, with 90% cotton-10% soybean, 70% cotton-30% soybean and 50% cotton-50% soybean protein blends. In the fabric performance tests, it was observed that soy fiber did not provide a performance-reducing effect. In addition, soy protein fibers has between 10-13% moisture absorption properties [46]. Viscose, also known as rayon, is a regenerated and semi-synthetic fiber made from cellulose. Ma et al. [51] created regenerated cellulose fiber from recycled waste denim. They observed that the produced regenerated cellulose fibers have mechanical properties and morphology similar to viscose fibers commonly used in the textile industry. Ramie is known for its durability, strength, silky lustre and natural resistance to bacteria and mildew, and it reduces to wrinkling. In addition, ramie is not as strong as cotton, but use as a good denim material in a blend [48].

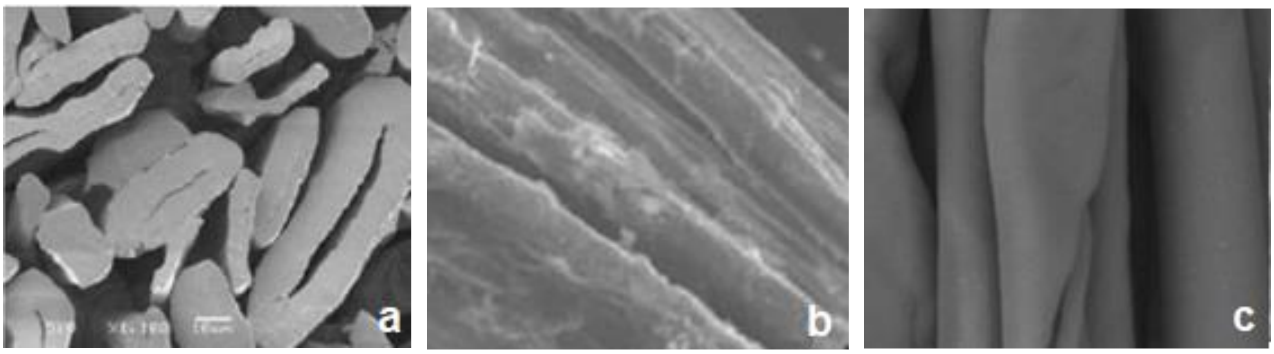

Figure 4. Microscopic View of Bamboo [a][52], Hemp[b][53], and Linen [c][54] Fibers

Table 1. Physical and mechanical properties of some eco-friendly fibers in denim fabric [48, 55, 56, 57]

Properties / Fibers	Length (mm)	Fineness (dtex)	Tenacity (cN/dtex)	Breaking extension (%)	Density (g/cm^3)
Bamboo	38-76	1,3-5,6	2,33	23,8	0,8-1,32
Hemp	300-400	9,63	3,7-4,5	35-45	1,48
Soy protein	38-76	0,9-3	3,8-4,0	18-21	1,29-1,31
Viscose	38	1,24	2,32	22,17	3,2

4.2. Recycled Denim

Denim recycle is the process of transforming used or waste denim into new products, reducing waste and conserving resources in the textile industry. The process involves collecting and sorting used denim garments or scraps, shredding them into fibers, cleaning and carding the fibers, spinning the fibers into yarn, and finally weaving the yarn into new denim fabric. This process is eco-friendly as it reduces the amount of waste generated by the textile industry, conserves resources, and reduces the carbon footprint associated with the production of new denim products.

Denim clothing consumption is widespread all over the world. Other dangerous chemicals such as cadmium, mercury, and lead, which are the remains of denim finishing, are also dumped into water sources. In addition, in the denim attrition process, coloring with toxic dyes, acid baths and sandblasting, and then chemical baths are made. Denim production, which uses a lot of water and chemicals, causes many harms to the environment, drinking water and people [58]. Non-biodegradable denim waste pollutes the environment by polluting and decomposing groundwater, producing the greenhouse gas methane [59]. With recycled denim, it is aimed to prevent these damages and to protect natural resources.

Recycling of waste in denim is divided into two as during denim production and post-consumer recycling. In denim jeans production, cutting waste is between 10% and 15% and this part is recycled by dissolving and reusing the fibers. Denim fabrics with cut waste are recycled by unwinding and reusing the fibers in additional yarn production (weft direction) [60]. There are color and fiber quality differences in post-consumer denim recycling. In addition, operations such as separation of non-textile parts such as buttons, zippers, rivets, and labels are required. Metal detectors are used to remove metal buttons and zippers. The recycled fibers from the separated pieces (can be seen in figure 5.) can also be used in open-end spinning [61]. Alp [62] produced denim fabrics from Open-End Rotor weft yarns in different blends in thesis study. He concluded that when the recycled cotton ratio increased, the weft direction breaking strength, warp and weft direction tearing strength, relative water vapor permeability, thermal conductivity, thermal absorptivity values decreased and the thickness values increased.

Figure 5. Recycled denim fibres [61]

With the government laws, regulations are being developed to reduce the solid waste management program, landfill through reuse and recycling [47]. For example, an average of 14 kilos of clothing is consumed in Sweden each year and 7.5 kilos of this is thrown away. Discarded clothing and textiles are often directly incinerated. When the waste is incinerated, there is a risk that the entire ecosystem will be exposed to combustible gases (KEMI). If not incinerated and disposed of in landfills, there is a risk of leakage and release of toxic substances from the clothing. For this reason, studies are carried out to separate textile wastes in Scandinavian countries [63].

4.3. Eco Labels for Denim Production

In the near future, policies such as sustainable denim production, increasing global warming, depletion of natural resources, and reducing the use of chemicals and energy are turning to the eco-labelling system. For this reason, it is necessary to monitor and report the carbon footprint at every stage of denim production, from raw materials to finishing and washing, transportation of finished products to transportation and consumer use. More than 40 eco-labels containing sustainable information such as "ethical", "eco-friendly", "organic" and "fair trade" are used in the textile and apparel industry [64]. The main ecological labels widely used in the world are EU Eco-Label, Bluesign, Blue Angel, Swan or Nordic Ecolabel, GOTS (Global Organic Textile Standard), Organic Exchange (Organic Content Standard), OEKO-TEX Standard 100 are listed as. n the EU-Eco-Label, some criteria have been determined by controlling the residues formed in the production of the fiber, air and water pollution, processes, chemicals used, purpose of use and life cycle of the product. There are decisive criteria for all natural or synthetic fibers used in a product [65]. Another widely used eco-label is the Bluesign label. This effect is used in applications for human and environmental protection such as reducing water use, CO_2 emissions, use of harmful substances, preventing the formation of environmental effects, ensuring consumer safety, and using environmentally friendly textiles [66]. The purpose of using another eco-label, Blue Angel has been to address environmental and health-related aspects of products and services. In addition, it is stated that Blue Angel eco-label users must comply with the basic principles and universal human rights specified in the basic labor standards in the production chain of the International Labor Organization (ILO) [67]. The Swan or Nordic ecolabel examines the entire life cycle of the textile product and all materials, including the accessories that make up the product, must comply with Swan standards. The production of the raw material in a textile product, the chemicals used in the processes of the product and the resources are evaluated separately [65]. It is a sustainable production and consumption-oriented approach that includes elements such as prevention of environmental destruction, reduction of emissions and waste, use of non-toxic materials and social responsibility. The GOTS label is the global standard for textiles using organic fibers. A high level of environmental and social responsibility is expected at every stage of the supply chain until the GOTS label is affixed to the product. It is necessary to document and evaluate all the inputs and accessories used in the creation of a textile product. This process continues from the organic structure of the fiber to the wastewater treatment structure of the enterprise, to its social responsibility [68]. For example, sandblasting of denim is prohibited as per the GOTS certificate, because of it puts worker health. Organic Exchange (Organic Content Standard), another global standard, detects the presence and amount of organic material in a final product. It examines the process of a raw material from the source to the final product and this process is approved by the expert. OEKO-TEX Standard 100 is a standard developed for the production of textile products that will not pose any risk to health and will not contain harmful chemicals. With the OEKO-TEX standard, textile raw materials, intermediate and final products are tested at all processing stages. Risks to human health in cases such as inhalation, ingestion, and skin absorption of harmful substances are controlled by regular control tests [69].

5. SUSTAINABILITY OF DENIM PRODUCTION PROCESSES

Sustainability in denim production continues throughout the entire life cycle of denim products, from raw material sourcing to manufacturing, transportation, use and disposal. Chemical management in denim production is the most important step in terms of sustainability. The careful and responsible handling of chemicals used in various stages of denim production, such as dyeing, finishing, and washing, helps to reduce environmental impacts.

There are various processes that can be used in denim dyeing, including rope dyeing, slasher dyeing, and continuous dyeing. Sustainable aspects of denim dyeing may include the use of eco-friendly and biodegradable dyes, reducing the amount of water used in the dyeing process, and implementing closed-loop systems that allow for the recycling and reuse of dyeing chemicals and water. There are several processes that can be used in denim washing, including stone washing, acid washing, bleach washing, enzyme washing, and laser fading. Each process achieves a different look and effect on the denim fabric. However, it is important to consider the environmental impact of these processes and prioritize the use of sustainable techniques such as laser fading and ozone washing. In this section, sustainable chemicals and methods used in denim finishing process will be explained.

5.3. Dyeing in Denim Products

Denim generally are customed dyed with indigo to produce brilliant blue shades with the desired wash effect. This rate is about 80% of denim worldwide being dyed in classic blue, black-blue or blue-black tones using indigo and sulphur black dye. Apart from these dyes, the remaining 20% denim products are dyed in different tones using sulphur for reduce cost, indanthrene, and another dye class [70-72]. Indigo can be dyed into cotton fibers very well. The best feature of indigo dyed jeans is the possibility of obtaining wash effects without losing the freshness of the color in repeated washings [72]. Indigo is a naturally water-insoluble dye and therefore an alkali and reducing agent must be converted to a soluble form before it can be applied to denim warps [73]. For indigo dyeing, 84 500 tonnes of sodium hydrosulphite and 53 500 tonnes of caustic soda are required each year [74]. In addition, İndigo dye has heavy metals and hazardous pollutants. Indigo is very difficult to decompose biologically, and high concentrations of indigo dye waste in the resulting effluent could damage to environment [75]. For these reasons, it is used synthetic indigo contains toxic chemicals such as aniline and N-methylaniline residues in denim dyeing. Apart from synthetic indigo, denim products are dyed with sulphur, reactive pigment, and direct dyestuffs. Most of these dyes contain heavy metals such as chrome, copper, and zinc [71]. Since indigo is insoluble in water, it mixes with wastewater and causes significant environmental damage. For this, conventional treatments such as activated sludge biological plants or/or coagulation-flocculation processes are applied. Membrane techniques, which are a sustainable approach to recover and reuse both chemicals and water by purifying wastewater, are being developed [76]. Another method for reduce environmental waste, the use of natural dyes could be used in denim production. It is possible to obtain different tones on denim by using environmentally friendly mordants such as onion extract, natural and synthetic mordant. Natural indigo may have important additional properties, including potent antimicrobial activity against various pathogens, anticancer activity, antioxidative activity, and UV-repellent properties [74]. Sustainable indigo dye can be made using natural indigofera plants, which are renewable resources that can be grown without harmful chemicals. Tia et al. [77] observed that natural indigo could be stabilized on a nanocellulose matrix carrier without chemicals, making the dye more ecologically safe to use on cellulosic materials. Natural indigo is biodegradable and using natural indigo reduces the amount of synthetic dyes and chemicals used in the dyeing process. However, it will be generally more expensive and time-consuming to produce than synthetic indigo, and the color will vary depending on factors such as the plant source, climate, and processing methods.

5.4. Desizing in Denim Products

Desizing, which applied to warp yarn, is the process to strengthen the yarn for weaving. The most used method of removing starch from denim products is to use amylase enzyme. Amylase enzyme is break down the long starch molecular chains (water insoluble) into smaller molecules (water soluble) which can be more easily washed away. Generally, enzymes are environmentally friendly and do not creating health hazards but sometimes they could be skin irritation. For sustainable desizing in enzyme, operators should use self-protective clothing such protective wear, hand gloves, safety goggles and face masks [39, 71].

5.5. Mercerization Process in Denim

Mercerization is the treatment of pure cotton fabric or yarn with a strong causticizing agent to significantly increase the strength of the dye and the strength and smoothness of the yarn. Then, the caustic soda is removed by washing. In denim, the fabric is held under tension using a strong sodium hydroxide solution (approximately 18-24%) and washed off the caustic after 1-3 minutes [78]. Caustic soda removed by washing causes environmental damage. Varol et al. [79] achieved caustic recovery from mercerized wastewater originating from a denim textile manufacturing facility by using membrane technology. Thus, they aimed to prevent environmental problems for caused by caustic material with high pH (12-13) values in wastewater. Yükseler et al. [80] observed that methods such as Best Available Techniques for the treatment, reuse, and reduction of wastewater amount in dyeing and nanofiltration for the recovery of caustic from wastewater can be effective. They achieved satisfactory results in meeting wastewater reuse criteria by providing a 30% reduction in total specific water consumption in denim production.

5.6. Fading Technologies in Denim

Sustainable fading techniques in denim production typically involve the use of innovative technologies and processes that reduce the environmental impact of traditional denim washing and finishing methods. These techniques include enzyme fading process including eco-friendly chemicals, ozone fading process and laser fading process. In addition, it is aimed that the reuse of water in the washing process to reduce water consumption and pollution. In this section, these sustainable fading techniques will be explained.

5.6.1. The Enzyme Fading Process

To fading denim fabrics, the products are washed with pumice stone and partially bleached with sodium hypochlorite, neutralized, and washed again. Since all these processes cause great environmental pollution, bleaching is done with enzyme applications. Since the cellulase enzyme has a cleansing effect on the fiber surface, it can partially replace the pumice stones to obtain the stone washing look. Laccase enzyme that works faster than traditional bleaching techniques [51], has the feature of bleaching indigo dyed denim clothes to lighter shades [81]. Kan et al. [82] investigated the effect of enzyme treatment using neutral cellulase on the colour fading properties of cotton denim fabrics. They observed that denim fabrics treated under optimum condition retain the best color yield with the desired aging effect. In addition, cellulase has property as catalyses the hydrolysis of cellulose molecules' 1, 4-beta glycoside bond and so it produces less pollution and is easier to treat in effluent plants [47]. Uses enzyme in denim fabrics for fading are both sustainable and efficiency approach.

5.6.2. The Ozone Fading Process

Ozone (O3), can be used to create the color fading effects in denim [83], can be utilized to oxidize many organic and inorganic impurities [84]. Ozone can be applied directly as the gas phase without a water bath, thereby reducing water consumption significantly. Being an environmentally friendly substance, ozone is seen as a very good option for substances such as hydrogen peroxide and chlorine bleach [85]. Ozone fading is a sustainable process which could use no chemicals and no waste. Because ozone has very high oxidizing power, it can attack the glycosidic bond of cotton fiber and has an effect that can break down the olefinic groups of indigo dye. Thus, ozone is a sustainable alternative that can be used in bleaching denim fabrics [86]. Rajkishore et al. [83] listed 4 sustainability benefits of ozone bleaching over traditional bleaching methods. These benefits are environmental, economic, social, and production benefits. Ozone bleaching is a method that reduces environmental pollution and does not cause wastewater generation and recycling problems. Economically, the consumption of chemicals, water and energy is low. As a social benefit, it reduces the workload, and fatigue of the employees. In terms of production, the ozone bleaching process is faster, thus saving energy and operating costs. Besides its sustainability feature, ozone is an effective oxidant and disinfectant that can break down the cellular structure of viruses, parasites, and bacteria. It has some advantages over chlorine, which is widely used in the textile industry, such as not being permanent and not leaving secondary derivatives [87]. Ozone washing taking attention with minimal production costs and high production capacity system enhances whiteness and eradicates the back staining as well as other potential organic spots (Figure 6.) [88]. Another important issue in the use of ozone bleaching is the effects on the physical and mechanical properties of denim fabrics. Ben Faraj et al. [86] observed that ozone treatment had significant effects on the mechanical and color properties of denim, such as the loss of force at break and the decrease in the bagging resistance. For this reason, they suggested that denim fabrics should be treated with medium-intensity ozone for a short time.

Figure 6. Before and After Ozone washing in denim [88]

5.6.3. The Laser Fading Process

Sustainable laser fading technology is an innovative and eco-friendly technique of fading denim fabrics, which has been gaining popularity in the denim industry as a more sustainable alternative to traditional methods such as sandblasting and acid wash, bleach wash, stone wash, and enzyme wash [89]. Sustainable laser technology has several advantages over traditional methods, including reduced water and chemical consumption, energy consumption, and process flexibility, as well as reduced environmental pollution. The laser fading process can be easily applied to ab industrial processes for more detailed and complex designs to be created [90]. The laser creats extensive heat in denim fabric. Laser energy is absorbed as taking heat and the material rapidly heats occur melting as a phase change from solid to liquid takes place on denim. Laser fading works with a burning mechanism [91]. The fading efficiency is related to the laser wavelength, power density, exposure time, and beam width (Figure 7.) [92]. Also, laser fading is a popular computer-controlled process on denim products. Laser fading works with better accuracy and higher productivity than other bleaching methods. Many types of lasers are used in denim laser fading. These are medium of laser that may be a solid (e.g., Nd: YAG), gas (e.g., CO2, Ne), or liquid (dye). In literature, color fading, the following laser medium, including Nd: YAG, CO2, and CTH: YAG was seen. Especially, Nd: YAG processes have a shorter wavelength and are best suited to the pulsed application mode,which includes smaller coverage, deeper penetration, and precision machining for specific purposes [93]. Some researchers have concluded that CO2 laser [93-95] more efficient utilizing low heat generation, clean production and low cost. Color fading with CO2 laser is widely applied in the textile industry [94]. Ortiz et al. [95] observed that CO2 laser bleaching has higher efficiency, lower energy waste, less heat generation, simpler and cheaper cooling systems, and less water consumption than other laser types. In another study, Kan [96] concluded that the CO2 laser process is a cleaner production method for color fading of denim fabric than other methods, and that high laser power creates paler tones in denim fabrics. Similarly, Venkatraman and Liauw [97] investigated the performance properties of indigo dyed denim fabrics of different densities after CO2 laser bleaching. As a result of the study, they observed that the degree of grayscale affects the color change and increases color fading in all kinds of fabrics, as the increased structural damage in the cellulose polymer will increase as the grayscale level increases. However, in the study by Chow et al. [98], it was concluded that in the laser bleaching process, the laser level causes thermal degradation on the cotton fabric, and the chemical composition of the treated cotton fabric surface changes. From this point of view, keeping the CO2 laser level at an optimum level is the right approach. In addition, the appropriate level of laser level is also an important issue for the health of textile workers. Lasers with deadly voltages contain hazards such as electric shock, vision loss, and skin injury. To reduce these hazards, training of working personnel, use of protective equipment, administrative and engineering controls should be carried out [99].

Sakib et al in their study, were determined of color fastness to rubbing in laser fading for denim fabrics. They were seen that non-wash condition and the wash condition of the denim fabric wet rubbing is so different for fastness in laser denim [100] The LEVI'S Standards (LS&CO. Global Fabric Performance Standards) suggest that denim fabric has very low wet rubbing fastness. In addition, according to OEKO-TEX standards, the pH reference range that should be in denim fabrics is between 6 and 7.5. In their study, Tölek and Kadem (2016) stated that a standard cotton denim fabric has a color fastness to light 5, pH 5.5, color fastness to wash 3, color fastness to rubbing -shade change in dry 5, in wet 3-4 [101].Wash fastness is related to the adhesion of nanoparticles to the fibers, and it is possible to increase the washing fastness by immersing the nanoparticles fabrics in a solution containing a certain binder. Thus, covalent bond formation can occur between nanoparticles and the fabric surface. Nano-Ag process is applied to increase washing and light fastness [102]. In addition, with synthetic indigo dyes used in denim fabrics, the fastness and washing properties of the textile material can be improved by factors such as pH and number of dips [103].

Figure 7. Laser Fading Process in Denim Fabrics [91]

5.7. Washing Technologies in Denim

Sustainable washing process in denim refers to a method of washing denim garments without causing harm to the environment or using excessive amounts of water and energy. This process is aimed to reduce the environmental impact of denim production by adopting eco-friendly practices. Washing with natural materials and water reduction technologies in the washing process, which are frequently used in sustainable washing, are described in this section.

5.7.1. Washing by Natural Resources

Due to the use of chemicals and stones in denim washing processes, a waste problem arises that questions the sustainability of the process. For this reason, efforts are being made to develop a denim washing process with ecological washing techniques that can result in zero waste discharge. Dry processes or nearly waterless processes are slowly becoming a sustainable trend to replace traditional wet processes in denim garment washing [35]. Shibly et al [104] observed in their studies, the washing effects natural reagents such as lemon, pomelo, guava, ginger, and spondias mombin on indigo dyed denim fabric. The use of natural reagents in denim washing provides less polluting natural washing. Hoque et al [105] focused on in their studies washing 100% cotton indigo dyed denim garments with natural substances like soapnut, lemon juice, tamarind, and sunlight. Natural washed samples were seen less amount of shrinkage as well and greater strength and less color difference values than the samples washed by synthetic chemicals (Figure 8.). Using natural agents in washing denim are seen optimum eco-friendly method for sustainability.

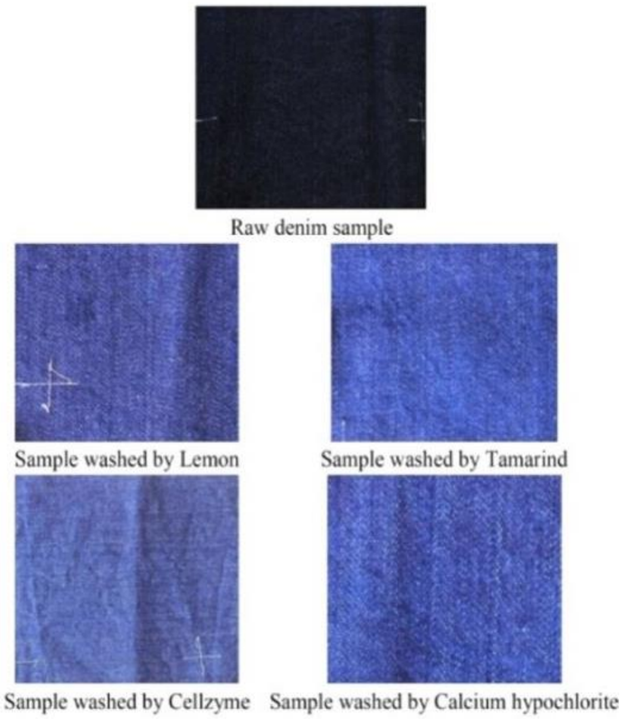

Figure 8. Color difference on fabric samples washed by natural and synthetic reagents [105]

5.7.2. Water Reduction Technologies

Reduced water washing techniques are a set of denim washing techniques that are designed to conserve water and reduce the environmental impact of denim production. These techniques use less water than traditional washing methods and rely on alternative methods to achieve the desired effect. These sustainable washing techniques are those that can obtain a washed look and excellent handle using a minimum quantity of water [36]. These washing techniques are classified as using laser, ozone, nano bubble, new enzyme formulations and crosslinking agents. How each technology can affect water consumption, and its advantages in reducing water footprint comes from the combination of these technologies and their use in finishing [106]. Laser technology is used to create the desired fading and distressing effects on denim faster and without the need for water. Kan (2014) [107] concluded that traditional denim washing requires more rinse steps and laser treatment can save water in the manufacturing process. While the denim design, which was created with the classical method, was created by washing the stone with an enzyme for 45 minutes at 55 °C, the same design was produced by laser process within 3 minutes at room temperature. This shows that laser fading saves energy, water, time, and chemicals compared to the traditional process. Another reduced water washing technique is ozone technology, which uses ozone gas to bleach and fade denim, which reduces the need for water and chemicals. Ozone gas is produced by an ozone generator and is injected into the washing machine during the wash cycle. When the cycle is over, ozone is converted back to oxygen and this oxygen is released back into the atmosphere [106]. In addition to being a clean process, ozone is a type of washing that can provide good performance properties. In their studies, Kamppuri and Mahmood [108] observed that wet ozone washing, in which ozone dissolves in water, can bleach jeans and reduce back staining without a significant loss in the strength of the fabrics. Another eco-friendly washing is the nano bubble technology technique used in denim washing for reduced water consumption which involves the use of water infused with ultra-fine bubbles. These tiny (1mm) bubbles have a diameter of less than 100 nanometers and are highly pressurized, allowing them to penetrate deep into the denim fibers and remove impurities without the need for large amounts of water. A minimum amount of water is required in the nanobubble technique and there is zero discharge from the process. Air from the atmosphere is fed into an electroflow reactor and subjected to an electromechanical shock that creates nanobubbles and a stream of wet air [109]. To reduce the use of water in denim washing, there are also the use of some enzymes and cross-linking agents in addition to the machine technologies mentioned above. The use of cellulase enzymes instead of alpha amylase enzymes in desizing and abrasion processes in denim processing reduces the need for both washing and rinsing. At the same time, the use of cross-linking agents such as glyoxal resins in denim finishing is a new approach that reduces the need for water in denim washing. The crosslinking agents possessed by glyoxal resins have a strong effect on fabric strength as sustain a significant change in fiber structure. Thus, the loss of strength can be controlled. In addition, this property is used to embrittle, break and eventually remove the fibers from the surface through dry mechanical action. This abrasion is effectively produced by dry pumice stones so that denim production does not need water to achieve the highs and lows and increased white and blue contrast in the stitching and fabric panel [106]. These reduced water washing techniques in denim washing described above not only reduce water usage but also reduce the amount of energy and chemicals required, resulting in a more sustainable denim production process in all denim production processes.

6. CONCLUSIONS

Overall, sustainable denim production involves a holistic approach that considers the entire life cycle of denim production, from raw materials to finished products. In order to implement sustainable denim production correctly, first of all, it is necessary to understand sustainability and its basic approaches correctly. Sustainability is a comprehensive practice consisting of environmental, economic, and social components. In this study, the denim production process, eco-friendly denim, and recycled denim products used in denim production and sustainability practices applied in dyeing, desizing, mercerization, fading and washing processes were explained. In the scope of the study, it was seen that sustainable denim production reduce the environmental impact of these processes by minimizing water usage, using renewable energy sources, and using safer, eco-friendly materials.

It is possible to summarize the sustainable denim approaches obtained within the scope of the study as follows:

- Both organic and recycled cotton can be used in the production of denim fabric. When used, these sustainable materials can help reduce the environmental impact of denim production by reducing the use of synthetic materials, conserving water, and reducing waste.

- Ecological fiber blends such as hemp, bamboo, tencel, flax, soybean, viscose, ramie have used as the amount of cotton in denim decreases. Using these alternative green fibers in denim production, it could reduce the environmental impact of denim production by reducing the use of synthetic materials, conserving water, and reducing waste.

- The process of creating recycled denim often uses less water and energy than producing new denim from scratch, making it a more sustainable and eco-friendlier alternative. Recycling of waste in denim is divided into two as during denim production and post-consumer recycling. Approximately 10% and 15% denim cutting waste are recycling by dissolving and reusing the fibers. In post-consumer denim recycling, generally are produce Open-End Rotor weft yarns from second hand denim waste.

- An eco-labelling system in textiles is crucial for promoting sustainable and environmentally friendly practices in the textile industry. Protection to global warming, effective use of natural resources, and reducing the use of chemicals and energy are falls within the scope.

- Indigo is often used in denim dyeing and since indigo is insoluble in water, it ends up in wastewater, causing significant environmental damage. For this reason, the use of natural indigo reduces the use of synthetic dyes, wastewater and chemicals used in the dyeing process.

- Sustainable desizing process uses amylase enzyme, mercerization process uses best available techniques for dyeing treatment, reuse, and reduction of wastewater and nanofiltration for caustic recovery from wastewater.

- Sustainable fading process in denim refers to a method of achieving a worn or faded appearance on denim fabric without using harmful chemicals or excessive water consumption. This process generally include enzyme fading process, ozone fading process and laser fading process. In enzyme fading, cellulase enzyme has a cleansing effect on the fiber surface and it produces less pollution. Ozone fading is a sustainable process which could use no chemical and no waste. Ozone fading is a sustainable method that reduces environmental pollution, the consumption of chemicals, water, workload and fatigue of the employees and is faster. Sustainable laser technology has several advantages such as reduced water and chemical consumption, energy consumption, and process flexibility, could produce more detailed and complex designs. Kan (2014) [96] seem that CO2 laser process is a cleaner production method in color fading of denim fabric than other fading methods, and that high laser power could create paler tones in denim fabrics.

- Sustainable washing process in denim refers to a method of washing denim fabric and garments using eco-friendly and low-impact methods that reduce water consumption, chemical usage, and environmental impact. Washing by natural resources and reduce water technologies are often used in washing process. For washing with natural materials, it could see that [104] washing effects natural reagents such as lemon, pomelo, guava, ginger, and spondias mombin on indigo dyed denim fabric. Reduce water washing techniques are included laser, ozone, nano bubble, new enzyme formulations and crosslinking agents. These techniques are both reduce water usage but also reduce the amount of energy and chemicals required, resulting in a more sustainable denim production process.

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SİVRİSİNEK KOVUCU TEKSTİL MALZEMELERİ ÜZERİNE BİR DERLEME

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ÖZ: Koruyucu tekstiller modern insan hayatının önemli bir parçası haline gelmiştir. Değişen iklim koşulları ve yaygınlaşan bulaşıcı hastalıklar, insanların koruyucu tekstillere olan ihtiyacını arttırmaktadır. Sivrisinekler, pek çok zararlı organizmayı insanlara taşıyan, bu nedenle de hastalıklara ve ölümlere sebep olan böceklerdir. Toplum sağlığı açısından önemli bir tehdit kaynağı oldukları için sivrisineklerden korunma yöntemleri büyük önem arz etmektedir. Sivrisineklere karşı en etkili korunma yöntemi ise, tekstil malzemeleri ile kişisel korunmanın sağlanmasıdır. Sivrisinek kovucu maddelerin çeşitli yöntemlerle, konvansiyonel ve özellikle nanolifli tekstil yüzeylerine dâhil edilmesiyle hem yüksek oranda hem de uzun süre koruyuculuk sağlayan ürünler elde etmek mümkündür. Sivrisinek kovucu maddeler içerisinde doğal yağlar, insan sağlığı ve çevresel etkenler nedeniyle önem kazanmaktadır. Ancak bu maddeler uçucu yapıda oldukları için kalıcılıkları sınırlıdır. Bu nedenle, sivrisinek kovucu maddenin kontrollü salımına ve uzun süreli etkili olmasına olanak sağlayan mikrokapsülasyon teknikleri ön plana çıkmıştır. Bu makalede, sivrisineklerden koruma sağlayan tekstil malzemelerinin üretimi ve etkinliği üzerine yapılan çalışmalar incelenerek detaylı bir şekilde sunulmuştur. Ayrıca; sivrisinek kovucu maddelerin ve tekstil yapılarına entegrasyonunun, koruyuculuk ve toplum/çevre sağlığı üzerindeki etkileri tartışılmıştır.

Anahtar Kelimeler: Sivrisinek, koruyucu tekstil, mikrokapsül, nanolif, kovuculuk testleri

A REVIEW ON MOSQUITO REPELLENT TEXTILE MATERIALS

ABSTRACT: Protective textiles have become an essential part of modern human life. Changing climatic conditions and spreading infectious diseases increase people's need for protective textiles. Mosquitoes are insects that carry numerous harmful organisms to humans, causing diseases and even fatalities. Due to their significance as a threat to public health, methods of protection against mosquitoes are of great importance. The most effective method of protection against mosquitoes is to provide personal protection using textile materials. It is possible to obtain products that offer both high and long-lasting protection by incorporating mosquito repellent substances into conventional and especially nanofiber textile surfaces with various methods. Among mosquito repellent substances, natural oils have attained significance due to their impact on human health and the environment. However, the durability of these substances is limited since they are volatile. Therefore, microencapsulation techniques, which allow the controlled release and prolonged effectiveness of mosquito repellent agents, become prominent. In this paper, the studies on the production and efficacy of textile materials that provide protection against mosquitoes are investigated and presented in detail. Furthermore, the effects of mosquito repellent materials and their integration into textile structures on protection and community/environmental health are discussed.

Key words: Mosquito, protective textile, microcapsule, nanofiber, repellency tests

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1. GİRİŞ

Gelişen teknoloji ile birlikte teknik tekstil ürünleri içerisinde insan vücudunu tehlikeli ortamlardan ve etkilerden korumayı sağlayan tekstil yapıları önem kazanmaya başlamıştır. Koruyucu tekstiller; kişinin zararlı maddelere, kötü çevre koşullarına maruz kalma riskini önlemek ve bu riskten korunmasını sağlamak ve/veya bu riski azaltmak için kullanılan polimerik malzemelerdir. Sivrisinek kovucu özellik taşıyan tekstil malzemeleri, kovucuların topikal uygulanmasına gerek kalmadan, uzun süreli kişisel koruma sağlayarak hem hastalanmayı hem de hastalığın yayılmasını engeller ve böylece, toplum sağlığına katkıda bulunur.

Sivrisinek ısırıklarından kişisel korunma, özellikle sıtma hastalığını kontrol etmek için en çok başvurulan önlemlerden biridir. Son zamanlarda, sivrisinek kaynaklı hastalıkların bulaşmasını önlemek için kovucuların kullanımı giderek daha fazla ilgi görmektedir. Genel olarak kovucular, buhar fazında hareket eden yüksek uçuculuktaki sıvılardır. Kovucuların buharlaşma oranını sınırlamak, daha uzun ömürlü bir itici geliştirmenin anahtarıdır. Bu nedenle böcek kovucuların kapsüllenmesi, dağıtımlarını kontrol etmenin ve kullanıcının gereksiz yere maruz kalmasını sınırlamanın kilit bir yöntemidir [1].

Aktif kovucuların çeşitli matrislerde kapsüllenmesi ve salınması, yeni nesil kovucu sistemlerin geliştirilmesi için alternatif bir yöntem olarak ortaya çıkmıştır. Kapsülleme yöntemleri, uçucu yağın aktif bileşenlerinin kademeli ve kontrollü salınımını sağlarken etkinlik süresini artırmaktadır. Böylece, kovucuların ciltle doğrudan temas etmesi önlenirken; lifli yapıların yüksek spesifik yüzey alanları sayesinde maksimum iticilik sağlayan optimum buharlaşma kapasitesi elde edilebilmektedir [2-5]. Bugüne kadar çeşitli uçucu yağların kapsüllenerek tekstil yüzeylerine emdirilmesi yönünde çok sayıda çalışma yapılmıştır. Ancak söz konusu çalışmalarda geliştirilen özellikle giysi amaçlı çok kullanımlık tekstil kumaşlarının yıkama, aşınma gibi etkilere karşı dayanımları kritik hale gelmiştir. Tek kullanımlık nanolifli bir yüzey ile birleştirilmiş çeşitli uçucu yağ kapsüllerine yönelik çalışmalar ise daha başlangıç aşamasında olup, devam etmektedir.

Bu derlemede; sivrisinek kovucu tekstil malzemelerinin önemi, üretim yöntemleri, özellikleri ve etkinlikleri ile test yöntemlerine yer verilmiştir. Ayrıca; bu malzemelerin geliştirilmesinde nanoteknolojinin, kapsülasyon tekniklerinin ve bitkisel kaynakların kullanımının etkileri, literatürdeki son çalışmalar dikkate alınarak vurgulanmıştır.

2. SİVRİSİNEK VE ÖLÜMCÜL ETKİLERİ

Sivrisinek; subtropikal veya tropikal bölgelerde yaşayan çift kanatlılar (Diptera) takımı, böcekler (Insecta) sınıfı ve eklem bacaklılar (Arthropoda) şubesinin üyesidir ve dünyadaki en ölümcül hayvanlardan biridir. Sivrisinekler, insanlara çeşitli hastalıkların bulaşmasındaki rolleri nedeniyle dünya çapında böcek tehdidi olarak kabul edilmektedir. Özellikle; sıtma, dang humması, sarıhumma, ensefalit (beyin iltihabı) ve filaryaz (fil hastalığı) gibi birçok parazitsel hastalığı insanlara bulaştırırlar. Her yıl %90'ı Afrika'da olmak üzere 500 milyon kadar sıtma vakası meydana gelmekte ve yılda 2,7 milyon kadar ölüm olmaktadır [6]. Dünya Sağlık Örgütü'ne göre; 2018 yılında 228 milyon, 2020 yılında 241 milyon sıtma vakası meydana gelmiş ve bunun sonucunda 2018 yılında 405.000, 2020 yılında 627.000 ölüm gerçekleşmiştir. Ölümlerin %80'i beş yaşın altındaki çocuklardır [1, 3, 7-9]. Dang humması, enfeksiyon riski taşıyan 2500 milyon insan ve 100'den fazla ülkede yılda 20 milyon vaka ile dünyanın en önemli sivrisinek kaynaklı virüs hastalığıdır [10]. Dünya çapında dang humması insidansı son 30 yılda 30 kat artmıştır [11]. Dünyada 3000'den fazla sivrisinek türü vardır, ancak pek çok ölüm ve hastalıktan sorumlu olduğu bilinen üç türü özellikle risklidir: Aedes, Culex ve Anopheles. Bu sivrisineklerin taşıdıkları hastalıklar Tablo 1'de listelenmiştir.

Sivrisinek ısırıkları nedeniyle; alerjik reaksiyonlar gelişebilmekte, bulaşıcılık artmakta, ısırıkların kaşınması sonucu cilt bariyerinin zarar görmesi ile bakteriyel enfeksiyonlar oluşmakta ve yaşam kalitesi düşmektedir. Bütün bunların yanı sıra, özellikle sivrisinek kaynaklı hastalıkların yaygın olduğu bölgelerde, sivrisinek çoğalmasının önüne geçilmesi ve kontrol altına alınması ek maliyetler getirmekte ve küçümsenmeyecek bir ekonomik yük yaratmaktadır [12-14].

Tablo 1. Çeşitli sivrisinek türleri ile taşınan hastalıklar [6].

Sivrisinek türü	Taşıdığı hastalıklar
Aedes	Dang humması Çikungunya ateşi Rift vadisi ateşi Sarıhumma Zika virüsü
Culex	Japon ensefaliti Lenfatik filaryaz Batı Nil humması
Anopheles	Sıtma

3.SİVRİSİNEK KOVUCU MADDELER

Sıcakkanlı canlılarda bulunan karbondioksit ve laktik asit, sivrisinekler için çekici bir madde görevi görür. Sivrisinek kaynaklı hastalıklara karşı etkili bir aşının olmaması, sivrisinek ısırıklarının kişisel korunma yöntemleriyle önlenmesini en önemli strateji haline getirmektedir. Bu nedenle, doğrudan açıkta kalan cilt üzerinde sivrisinek kovucuların kullanılması şiddetle tavsiye edilir. Sivrisinek ağı gibi fiziksel engeller dışında, böcek ısırıklarını azaltmanın en başarılı yöntemi, böcekleri belirli bir alandan veya kişiden uzaklaştıran kimyasal bazlı kovucuların, genellikle aerosol tipi sprey veya topikal losyon ve jellerin uygulanması olmuştur [15]. Kovucu maddeler, sivrisinekleri çeken insan tenindeki kokuyu maskelemeyi hedefler. Piyasada; B vitamini içeren yamalar, sonik cihazlar, kovucu kimyasal emdirilmiş bileklikler, kovucu madde içerikli kaplama boyaları, uçucu yağlar içeren difüzörler gibi pek çok farklı türde sivrisinek kovucu ürün (Şekil 1) mevcuttur [16]. Bununla birlikte mevcut kovucuların çoğu doğası gereği uçucudur ve etkinlikleri yalnızca kısa bir süre ile sınırlı olduğundan, sıklıkla yeniden uygulanmaları gerekir [4].

Şekil 1. Ticari sivrisinek kovucu ürün örnekleri [17-21]

Sivrisinek kovucu maddeler doğal ve sentetik olarak iki başlık altında sınıflandırılır. Yaygın olarak kullanılan doğal ve sentetik sivrisinek kovucu maddeler Tablo 2'de listelenmiştir.

3.1. Sentetik sivrisinek kovucu maddeler

Sentetik sivrisinek kovucu maddeler arasında en çok kullanılanlar Amerikan Gıda ve İlaç Dairesi (U.S. Food and Drug Administration, FDA) tarafından onaylanmış; DEET, Pikaridin, IR3535 ve Permetrin'dir. DEET böcek kovucu olarak 1946 yılında keşfedilmiş ve 1957 yılında ticari olarak kullanılmaya başlanmış en yaygın kullanılan sivrisinek kovucu kimyasallardan biridir [9, 22, 23]. Permetrin, krizantem çiçeklerinden elde edilen doğal bir insektisit olan piretrinlere benzer piretroid bazlı bir insektisittir. Birleşik Devletler Çevre Koruma Ajansına göre; kullanılan tek böcek veya sinek kovucu kimyasal olan permetrin, hem kovucu hem de öldürücü olarak fare, bit, kene, pire, sivrisinek ve siyah sineklere karşı kullanılır [6, 24, 25]. Pikaridin; DEET kadar güçlüdür, yapısal benzerliği nedeniyle DEET gibi benzer koku bağlama bölgeleriyle etkileşime girer. Ancak daha az toksiktir, daha az cilt tahrişine ve daha uzun süreli etkiye sahiptir. Diğer üç sentetik kovucuya göre bileşiminde daha az toksisite sunan IR3535, 6 aylıktan büyük çocuklara ve hamile kadınlara reçete edilebilir. Düşük toksisite seviyesi nedeniyle diğer kovucular arasında en iyi seçenek olmuştur [26].

Sentetik kovucuların bazıları, zararlı ve toksik etkilerle ilişkilendirilirken; bazıları, alerjik reaksiyonlara ve sinir sisteminde hasara neden olur. Örneğin; lipofilik özelliğinin bir sonucu olarak cilt tarafından emilerek daha derin katmanlara ve kan damarlarına ulaşabilen DEET'in, yüksek konsantrasyonlarda ve uzun süreli kullanılması sonrasında kan dolaşımında yan etkiler, deri döküntüsü, nöbetler, beyin dejenerasyonu ve merkezi sinir sistemi toksisitesi bildirilmiştir [4, 22, 27, 28]. Bunların dışında sentetik kovucular sadece insanlar için toksik olmakla kalmayıp aynı zamanda çevreyi kirletmektedirler. Çevresel kaygılarla birlikte bazı sivrisineklerin mevcut sentetik kovuculara dirençli hale gelmesi sentetik kovucuların etkili kullanımlarını engellemiştir [29]. Son yıllarda, insan kullanımı için daha güvenli ve çevre dostu oldukları düşünüldüğünden, doğal kovuculara olan ilgi artmıştır [2].

3.2. Doğal sivrisinek kovucu maddeler

Günümüzde bitkisel kaynaklı ve doğal ürünlere olan talep tıbbi ve aromatik bitkilerin kullanım hacminin gün geçtikçe artmasına neden olmaktadır. Son 20 yılda, tıbbi ve aromatik bitki ticaretinin yılda yaklaşık 60 milyar dolarlık pazar payına sahip olduğu bildirilmiştir. Bu veri, dünyadaki yıllık ilaç pazarının yaklaşık %20'sidir. Diğer taraftan, bilinen 3000 adet uçucu yağ çeşidinden sadece 300'ünün ticari öneme sahip olduğu kabul edilmektedir [30-33]. Tıbbi ve aromatik bitkilerin içeriğindeki etken maddelerin, sentetik yollarla sentezlenen etken maddelere göre etkisi daha fazladır. Bu nedenle tıbbi ve aromatik bitkiler; ilaç sanayi, tarım, dişçilik, kozmetik, parfüm, gıda ve meşrubat gibi pek çok endüstri alanında hızlı bir tüketime sahiptir [34-36].

Uçucu yağlar, terapötik aktiviteye sahip bitkilerin farklı bölgelerinden (tohum, yaprak vb.) elde edilen aromatik bileşiklerdir. Oda sıcaklığında sıvı olarak bulunan bu yağlar, açık sarı ya da sarı renkte ve yoğun kokuya sahiptirler. Kimyasal yapılarını yoğun şekilde terpen grupları oluşturmaktadır. Terpenlerin yanı sıra alkoller, fenoller, esterler, aldehitler, azotlu ve kükürtlü bileşikler de içermektedirler. Gıda katkı maddeleri, parfümler, kozmetik ve kişisel bakım ürünleri ve farmasötik ilaçlarda koku ve aroma olarak yaygın şekilde kullanılan bazı bitki uçucu yağlarının böcekleri uzaklaştırdığı uzun zamandır bilinmektedir ve sivrisinek kovucu olarak da tavsiye edilirler [37, 38]. Uçucu yağlar, yüksek iticilik derecesine, iyi bir kokuya sahip oldukları ve pratik olarak hiçbir zararlı etki göstermedikleri için alternatif bir doğal böcek kovucu olarak ortaya çıkmıştır. Doğal kovucu yağlar, böcekleri insan ve hayvan derisinden caydırabilen veya uzaklaştırabilen bir buhar bariyeri görevi görürler [28, 39].

Tablo 2. Yaygın olarak kullanılan doğal ve sentetik sivrisinek kovucu ve/veya itici maddeler [6]

Sentetik sivrisinek kovucular	Doğal sivrisinek kovucular	
DEET (N,N-dietil-meta-toluamid)	Sitronella yağı	Lavanta yağı
Permetrin (3-fenoksibenzil (1RS)-cis, trans-3-(2,2-diklorovinil)-2,2-dimetil siklopropan karboksilat)	Biberiye yağı	Karanfil yağı
Pikaridin (1-(1-metilpropoksikarbonil)-2-(2-hidroksietil) piperidin)	Nane yağı	Neem yağı
IR3535 (etil-3 [asetil(butil)amino] propionat)	Fesleğen yağı	Limon yağı
Malathion	Çay ağacı yağı	Kekik yağı
Karbamatlar	Okaliptüs yağı	
N,N-dietil fenilasetamid (DEPA) dimetil karbat		
Alletrin		

Literatürde; zencefil [40, 41], rezene [42, 43], fesleğen [44], karanfil [45], sandal ağacı [46], adaçayı, lavanta, yasemin [47], zerdeçal [48], biberiye [49], karabiber [50], paçuli [51], papatya [52], nane [53], zeytin [54], çay ağacı [55], sardunya [56], süpürge otu [57], okaliptüs [58], dere otu [59], hint inciri [60], kişniş [61], portakal [62, 63], sedir [64], tarçın [65], kafur [66], anason [67], civan perçemi [68] gibi çok sayıda uçucu yağın sivrisinek kovucu etkinliği ispatlanmıştır. Bu çalışmalarda, kullanılan yağların 20 dakika ile 8 saat arasında değişen sürelerde %90'dan fazla koruma sağladığı bildirilmiştir.

Doğal sivrisinek kovucular, geleneksel sinek kovucuların zarar verebileceği birçok hassas ağaç, çalı ve çime uygulanabilir, ayrıca doğal özler faydalı olan böcekleri etkilemez. Bu avantajlarının aksine doğal sivrisinek kovucuların etkinlik süreleri kısadır. Dolayısıyla uzun süre yoğun sivrisinek bulunan bir ortamda kullanılacaklarsa, uygulamayı sık sık tekrar etmek gerekmektedir. Ayrıca keskin kokuya sahip olduklarından solunum rahatsızlıklarını tetiklemektedirler [16].

Önceki çalışmalar, uçucu yağların birçok haşere zararlısına karşı kovucu etkileri yanında, memeliler için düşük toksisite, hedef olmayan organizmalarla uyumluluk ve daha az zararlı çevresel etkiler gibi faydalı özelliklerini de göstermiştir [69-72]. Ancak bu özelliklerine rağmen hızlı bir buharlaşmaya ve dolayısıyla kısa bir koruma süresine sahiptirler. Ayrıca uçucu yağların çoğu, suda düşük çözünürlük ve ısı, nem ve oksijen gibi çevresel faktörlere karşı düşük stabilite gibi zayıf fiziksel özelliklere sahiptir. Bu nedenle, uçucu yağların bir nanotaşıyıcı içinde kapsüllenmesiyle emülsiyon, misel, jel, yama, mikrokapsül, nanopartikül veya nanokompozit şeklinde kontrollü bir salım sisteminin oluşturulması ve böylece, aktif bileşenlerinin korunması ve stabilitelerinin arttırılması zorunludur [38, 73-75].

4. SİVRİSİNEK KOVUCU ÖZELLİKTE TEKSTİL MALZEMELERİ

İnsan vücudunun büyük bir bölümünü kapladığından, dış etkilere karşı koruma sağlamak için ideal olan tekstil malzemeleri; böceklerin, sineklerin/sivrisineklerin ve diğer antropoidlerin girişine karşı fiziksel olarak bir bariyer görevi görebilirler. Giysilere ve farklı kumaş yapılarına sivrisinek kovucu ajanların uygulanması, cilt üzerine yapılan direk uygulamalara kıyasla, aşırı duyarlı tepkilerin olasılığını azalttığı için daha fazla tercih edilmektedir. Sivrisinek kovucu özellikte bir tekstil malzemesi, sivrisinekleri uzaklaştırabilir veya temas halindeyken öldürebilir [76]. Sinek veya sivrisinek kovucu tekstil ürünleri ilk defa Rozendaal [77] tarafından Tablo 3'teki gibi sınıflandırılmıştır.

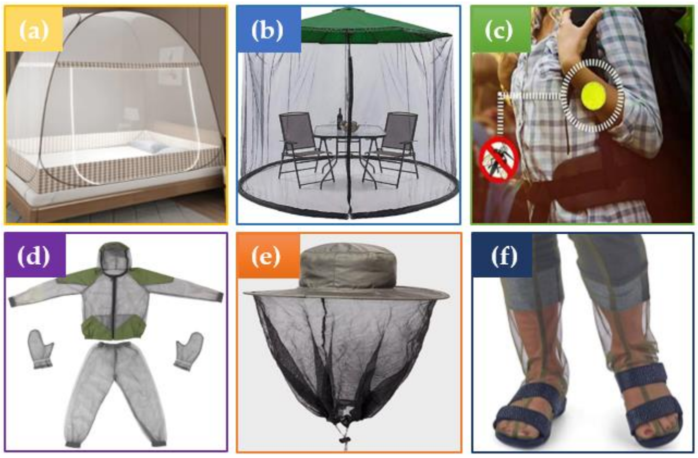
Günümüzde, gelişen teknoloji sayesinde daha farklı yapıda ve fonksiyonel özellikte ürün çeşitliliği mevcuttur. Şekil 2'de sivrisinek kovucu tekstil ürünlerine ait örnekler sunulmuştur.

Sivrisinek kovucu doğal veya sentetik maddelerin, aşağıdaki yöntemlerle tekstil yapılarına uygulanması/dahil edilmesi ile sivrisinek kovucu özellikte tekstil malzemelerinin eldesi mümkündür:

1. Kovucu maddenin sentetik iplik üretim aşamasında polimer matrise karıştırılması ile sivrisinek kovucu özellikte ipliklerin eldesi
2. Kovucu maddenin kumaş yüzeylerine emdirilmesi, püskürtülmesi, kaplanması vb. ile sivrisinek kovucu özellikte kumaşların eldesi
3. Kovucu maddenin nanolif üretimi esnasında polimer matrise karıştırılması ile sivrisinek kovucu özellikte nanolifli yüzeylerin eldesi

Tablo 3. Sinek/sivrisinek kovucu tekstil ürünlerinin sınıflandırılması [77]

Giysi	Döşemelik kumaş/ Dış mekân tekstili
Kaplanmış ceket	Çıkarılabilir yamalar
File ceket	Hamak
Kuşak ve çorap	Perde
File başlık	Yatak örtüleri
Yelek	Cibinlik
Tişört ve pantolon	Sineklik



Şekil 2. Sivrisinek kovucu tekstil ürünleri; (a) cibinlik, (b) dış mekanlar için cibinlik, (c) yapıştırılabilen yama, (d) ceket, pantolon ve eldiven, (e) fileli şapka, (f) çorap [78-82]

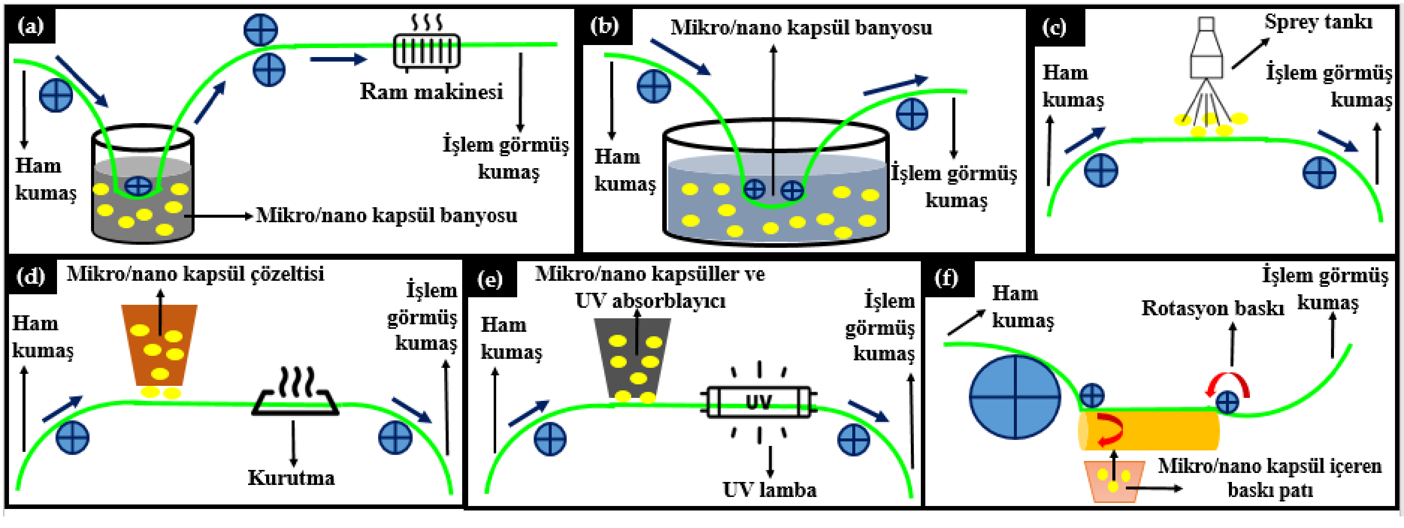
Hem ticari ürünlerde hem de yapılan çalışmalarda, sinek kovucu etkinliğin ömrü endişe edilen noktalardan biridir. Farklı sinek kovucular farklı koruma sürelerine sahiptir. Aynı zamanda sinek kovucu malzemelerin yıkamaya karşı dayanımının da yüksek olması istenir [6, 83-85]. Bu nedenle genellikle, kapsülasyon tekniği kullanılarak koku bileşikleri önce kapsüllenir ve ardından tekstil yüzeylerine uygulanabilir veya dahil edilebilir. Temel olarak, kapsüllenme prosesinde, küçük küreler aktif malzemeyi korumak için ince bir kabuk filmle kaplanır. Isı, ışık ve oksijen gibi çevresel faktörler tarafından etkilenen antimikrobiyel, böcek itici gibi malzemelerin özellikleri bu teknoloji sayesinde kolaylıkla korunur. Buna ek olarak, insanlar da bu malzemelerin daha düşük dozlarının maruziyetine uğramış olurlar. Sivrisinek kovucuların kapsüllenmesi aynı zamanda istenen etkiyi uzatması nedeniyle de cazip hale gelmiştir. Kapsülasyon prosesi ile fonksiyonel özellikleri korumak mümkündür [86, 87]. Şekil 3'de, mikro/nanokapsüllerin kumaş yüzeylerine uygulanma yöntemleri şematize edilmiştir.

4.1. Sivrisinek kovucuların iplik yapısına dahil edilmesi

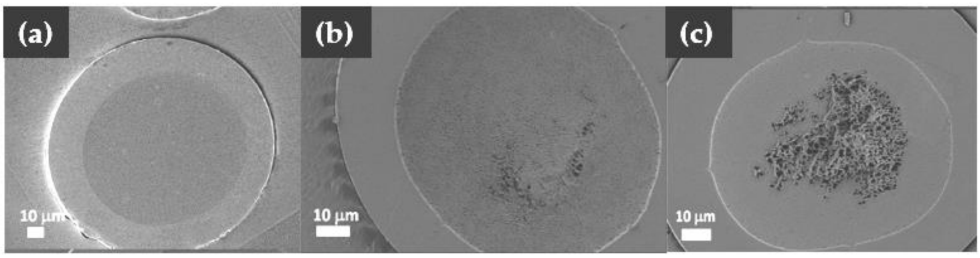
Sivrisinek kovucu özellikte iplikler üretmek, kovucu malzemenin lif çekimi sırasında polimer içerisine katılması ile mümkün olabilmektedir. Böylelikle; kovucu madde iplik yapısı içine hapsolacağından, kovuculuğun uzun süreli olması beklenmektedir. Sumitomo Chemical (Japonya) firması, lif çekimi sırasında permetrin katılması ile üretilen polietilen monofilamentlerinden Olyset® Net ticari adıyla sinek kovucu ağlar üretmişlerdir [6]. Olyset™ Net, Dünya Sağlık Örgütü (WHO) tarafından 2001 yılında uzun ömürlü böcek öldürücü olarak onaylanan ilk ağdır.

Literatürde sivrisinek kovucu iplik üretimiyle ilgili çeşitli çalışmalar bulunmaktadır. Akbarzadeh ve ark. [88], reaktif bir boyarmadde ve DEET'in bileşimini içeren sivrisinek kovucu özellikte poliamid 6 iplik üretmişlerdir. Üretilen ipliğin %90'a yakın kovuculuk özelliğine sahip olduğu bildirilmiştir. Özellikle son yıllarda yapılan çalışmalarda, çevreyi koruma ve daha az kirletme kavramından bahsedilerek doğal sivrisinek kovucu malzemelere dikkat çekilmektedir. Sibanda ve ark. [89] tarafından yapılan çalışmada, kontrollü salım yapabilen ve uygun maliyetli sivirisinek kovucu içiçe bikomponent iplik üretilmiştir. Çalışmada, DEET içeren çekirdek kısmının poli(etilen-ko-vinil asetat) polimerinden ve uçucu aktif maddenin atmosfere salım hızını azaltan kabuk kısmının yüksek yoğunluklu polietilen (HDPE) polimerinden oluşması tasarlanmıştır. Sivrisinek kovucu özellikteki iplikten (Şekil 4) üretilen örme kumaşlar, 20 yıkamadan sonra bile kovucu özelliğini korumuştur.

Dai ve ark. [90] doğal sivrisinek kovucu maddelerden biri olan armut otunu, poliester çözeltisine ilave ederek kesikli lifler üretmişlerdir. Çalışmanın devamında; sivrisinek kovucu poliester lifleri, zayıf nem absorbsiyonları nedeniyle, bambu lifleri ile birleştirilerek bambu-poliester sivrisinek kovucu iplik elde edilmiştir. Sivrisinek kovucu iplikten üretilen örme kumaşların konfor özellikleri test edilmiştir. Ferreira ve ark. [91] tarafından yapılan çalışmada; eriyik çekim yönteminde poli(D,L-laktik asit) (PDLLA) içerisine %20 oranında DEET dahil edilerek, çevresel etkisi azaltılmış ve biyolojik olarak parçalanabilir sivrisinek kovucu multifilament iplik üretilmiştir. DEET'in dahil edilmesiyle; mekanik özellikleri belirgin bir şekilde olumsuz etkilenmesine rağmen, ipliğin sıtma kontrolü için kullanılabilecek potansiyele sahip olduğu belirtilmiştir.



Şekil 3. Mikro/nanokapsüllerin tekstil yüzeylerine uygulanması için çeşitli yöntemler; (a) fulardlama, (b) daldırma, (c) spreyleme, (d) kaplama, (e) ultraviole, (f) baskı



Şekil 4. Sivrisinek kovucu bikomponent filamentin enine kesitinin SEM görüntüleri; (a) katkısız, (b) %10 DEET katkılı, (c) %20 DEET katkılı [89]

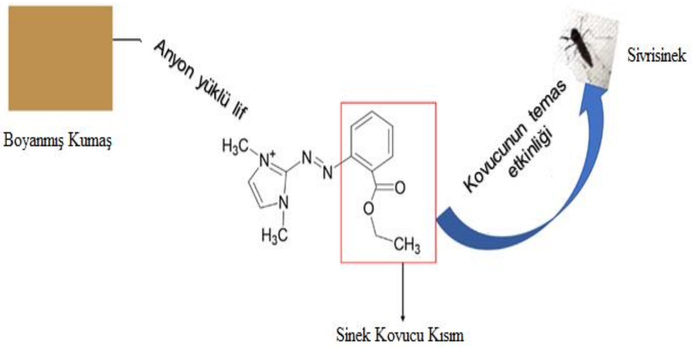
Sinek kovucu özellik gösteren iplik üretiminde karşılaşılan en büyük problemlerden bir tanesi iplik ile sivrisinek kovucu bileşen arasında zayıf bir bağlanma olmasıdır. Bu zayıf bağlanma nedeniyle, sivrisinek kovucu etkinlik özellikle yıkama sonrası düşer ve uzun süreli olmaz. Sivrisinek kovucu bileşen ile iplik arasındaki etkileşimin ve kovuculuğun etkinliğini arttırmak için, ipliğin kaplanması veya iplik içerisine mikrokapsüllenmiş bileşen eklenmesi gibi yöntemler geliştirilmiştir. Pinheiro ve ark. [92] tarafından yapılan çalışmada, polilaktik asit (PLA) içerisine ekstrüzyon işlemi sırasında doğal sivrisinek itici ajan olan Schinus Molle ekstraktı içeren silika esaslı mikrokapsüller eklenmiştir. PLA monofilament ipliklerden üretilen örme kumaşların 5 yıkama sonrasında da sivrisinek itici aktiviteye sahip olduğu görülmüştür. Chen ve ark. [93] ise patentlerinde, bu etkinliği arttırmak amacıyla daldırma yöntemi geliştirerek, ipliği permetrin ve oktilizotiyazolinon ile kaplamışlardır. Çalışma sonunda, 25 yıkamaya kadar etki sağlayan iplik ve kumaşlar elde edilmiştir.

4.2. Sivrisinek kovucuların kumaşlara veya giysilere uygulanması

Sivrisinek kovucu tekstil ürünleri ile ilgili araştırmaların büyük bir kısmı, sivrisinek kovucu maddelerin tekstil terbiyesi aşamasında uygulanması üzerinedir. Sivrisinek kovucular kumaşlara; boyama, baskı, kaplama gibi çeşitli terbiye işlemleri ile dahil edilebilmektedir.

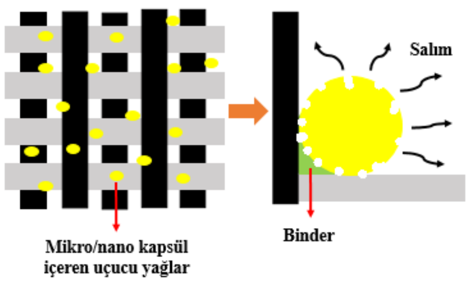
Pennetier ve ark. [94], sivrisinek kovucu askeri kıyafet geliştirmişlerdir. Standart permetrin emdirilmiş üniformaları, sadece sivrisinek itici KBR3023 ve bir organofosfat (Pirimiphos-Metil) kombinasyonu ile muamele edilmiş üniformalar ile kıyaslamışlardır. Sonuçta, sivrisinek itici ve organofosfat kombinasyonu ile muamele edilen üniformaların daha iyi sivrisinek iticiliği gösterdiği tespit edilmiştir. Sumithra ve ark. [95] doğal aromatik bitkiler kullanarak sivrisinek itici aprelerin geliştirilmesine yönelik bir çalışma yapmışlardır. Hintyağı, sinameki ve astım bitkisi özütlerini dört farklı denim kumaşa direkt olarak fulardlama-kurutma yöntemiyle (pad-dry) uygulamışlardır. %100 pamuklu denim kumaşların sivrisinek kovuculuğunu 30 yıkamaya kadar koruduğunu tespit etmişlerdir. Ramasamy ve ark. [96] tarafından yapılan çalışmada, sivrisinek kovucu etkinliği arttırmak için nanoparçacıklardan faydalanılmıştır. Vitex Negundo bitkisinin yapraklarından elde edilen özütü içeren nanoparçacıklar, pamuklu kumaşlar üzerine geleneksel fulardlama-kurutma yöntemi ile uygulanmıştır. Bu yöntemle, kumaşların sivrisinek kovucu etkinliği 15 yıkamaya kadar devam etmiştir. Bhatt ve Kale [97] krizantem yağı nanoemülsiyonu ile kumaşlara sivrisinek kovucu özellik kazandırmışlardır. Sivrisinek kovucu tekstil malzemesi, naylon tül kumaşların nanoemülsiyonla katman biriktirme (layer by layer) tekniği kullanılarak işlenmesiyle elde edilmiştir. İşlem görmüş kumaşlar %100 sivrisinek kovucu etkinlik ve %90 ölüm oranı göstermiş ve 25 yıkamaya kadar aktivitelerini korumuştur. Teli ve Chavan [98] çalışmalarında, DEET'i modifiye ederek sivrisinek kovucu bir kimyasal geliştirmişlerdir. Bu kimyasalı pamuklu kumaşlara geleneksel fulardlama-kurutma-kürleme (pad-dry-cure) metodu ile aktarmışlardır. Sonuçta modifiye edilmiş DEET ile muamele edilmiş kumaşların sivrisineklere karşı daha yüksek ve daha uzun süreli koruma sağladığı tespit edilmiştir. Khanna ve Chakraborty [99], β-Siklodekstrin sitratın (β-CD CA) sedir ağacı, karanfil, okaliptüs, nane, lavanta ve yasemin esansiyel yağları ile bileşimini, fulardlama-kurutma-kürleme yöntemiyle pamuklu kumaşa uygulayarak sivrisinek kovucu etkinliğini değerlendirmişlerdir. Lavanta ve sedir ağacı yağı ile olan bileşimler, sırasıyla 210 ve 160 dakika ile en uzun koruma sağlarken, yasemin ve nane yağları sırasıyla 20 ve 60 dakika ile en az koruma göstermiştir.

Sivrisinek kovucuların terbiye işlemleriyle hızlı bir şekilde kumaşa aktarılması zordur. Bu tip kimyasal apreli tekstiller, yıkama işlemlerinden sonra koruyuculuğunu kaybedebilmektedir. Binderler ve çapraz bağlama ajanları gibi kimyasalların kullanımı da, tekstil malzemelerinin fiziksel özelliklerini etkilemektedir. Tekstil malzemelerinin çoğu renkli olduğundan; sivrisinek kovucu boyaların geliştirilmesi, renklendirme ve fonksiyonel apre işleminin birleştirilmesine yardımcı olabilmektedir. Sivrisinek kovucu boyalar, uygun boya-lif etkileşimi ile tutunabileceğinden, fiksaj için binderlere ihtiyaç duyulmaz. Dolayısıyla; renk, sivrisinek kovuculuk ve diğer işlevler tek bir boyama işleminde elde edilebilir ve bu da boyama işlemini sürdürülebilir bir seçenek haline getirmektedir [100]. Sumithra ve ark. [101], bambu kumaşlara sivrisinek kovucu özelliği kekik yağı ile kazandırmayı amaçlamışlardır. Bambu kumaşları annotto tohumu, soğan kabuğu ve kızılağaç odunu ile boyadıktan sonra kekik yağı ile kaplamışlardır. Sonuçta en iyi sivrisinek kovucu özelliği, annotto tohumu ile boyanmış numunenin gösterdiğini gözlemlemişlerdir. Teli ve Chavan [102] tarafından yapılan çalışmada, poliamid 6 kumaşlara sivrisinek kovucu bitim işlemi tek boyama ve bitim işlemi ile kazandırılmıştır. Bu yaklaşım, yaygın olarak kullanılan sivrisinek kovucu DEET ve içeriği DEET'e dayanan bir reaktif boyarmaddenin sentezlenmesine dayanmaktadır. Bu boyarmadde sentezlendikten sonra poliamid 6 kumaşa kovalent bağlarla bağlanmış ve kumaşa sivrisinek kovucu özellik kazandırılmıştır. Teli ve Chavan 'nın [103] daha sonraki bir çalışmasında ise, DEET bazlı yeni bir azo boyarmadde sentezlenmiş ve sivrisinek kovucu malzeme üretmek için pamuklu kumaşa uygulanmıştır. Boyanmış kumaşların sinek kovucu özelliği 2–30 dakika arasında değişen farklı zaman aralıklarında ölçüldüğünde, yaklaşık %81-95 arasında değişen kovuculuk oranları elde edilmiştir. Aynı zamanda boyalı kumaşlar, sivrisinek kovuculuğunu önemli ölçüde kaybetmeden ışık, yıkama ve sürtünmeye karşı iyi haslık özellikleri göstermiştir. Singh ve Sheikh [100] çalışmalarında, DEET türevi olan etil antranilat ve 4-hidroksikumarin gibi sivrisinek kovucuların bir kombinasyonundan yeni sivrisinek kovucu boyarmaddelerin sentezlenmesini amaçlamışlardır. Sentezlenen boyarmaddeler poliester kumaşların boyanması için kullanılmıştır. Boyanan kumaşlar %100 sivrisinek kovucu özelliğin yanında antibakteriyellik ve UV ışınlarına karşı koruyuculuk da göstermiştir. Singh ve Sheikh [104] çalışmalarında; poliester kumaşa sivrisinek kovucu, UV ve antibakteriyel özellik kazandırmak için yeni bir dispers boyarmadde sentezlemişlerdir. Boyama işleminden sonra, boyanmış kumaşın sivrisinek kovucu etkinliği ölçülmüş ve %100 koruyuculuk elde edilmiştir. Singh ve Sheikh' in [105] bir diğer çalışmasında ise, akrilik kumaşlara hem sivrisinek kovucu hem de UV koruyucu özellik kazandırmak için yeni bir katyonik boyarmaddenin sentezlenmesi amaçlanmıştır. Geliştirilen boyarmadde akrilik kumaşlara infrared boyama makinesi ile uygulanmıştır. Yapılan testler, kumaşların sivrisinek kovucu ve UV-koruyucu özellik gösterdiğini ispatlamıştır (Şekil 5). Ayrıca boyanmış kumaşlar, yıkama sonrasında multifonksiyonel özelliklerini korumuşlardır.



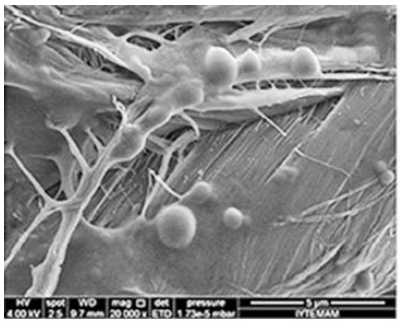
Şekil 5. Çalışmada sentezlenen boyarmadde molekülü ve boyanmış sivrisinek kovucu akrilik kumaş [105]

Tekstil bitim işlemlerinde mikro veya nano kapsüllerin kullanımı ile daha az itici malzeme kullanarak yıkamaya dayanıklı tekstil ürünleri üretmek de mümkün olmaktadır. Kullanım sırasında aromatik bileşiklerin yavaş salımı da sivrisinek ısırmasına karşı gerekli korumayı sağlar [6]. Şekil 6'da mikrokapsüllerin tekstil yüzeyine uygulanması ve kontrollü salımın gerçekleşmesi gösterilmektedir.



Şekil 6. Mikrokapsüllerin kumaş yüzeyine uygulanması ve kontrollü salımın gerçekleşmesi

Specos ve ark. [106] sitronella yağı içeren mikrokapsülleri, %100 pamuklu bezayağı dokuma kumaşa uygulamışlar ve sivrisinek kovuculuğunu test etmişlerdir. Mikrokapsüllenmiş sitronella yağı içeren kumaşlar ile uçucu sitronella yağı püskürtülmüş kumaşlar iticilik bakımından kıyaslanmıştır. Mikrokapsüllü kumaşların daha uzun süreli ve %90'dan fazla itici bir etki sağladığı gözlenmiştir. Anitha ve ark. [107] limon otu yağını sodyum aljinat içinde kapsülleyerek poliester kumaşlara fulardlama-kurutma yöntemi ile uygulamışlardır. Elde edilen sonuçlara göre %92 oranında kovucu aktivite rapor edilmiştir. Ramya ve Maheshwari [108], *Andrographis panikulata* bitkisinden ekstrakte edilen Andrographolide içeren sodyum aljinat mikrokapsüller hazırlamış ve bambu/pamuk karışımı kumaşa çektirme yoluyla uygulamışlardır. Sivrisinek kovucu etkinlik, mikrokapsül uygulanan kumaşta %94 ve doğrudan apre işlemi uygulanmış kumaşta ise %96 olarak kaydedilmiştir. Kovucu etkinlik 30 yıkamadan sonra kapsüllü ve direkt apreli kumaşlar için sırasıyla %52 ve %40'a düşmüştür. Geethadevi ve Maheshwari [109] çalışmalarında, sivrisinek kovucu bir kumaş elde etmek için mikrokapsüllenmiş esansiyel yağlar kullanılarak bambu/ tencel karışımlı bir kumaş hazırlamışlardır. Mikrokapsüllerin kabuk malzemesi olarak sodyum aljinat, akasya arabica ve *Moringa oleifera* sakızı, çekirdek malzeme olarak kekik, selvi ve greyfurt yağları kullanarak mikrokapsülleri hazırlamışlar ve bambu/tencel karışımı kumaş üzerine çektirme yöntemiyle uygulamışlardır. Moringa oleifera mikrokapsülleri, iyi bir sivrisinek kovucu aktivite, yüksek UV koruması ve cilt üzerinde alerjik reaksiyon olmaksızın yüksek dayanıklılık göstermiştir. Kumaşın sivrisinek kovuculuğu 30 yıkamadan sonra bile %60 oranında belirlenmiştir. Rana ve ark. [110] kovucu etki için kadife çiçeği ve beşparmak ağacı metanol özünü kullanmışlardır. Aromatik yağlar, jelatin ve arap zamkı kullanarak mikrokapsüllenmiştir. Mikrokapsül emdirilmiş %100 pamuklu kumaşların, özel olarak tasarlanan kafeslerde sivrisineklere karşı etkinlikleri test edilmiştir. 15 yıkama sonrasında dahi kumaşların iticilik performanslarının %50'nin üzerinde olduğu belirlenmiştir. Türkoğlu ve ark. [111] tarafından yapılan çalışmada; iki farklı insektisidal etken madde (limonen ve permetrin) kapsüllenmiş ve ardından pamuklu kumaşlara uygulanmıştır (Şekil 7). Sivrisineklerin işlenmiş kumaşlardan uzak durma eğiliminde olduğu ve sivrisinek ölüm oranlarının limonen ve permetrin için sırasıyla %41 ve %54 olduğu kaydedilmiştir. 20 tekrarlı yıkama sonrasında bile kumaş yüzeyinde kapsüllerin varlığı tespit edilmiştir.



Şekil 7. Çalışmaya ait limonen mikrokapsülleri ile işlem görmüş kumaşın SEM görüntüsü [111]

Dhillon ve ark. [112] pamuklu kumaşlara sinek kovucu özellikler kazandırmak amacıyla okaliptüs ve biberiye uçucu yağlarını mikrokapsüllemişlerdir. Uçucu yağ içeren pamuklu kumaşlar 15 tekrarlı yıkamaya maruz bırakılmış ve sinek kovuculuk aktiviteleri tayin edilmiştir. Sonuçta, okaliptüs yağının daha etkili olduğu bildirilmiştir. Singh ve Sheikh [113] çalışmalarında, kabuk materyali olarak kitosan fosfat kullanarak kekik yağı özlü fonksiyonel mikrokapsüller hazırlamış ve bunu keten kumaşa fulardlama-kurutma yöntemi ile uygulamışlardır. Sinek kovucu özellik başta olmak üzere, güç tutuşurluk, antibakteriyellik gibi farklı fonksiyonel özelliklerin incelendiği çalışmada, %100 oranında mükemmel bir sivrisinek kovucu özellik elde edilmiş, 20 yıkama sonrası bile %90 sivrisinek kovuculuk oranı elde edilmiştir. Singh ve Sheikh [114] çalışmalarında, öz kısımda tarçın kabuğu yağı içeren kitosan-jelatin mikrokapsüller hazırlamış, sinek kovucu özelliği de içinde barındıran çok fonksiyonlu bir koruyucu keten kumaş üretmişlerdir. İşlem görmüş kumaşlar, %100 oranında mükemmel bir sivrisinek kovucu özellik göstermiş ve 20 yıkama sonrası bile sivrisinek kovucu özelliğini korumuştur. Tariq ve ark. [115] sitronella yağı içeren mikrokapsüllerin hazırlanmasını ve poliester/pamuk karışımlı kumaşa daldırma yöntemi ile uygulanmasını çalışmışlardır. Kumaşın sivrisinekleri uzak tutma yeteneği kafes testi ile değerlendirilmiştir. Sitronella yağı mikrokapsülleri ile aprelenen kumaş numunesi, yıkama öncesi %90, 30 yıkama sonrası %80 sivrisinek uzaklaştırma özelliği sergilemiştir.

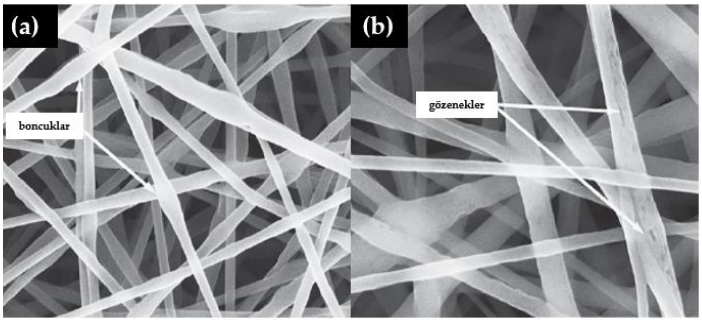
4.3. Sivrisinek kovucu nanolifli yüzeylerin üretilmesi

Nanolifli yüzeylerin tıptan savunma sanayine kadar pek çok uygulama alanı mevcuttur. Son zamanlarda dikkat çeken uygulamalarından biri de, nanoliflerin içerisine etken madde eklenerek fonksiyonelleştirilmesi ve farklı alanlarda uygulanmasıdır. Etken maddeler; emülsiyon, karışım veya dispersiyon çözeltilerinin elektro çekimi vasıtasıyla nanoliflere dahil edilebilir [116]. Elde edilen yapıların artan yüzey alanı nedeniyle, birim alanda daha fazla etken madde bulunur ve dolayısıyla daha etkili yüzeyler ortaya konabilir.

Dünya üzerinde sivrisinek ısırmasına bağlı olarak gerçekleşen hastalık ve ölümler düşünüldüğünde, nanolifli yapılar içerisine sivrisinek kovucu malzemelerin entegresi, bu durumun önüne geçmek için önemli bir alternatif haline gelmiştir. Sentetik veya doğal sivrisinek kovucu etken maddelerin katılmasıyla hazırlanan karışım çözeltilerinden nanolif üretimi çalışmaları literatürde yer almaktadır. Iliou ve ark. [2], sivrisinek kovucu ajan olarak sitronella yağı içeren selüloz asetat ve polivinilpirolidon (PVP) bazlı tek ve üç katmanlı elektro çekilmiş yüzeyler üretmişlerdir. Polimer çözeltilerine %5 ve %20 olmak üzere iki konsantrasyonda sitronella yağı ilave edilerek karışım elektro çekim çözeltileri hazırlanmıştır. Üretilen tüm yüzeyler, en az 4 hafta boyunca sitronella yağı salımı ve sivrisinek itici aktivite sergilemiştir.

Konchada ve ark. [117] tarafından yapılan çalışmada, neem yağı içeren poliesteramid (PEA) nanolifli yüzeyler üretilmiştir. Neem yağı, PEA polimer sentezi esnasında reaksiyon karışımına damla damla eklenmiştir. Ardından, neem yağı içeren PEA/kloroform çözeltisi polikaprolakton (PCL)/kloroform çözeltisi ile farkı oranlarda karıştırılmıştır. Hazırlanan karışım çözeltilerden elektro çekim yöntemiyle üretilen nanolifli yüzeylerin, 12 saat boyunca sivrisinek öldürme kapasitesinin %100 olduğu bildirilmiştir. Shao ve ark. [118]; yüksek performanslı, antibakteriyel ve sivrisinek kovucu hava filtreleri üretmiştir. Tarçın yağının etken maddesi olan sinnamaldehit (CMA) ve antiseptik bir madde olan poli(heksametilen biguanid (PHMB), selüloz asetat (CA)/aseton/dimetil asetamid çözeltilerine dahil edilmiştir. CA/CMA/PHMB elektro çekim nanolifli yüzeyin sivrisinek kovuculuğu, başlangıçta %92,7 ve 30 gün sonra %77,5 olarak belirlenmiştir. Thum ve ark. [1] yaptıkları çalışmada, sentetik esaslı sivrisinek kovucu olan DEET kimyasalını %50'ye kadar farklı oranlarda poliamid 6,6 çözeltilerine karıştırmışlardır. Hazırlanan çözeltilerden elektro çekim yöntemi ile üretilen poliamid 6,6 nanolifli yüzeylerin karakterizasyonu sonucunda; DEET etkinliğinin yüzeyin ağırlığı ve içerdiği DEET miktarı ile ilişkili olduğunu, bu etkinliğin 72 saat ile 200 saat arasında değişebileceğini belirlemişlerdir. Bonadies ve ark. [119], sivrisinek kovucu DEET içeren poli(l-laktik asit) (PLLA) esaslı nanolifli yüzeyler üretmişlerdir. Kloroform ile hazırlanmış PLLA çözeltilerine dört farklı konsantrasyonda (%1, %2, %3, %4) DEET ilave edilmiştir. Elektro çekilmiş nanolifler ile DEET'in buharlaşması geciktirilmiş, bu da böcek kovucunun düzgün ve kontrollü bir şekilde salınmasına izin vermiştir. Du ve ark. [120], sivrisinek kovucu olarak bilinen sentetik IR3535 maddesi içeren PLLA nanolifli yüzeyler üretmişlerdir. IR3535'in PLLA/IR3535 nanolifli yüzeyinden çevreye salımı, 60 ile 100 °C arasındaki sıcaklıklarda termogravimetrik analizle ölçülmüştür. Sonuçlar; vücut sıcaklığında birkaç günlük bir zaman diliminde, kovucunun oldukça yavaş buharlaştığını göstermiştir. Fulton ve ark. [121] tarafından yapılan çalışmada; aynı anda DEET ve pikaridin (1:1) içeren geri dönüştürülmüş polietilen tereftalat (PET) esaslı mikrolifler, elektro çekim yöntemiyle üretilmiştir. Elektro çekilmiş mikrolifler, kovucu etken maddeleri %97 oranında içermiş ve sivrisineklere karşı 1 hafta boyunca %100'e, 3 haftadan fazla sürede ise %80'e kadar iticilik sağlamıştır.

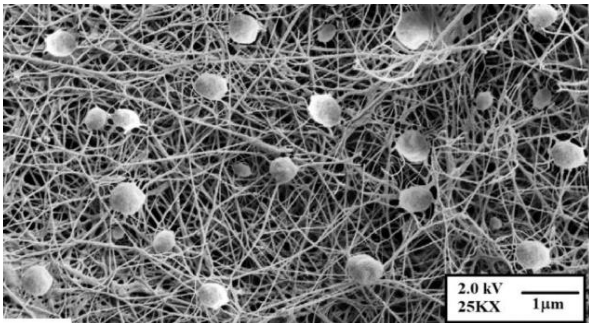
Son yıllarda özellikle ilaç salım uygulamalarına yönelik olarak, daha iyi işlevselliğe sahip ve yüksek performanslı nanolifler üretmek amacıyla elektro çekim yönteminde dikkat çekici modifikasyonlar yapılmaktadır. Bunlardan biri, iki farklı bileşenin özelliklerinden yararlanan çekirdek-kabuk şeklinde çift bileşenli nanoliflerin eldesidir [122, 123]. Çekirdek-kabuk nanolifler, birbirine karışmayan polimer emülsiyonlarının tek bir düze aracılığıyla elektro çekimi (emülsiyon elektro çekim) veya koaksiyel bir düze vasıtasıyla elektro çekimi (koaksiyel elektro çekim) yoluyla üretilebilirler [124]. Çekirdek-kabuk nanoliflerde, etken madde nanolifler tarafından bir çeşit kapsüllenmekte (nanolifler içine hapsedilmekte) ve monolitik lifler ile karşılaştırıldığında, hassas biyobileşiklerin kullanılması ve uzun süreli kontrollü salım kinetiği açısından avantajlar elde edilmektedir [125-127]. Ciera ve ark. [4]; permetrin, biber yağı ve kedi nanesi yağını farklı konsantrasyonlarda içeren polivinilalkol (PVA) emülsiyon çözeltilerinden nanolifli yüzeyleri (Şekil 8) elektro çekim yöntemiyle üretmiştir. Permetrin ve biber yağı ilave edilen numunelerin ısıl özellikleri etkilenmezken, kedi nanesi yağı içeren numunelerin özelliklerinde hafif bir azalma gözlenmiştir. Sivrisinek iticilik testlerinde ise; dahil edilen tüm katkılar, kontrole kıyasla sivrisinek konma sayısını önemli ölçüde azaltmıştır.



Şekil 8. Çalışmaya ait PVA nanolif SEM görüntüleri; (a) kedi nanesi yağı içeren, (c) biber yağı içeren [4]

Munoz ve ark. [128] tarafından yapılan çalışmada, sitriodiol yüklü etil selüloz nanolifli yüzeyler üretilmiştir. Çalışmada, elektro çekim yöntemiyle monolitik ve çekirdek-kabuk lifler elde edilmiştir. Sarıhumma sivrisineklerinin kullanıldığı itici aktivite testlerinin sonuçlarına göre; çekirdek-kabuk nanolifler, monolitik nanoliflere kıyasla daha uzun süre itme davranışı sergilemiştir. Çekirdek-kabuk nanolifler 34 gün boyunca %100 iticilik göstermiştir. Ryan ve ark. [15] tarafından gerçekleştirilen çalışmada, %10, %30 ve %50 oranında pikaridin içeren elektro çekim çözeltilerinden monofilament ve koaksiyel poliamid 6,6 nanolifleri üretilmiştir. Tüm yüzeylerde salım hızı, artan sıcaklık ve artan pikaridin ilavesi ile artmıştır. Monofilament lifler, ortam koşullarında kararlılık ve uzun süreli salım potansiyeli sergilemiştir. Koaksiyel liflerde ise dış koruyucu kılıf, uçucu bileşenin salımını değiştirmiştir.

Sivrisinek kovucu nanolifli yüzeyler üretirken, kovucu özellikte bir yağın karışım veya emülsiyon halinde polimer çözeltisi ile karıştırılması yerine, kapsüllenerek çözelti içerisinde disperse edilmesi, uçucu yağın uzun süreli kontrollü salımı açısından tercih edilmektedir. Kapsülleme işlemi sivrisinek kovucuların nanolifler içerisine hapsedilmesi sürecini ifade eder. Nanolifler, sivrisinek kovucu kapsüller için bağlantı noktası görevi görmektedir (Şekil 9). Mikrokapsüller nanolifli yapıya dahil edildiğinde; nanoliflerin oluşturduğu ağsı yapı mikrokapsüllere ikinci bir kapsülleme stratejisi sunmakta, kapsüllenmiş madde daha stabil kalmakta ve daha uzun süreli kontrollü bir salım gerçekleşmektedir. Ayrıca; nanoliflerin yüksek spesifik yüzey alanları nedeniyle, yüzeyler maksimum iticilikte bir fonksiyonelliğe sahip olmaktadır [129]. Son yıllarda uçucu yağların kapsüllenerek çeşitli polimerle birlikte nanolifli yapıların üretiminde (yapı içine dahil edilerek veya yapıya emdirilerek) özellikle antimikrobiyel etkinlik amaçlı kullanımına dair çalışmalar ilgi çekici hale gelmiştir (Tablo 4). Bu çalışmalar, sivrisinek kovucu özelliğe de sahip uçucu yağların kapsüllenerek nanoliflere dahil edilmesi, elde edilen yüzeylerin performanslarının, kararlılıklarının ve kontrollü salım özelliklerinin tespit edilmesi ve iyileştirilmesi üzerinedir. Yapılan araştırmaların sonuçları; nano/mikrokapsüller içeren nanolifli yüzeylerin, sivrisinek ısırmalarını önlemede de yenilikçi ve etkili stratejiler geliştirme potansiyeli olabileceğini ve bu yüzeylerin, sivrisinek kaynaklı hastalık ve ölümlerin azaltılmasına katkıda bulunabileceğini göstermektedir.

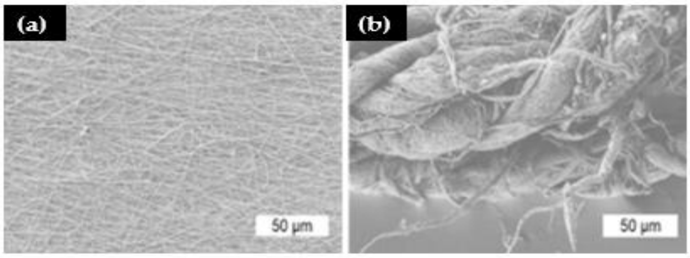


Şekil 9. Uçucu yağlar içeren mikrokapsüllerin nanolifli matris içerisindeki SEM görüntüsü [130]

Nanolifli yapılar, yüzey kaplama için ideal olmakla birlikte, geleneksel filament olarak veya konvansiyonel tekstil uygulamalarında kullanımları zordur. Nanolifli yapıların mekanik büküm ile iplik haline getirilmesi, bu tip yapıların konvansiyonel uygulamalara uygun hale getirilmesinde kullanılabilir. Lundin ve ark. [135] sivrisinek kovucu tekstillerin üretiminde bu yaklaşımı kullanmışlardır. Araştırmacılar, DEET katkılı naylon lifleri elektro çekim yöntemi ile üretmişler ve elde sonrasında iplik olarak eğirmişlerdir (Şekil 10). Böylece hem sivrisinek kovucu özelliği olan hem de mekanik iplik üretim teknikleri ile karşılaştırılabilecek yapılar elde etmişlerdir.

Tablo 4. Yağ kapsülü içeren nanolif üretim çalışmalarına örnekler

Uçucu Yağ	Mikrokapsül kabuk polimeri	Nanolif polimeri	Referans
Limon okaliptüs yağı etken maddesi	Melamin reçine	PVA	[4]
Kekik yağı bileşenleri (Timol ve Karvakrol) Fesleğen yağı bileşeni (Öjenol)	PLA	Bakteriyel selüloz	[130]
Karanfil yağı	PVA	Poliamid 6,6	[131]
Kekik yağı Tarçın yağı	β-siklodekstrin	Kitosan PVA	[132]
Kekik yağı	β-siklodekstrin	PLA PCL	[133]
Tarçın yağı	β-siklodekstrin	PLA	[134]



Şekil 10. DEET katkılı naylon nanolifli yüzeyin SEM görüntüleri; a) büküm öncesi, b) büküm sonrası [135]

5. SİVRİSİNEK KOVUCU ÖZELLİKTE TEKSTİL MALZEMELERİNİN TEST VE DEĞERLENDİRME YÖNTEMLERİ

Sivrisinek kovucu malzemelerin etkinliğinin ölçülmesi için farklı test metotları geliştirilmiştir. Laboratuvar çalışmalarının amacı, bir kovucunun etkili dozunun belirlenmesi ve uygulandıktan sonra tam koruma süresinin tahmin edilmesidir. Yapılan testlerde aşağıdaki sorulara yanıt aranmaktadır [136]:

1- Kullanılan malzeme sivrisinek itici midir?

2- İticilik için ne kadar miktarda (dozaj) kovucu gereklidir?

3- İticilik süresi ne kadar sürmektedir?

Ölçümlerin farklı parametrelerden ve ortam şartlarından etkilenmemesi, tekrarlanabilir/karşılaştırılabilir olması ve doğru sonuç elde edilebilmesi için uygun deney şartlarının hazırlanması gerekmektedir. Örneğin sivrisinekler; 27 ± 2 ^{0}C sıcaklıkta, %80 ± 10 bağıl neme sahip ve 12 saat aydınlık, 12 saat karanlık olacak bir alanda yetiştirilmeli ve test edilmelidir. Sivrisinekler şeker çözeltisi ile beslenmeli, kanla besleme yapılmamalıdır. Yine sivrisineklerin 12 saat aç bırakılmış ve dişi olması gerekmektedir [137, 138]. Bazı çalışmalarda; sivrisineklerin uzun süre (8 saat) yüksek sıcaklıkta aktivitelerinin bozulması nedeniyle, 25 ± 2 ^{0}C ve %60 ± 5 bağıl nemli ortamda çalışıldığı bildirilmiştir [139].

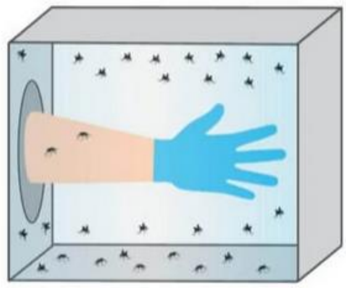
Kovucu ürünlerde son kullanıcının insan olması ve gerçek kullanım koşulları ile ilgili sonuçların talep edilebilmesi nedeniyle, çoğunlukla insan deneklerin kullanımı tercih edilmektedir. Laboratuvar çalışmalarına katılan gönüllülerin test edilecek bölgeleri önce kokusuz sabunla yıkanıp su ile durulanması, sonra %70 etanol veya izopropil alkol içeren su ile durulanarak havlu ile kurulanması gerekmektedir. Gönüllülerden testin 12 saat öncesinden itibaren koku kullanmamaları ve tütün ürünü tüketmemeleri beklenmektedir [137].

Laboratuvar şartlarında sivrisinek kovucuların etkilerini analiz edebilmek amacıyla birçok teknik geliştirilmiştir. Bu teknikler avantaj ve dezavantajlara sahiptir. Araştırmacılar sorularına çözüm ararken, bu tekniklerden kendileri için en kullanışlı olanını seçmişlerdir. Sahada yapılan kovuculuk testleri laboratuvar testlerine göre daha komplekstir. Ancak, bu testler ile gerçeği simule etmek çok daha kolaydır [140].

5.1. Kafes testi

Sivrisinek kovucularının etkinliğini test etmek için en yaygın kullanılan yöntem kafes testidir. Bu yöntem, topikal kovucular ve emdirme işlemi uygulanmış kumaşların test edilmesi için uygundur. Denek, işlem görmüş ve işlem görmemiş kumaşı ayrı ayrı giyer ve sivrisinek davranışı incelenir. Bu yöntemin avantajları, sivrisineklerin insanlara dokunmasının ve ısırmasının doğrudan gözlenebilir olmasıdır. Ancak yöntemin dezavantajı, insan deneklerini içermesidir ve deneklerin onayı ve etik onay gerektirir. Ayrıca, testte kullanılan sivrisineklerin patojenlerden arındırılmış olması gerekmektedir [7].

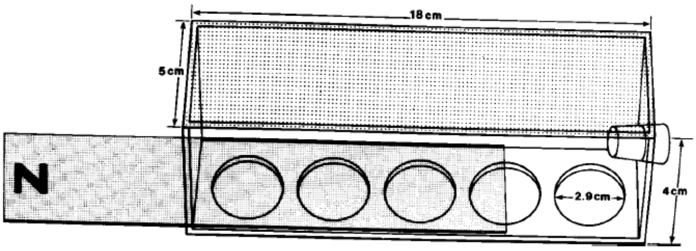
Testte, şeffaf akrilik kenarlara sahip 40 cm'lik alüminyum çerçeveli bir kafes kullanır. Testten 1 saat önce kafese 200 adet hiç doğurmamış, 7-8 günlük dişi sivrisinek yerleştirilir. Testi yapacak kişinin bir koluna kovucu ürün, diğerine ise DEET standart solüsyonu uygulanır. Ön kol kafese yerleştirilir ve 3 dakikada konan ve deriyi yoklayan sivrisinek sayısı gözlemlenir (Şekil 11). Gözlemler her 30 veya 60 dakikada bir tekrarlanır. Koruma süresi; deneyin gerekliliklerine bağlı olarak, kovucu uygulaması ile ilk belirlenen sivrisinek ısırığı arasında geçen süre veya kovucu uygulaması ile belirlenen ilk ısırıktan hemen önceki gözlem süresi arasında geçen süre olarak hesaplanır. Tüm aşamalarda "tam koruma süresi", "kovucu uygulama zamanı" ile "ilk sivrisinek konması ve/veya sondalama arasında geçen süre" ölçülür [136, 137].



Şekil 11. Kafes testi uygulaması [141]

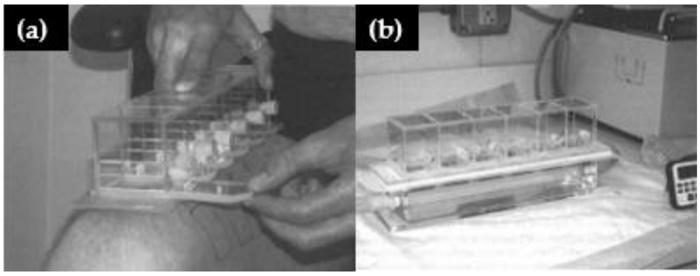
5.2. Modifiye edilmiş kafes testi

Avrupa Kimyasal Ajansı, sivrisinek kaynaklı hastalık riskleri nedeniyle saha testlerinden kaçınılması gerektiğini belirttiğinden yaygın olarak uygulanmakta olan kafes testi yerine alternatif ölçüm metotları geliştirilmiştir. ASTM E951-94 standardı ile, kovucuların etki dozları ve sivrisineklerin zaman içindeki işlevsel tepkilerini tanımlamak için modifiye edilmiş kafes testi önerilmiştir. Buna göre, alt yüzeyinde 29 mm çapında beş açıklık bulunan dikdörtgen şeffaf plastik test kafesi kullanılmaktadır (Şekil 12). Dört farklı konsantrasyondaki kovucu madde deriye uygulanır. Beşinci boşluk kontrol amaçlıdır. Kafes, gönüllünün koluna veya bacağına alt tarafı deriye gelecek şekilde bağlanır. Kafesin yanındaki açıklıktan 10-20 adet doğurmamış, 5-15 günlük dişi sivrisinekler yerleştirilir. Test kafesi tabanındaki açıklıkları kapatan plastik sürgü geri çekildiğinde test başlamakta ve sivrisineklerin kovucu ile işlenmiş cilde erişmesine izin verilmektedir. Belirli sürede deriye konan ve deriyi yoklayan sivrisinek sayısı kaydedilir [142].



Şekil 12. Modifiye test kafesi [142]

Aynı anda birden fazla sivrisinek türünün tek doz koruyucuya verdiği tepkiyi ölçmek için geliştirilmiş bir başka yönteme göre ise; insan derisine 3x4 cm'lik alanlar çizilerek belirlenir. Alanların birine kontrol amaçlı etanol, diğerlerine sivrisinek kovucu sürülür. *In vivo* yöntemde, her hücrede beş sivrisinek bulunan modül, cilt bölgesine konumlandırılır (Şekil 13a). *In vitro* yöntemde, su banyosu ile 38 ^{0}C de ısıtılmış haznelere 6 mL insan kanı doldurulur ve üzeri kollajen membran ile kaplanır (Şekil 13b). Her iki yöntemde de hücrelerin kapısı açılır. 2 dakika içinde deriyi ısıran veya kana bulanan sivrisinek sayısı kaydedilir [136].

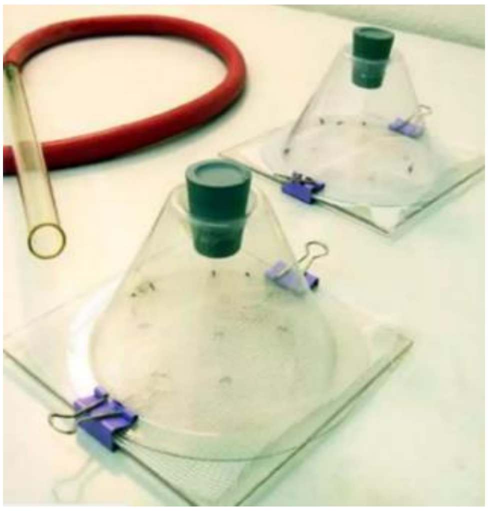


Şekil 13. Modifiye kafes testinin farklı uygulamaları; (a) *in vivo* yöntem, (b) *in vitro* yöntem[136]

5.3. Koni testi

Emdirilmiş tekstil yüzeylerinin aktivitesini test etmek üzere geliştirilmiş bu yöntemde insan deneği kullanılmamaktadır. Kovuculuk işlemi uygulanmış 15x15 cm ölçülerinde kumaşın üzerine şeffaf koni yerleştirilir (Şekil 14). Bir aspiratör ile her koniye 10 sivrisinek konulur. Konilerin dar kısımları işlem görmemiş pamuklu kumaş ile kapatılır. 3 dakikalık muamele sonrasında sivrisinekler çıkartılarak 25±2 ◦C'de %50-70 bağıl nemde, şeker solüsyonuna erişimi ve aspiratör sistemi olan bir kafeste 24 saat gözlemlenir. Sivrisinek ölümleri gözlemlenerek yüzde hesaplama yapılır [143]. Ayrıca, 3 dakikalık muamele süresi içinde numuneler üzerine konan sivrisineklerin sayısının tespit edildiği çalışmalar da mevcuttur [76].

WHO-tube testi, koni testi ile benzer parametrelerde gerçekleştirilmektedir. Test malzemesi, bir WHO standart tüpünün (Şekil 15) iç duvarına yapıştırılmıştır (WHO, 1998). Test esnasında, on dişi sivrisinek test tüpüne aktarılır ve belirli bir süre boyunca işlenmiş yüzeye maruz bırakılır. Testin sonunda sivrisinekler test tüpünden çıkarılır, daha fazla gözlem için küçük kafeslere yerleştirilir ve böcek ilacı içermeyen havada tutulur. Hareketsizleşmiş-devrilen sivrisinek sayısı bir saat sonra, ölen sivrisinek sayısı 24 saat sonra kaydedilir [145].

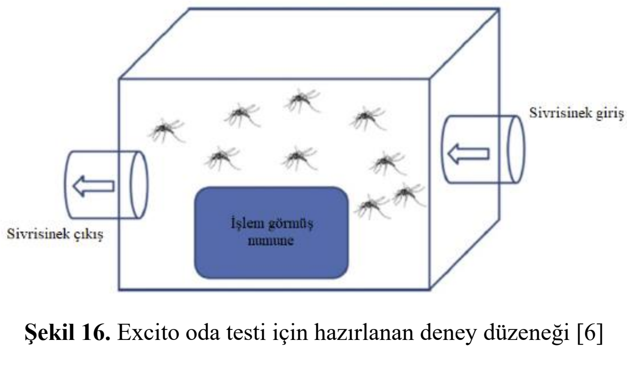


Şekil 14. Koni testi için hazırlanan deney düzeneği [144]

Şekil 15. WHO-tube test aparatları [145]

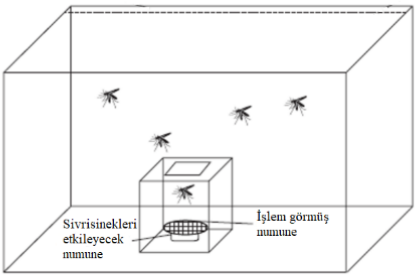
5.4. Kovuculuk odası (Excito oda) testi

Sivrisineklerin işlem görmüş kumaştan işlem görmemiş kumaşa geçiş şeklinde davranış değişikliğini gözlemlemek için modifiye edilmiş bir yöntemdir. İşlem görmüş ürünün yer aldığı kafesin (Şekil 16) bir ucundan numune gönderildikten sonra sivrisineklerin davranışları incelenir. 10 ve 30 dakika sonunda ölen ve kafesten kaçan sivrisinek sayısının tüm sayıya oranına göre değerlendirme yapılır [6].



Şekil 16. Excito oda testi için hazırlanan deney düzeneği [6]

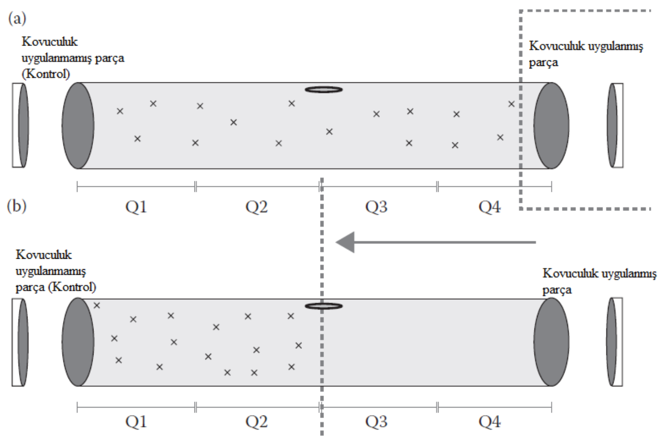
Bir başka deney düzeneğinde; test numunesi bir kutunun içine yerleştirilir. Numunenin altına, sivrisineklerin ilgilisini çekebilmek için bir başka numune (örneğin, kan emdirilmiş) konulur (Şekil 17). Test odasına belirli sayıda (genellikle 5 adet) sivrisinek yerleştirilir. 8 dakika içerisinde kaç defa iniş yaptıkları ve toplam iniş süreleri kaydedilir [146].



Şekil 17. Kovuculuk odası testi için alternatif deney düzeneği [146]

5.5. Statik havada kovuculuk testi

Bu testte, 9x60 cm ebatlarındaki tüpün bir ucuna kovuculuk işlemi uygulanmış malzeme, diğerine işlem uygulanmamış mal-zeme yerleştirilir (Şekil 18). 5-10 günlük 20-25 adet sivrisinek tüpün içine bırakılır ve dağılım kaydedilir. Kovucunun bulun-duğu yarı alandaki (Q3 ve Q4) sivrisinek sayısından diğer yarı alandaki (Q1 ve Q2) sayı çıkartılıp tüm sivrisinek sayısına bölünmesiyle etkinlik değeri hesaplanır. Ayrıca konumsal kovuculuk yanında kaçınma frekansı da ölçülebilmektedir [23]. Statik hava kovuculuk odasının avantajları, sivrisineklerin hareketlerinin geniş bir çevrede ölçülebilmesini sağlaması ve sivrisineklerin zamanla dağılımının saptanmasına izin vermesidir. Bu dezavantajları ise, yüksek dozda uygulanan kovucu bileşenlerin sivrisineklerin ölümüne neden olmasıdır.



Şekil 18. Statik havada kovuculuk test aparatı; a) başlangıç durumu, b) sivrisineklerin işlem görmüş malzemeden uzaklaşmaları [140]

6. SONUÇ

Estetik özelliklerden ziyade fonksiyonelliğin ön planda tutulduğu koruyucu tekstiller, teknik tekstillerin önemli alt kollarından biridir. Koruyucu tekstil malzemeleri ile olumsuz ortam ve koşullardan korunmak amaçlanmaktadır. Tekstil malzemeleri, insan vücudunun büyük bir bölümünü kapladığı için sivrisineklerin zararlı etkilerinden ve bunlardan kaynaklanabilecek hastalıklardan korunmada da büyük önem taşımaktadır.

Sivrisinekler, pek çok hastalığın insanlara bulaşmasına neden olabilen tehlikeli canlılardır. Özellikle sıcak ve tropik bölgelerde, sivrisinek kaynaklı hastalıklar hem bireyin hem de bulaşıcılığı nedeniyle toplumun sağlığını ciddi derecede tehdit etmektedir.

Doğal veya sentetik esaslı sivrisinek kovucu maddelerin çeşitli yöntemlerle tekstil malzemelerine katılmasıyla sivrisinek kovucu tekstil yüzeyleri üretilmektedir. Doğal ve sentetik sivrisinek kovucu maddelerin birbirilerine göre avantaj ve dezavantajları olmakla birlikte; son yıllarda çevre dostu yaklaşımların ve sürdürülebilirlik kavramlarının ön planda olması nedeniyle, akademik çalışmalarda doğal kovucu maddelere ilginin daha fazla olduğu görülmektedir. Sivrisinek kovucu tekstil yüzeyleri, kovucu maddenin lif üretimi aşamasında polimer matrisine katılmasıyla veya çeşitli terbiye işlemlerinde kumaşlara uygulanmasıyla elde edilebilmektedir. Literatürdeki çalışmaların büyük çoğunluğunu terbiye işlemleriyle elde edilen tekstil yüzeyleri oluşturmaktadır. Bununla birlikte, nanoliflerin yüksek spesifik yüzey alanları, birim alanda daha fazla kovucu madde yüklenebilmesine ve daha uzun süreli etkinliğe olanak sağlamaktadır.

Sivrisinek kovucu tekstil malzemelerinde aranan en önemli iki özellik, yüksek kovuculuk oranı ve kovuculuğun kalıcılık süresidir. Kapsülasyon teknolojisi ile elde edilen mikro/nano kapsüller, sivrisinek kovucu özelliğin süresini ve dayanımını arttırmak için son yıllarda dikkat çeken bir yaklaşımdır. Böylece, hem daha az kovucu madde kullanılabilmekte hem de kovucu bileşenlerin yavaş salımı sayesinde daha uzun süre kalıcılığa sahip tekstil yüzeyleri üretilebilmektedir.

Sivrisinek kovucu tekstil malzemelerinin etkinliğini test etmek için çeşitli yöntemler uygulanmaktadır. En yaygın kullanılan yöntem kafes testi olmakla birlikte; sivrisinek kaynaklı hastalık riski nedeniyle, insan temasının daha az olduğu veya hiç olmadığı farklı ölçüm yöntemleri de geliştirilmiştir. Tüm testlerde ortak amaç; belirli ortam şartlarında, tanımlanmış tür ve sayıdaki sivrisineğin kovucu malzeme ile etkileşiminin, temas sonrası davranışının ve kaçınma frekansının tespit edilmesidir.

Sonuç olarak; küresel ısınmasının artışıyla birlikte, sivrisinek kaynaklı hastalık ve ölüm tehlikesi de artmaktadır. Bu nedenle, sivrisineklerden korunma yöntemleri üzerine arayışlar devam edecektir. Bu amaçla; sivrisinek kovucu özellikte tekstil malzemelerinin geliştirilmesinde, nanoteknoloji ve kapsülasyon teknolojisi gibi yenilikçi yaklaşımlardan faydalanılması, ürün güvenliği ve çevresel etkilerin dikkate alınması, sürdürülebilirlik açısından kritik bir öneme sahiptir.

TEŞEKKÜR

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TEKSTİL VE MÜHENDİS DERGİSİ
YAZIM KURALLARI

“Tekstil ve Mühendis”dergisi, özgün bilimsel araştırmalar ile ilginç uygulama çalışmalarına yer veren ve bu niteliği ile hem araştırmacılara hem de uygulamadaki mühendislere seslenmeyi amaçlayan bir dergidir. Dergide tekstille ilgili bilimsel, teknik ve ekonomik içerikli yazılar yayımlanır. Bu yazılar, yazım kurallarına göre hazırlanmış özgün araştırma ürünü yazılar veya belirli bir konuyu yeterli sayıda kaynaktan araştırarak hazırlanmış derleme yazılar biçiminde olabilir. Dergide yayımlanacak özgün ve derleme yazılar ile ilgili yazım kuralları aşağıda verilmiştir:

Genel Yazım Kuralları

• Yazı dili Türkçedir. Metin yalın bir dil ile yazılmalı, Türkçe yazım kurallarına uygun olmalı, devrik cümleler içermemelidir. Dergide Türkçe özet çevirisi ile birlikte olmak kaydı ile İngilizce yazılmış bilimsel makaleler de yayınlanabilir.
• Dergide yayınlanması istenen yazılar, standart A4 boyutundaki kağıda üstten 3,5 cm, alttan 3,5 cm, sağdan 2,5 cm ve soldan 2,5 cm boşluk olacak şekilde hazırlanmalıdır.
• Yazılar, Windows uyumlu gelişmiş bir kelime işlemci (Winword) kullanılarak hazırlanmalıdır.
• Metin ve başlık bölümlerinin tamamı Times New Roman yazı karakteri ile yazılmalıdır.
• Yazı başlığı ortalanmış olarak 14 punto, büyük ve koyu harflerle yazılmalıdır. Yazı başlığı kısa ve açık olmalı, içeriği yansıtmalıdır. Yazı başlığından sonra iki satır boşluk bırakılıp sağ köşeye yaslatılarak yazar adları ve soyadları küçük harflerle 12 punto ile yazılmalıdır. Birden fazla yazar tarafından hazırlanmış yazılarda yazar adları alt alta yazılmalı, unvan kullanılmamalı, yazar adresleri yazar adlarının hemen altında verilmelidir.
• Metinin başına en çok 100 sözcükten oluşan, okuyucuya yazının konusunu, önemini, güncelliğini tanıtan özet konulmalıdır. Türkçe özet yazar adlarından sonra iki satır boşluk bırakılarak 12 punto koyu harfler ile yazılmış “ÖZET” başlığını takiben iki yana dayalı olarak yazılmalıdır.
• Türkçe özetten sonra bir satır boşluk bırakılarak çalışma alanını tanımlayan en az dört adet anahtar kelime verilmelidir.
• Anahtar kelimelerden sonra iki satır boşluk bırakılarak 14 punto büyük ve koyu harflerle ortalanmış olarak yazının İngilizce başlığı verilmelidir. İngilizce başlığın ardından bir satır boşluk bırakılarak 12 punto koyu harfler ile yazılmış “ABSTRACT” başlığını takiben iki yana dayalı olarak İngilizce özet yazılmalıdır.
• İngilizce özetten sonra bir satır boşluk bırakılarak çalışma alanını tanımlayan en az dört adet anahtar kelime (keywords) verilmelidir.
• Türkçe yazılarda; Türkçe başlık ve özet, İngilizce yazılarda ise İngilizce başlık ve özet önce gelmelidir.
• Metin içerisindeki ana başlıklar 12 punto, koyu ve büyük harf, alt başlıklar 12 punto koyu ve küçük harf, metin ise 12 punto olacak şekilde düzenlenmelidir.
• Metin, iki yana dayalı şekilde, bir satır aralıklı olarak yazılmalı, satır başı kullanılmayıp paragraflar arasında bir satır boşluk verilmelidir. Metin yazılırken hiçbir özel format (header, footer, heading) kullanılmamalıdır.
• Yazılarda, bölüm ve alt bölüm başlıkları numaralandırılmalıdır. Başlıklardan önce ve sonra bir satır boşluk bırakılarak takip eden metin yazılmalıdır.
• Yazılarda yalnızca SI birimleri kullanılmalıdır. Zorunlu olarak farklı birimler kullanılması gerekiyor ise parantez içinde SI eşdeğeri verilmelidir.

Şekiller, Tablolar ve Formüller

• Bütün şekiller basım kalitesi açısından mümkün olan en yüksek çözünürlükte hazırlanmalıdır. Şekil isimleri sıra ile numaralandırılmalı ve şekil altında ortalanarak 10 punto olacak şekilde yer almalıdır.
• Tablolar sıra ile numaralandırılmalı, tablo başlıkları 10 punto büyüklüğünde tablonun üstünde sola dayalı olarak yer almalıdır.
• Şekil ve tablolar metin içinde bir satır boşluk bırakılarak ilgili oldukları kısma konulmalı, şekil ve tablolardan sonra boşluk bırakılmadan şekil ve tablo isimleri yer almalıdır.
• Her türlü formül, bilgisayar ile yazılmalı ve yazı alanının soluna yaslanmalı, formül veya bağıntı veriliş sırasına göre yazı alanının sağ kısmına yaslanacak şekilde parantez içinde (1) şeklinde numaralanmalıdır.
• Metinde kullanılan semboller uluslararası kullanıma uygun seçilmeli; her bir sembol kullanıldığı yerde tanımlanmalıdır.

Kaynaklar-Alıntılar

• Kaynaklar metinin hemen sonunda yer almalıdır.
• Kaynaklar metin içerisindeki kullanım sırasına göre numaralandırılarak kaynaklar kısmına yerleştirilmelidir. Kullanılan kaynaklar metin içerisinde bu numaralar esas alınarak [köşeli parantez içerisinde] belirtilmelidir.
• Etik kuralları gereğince, alıntılar metinde tırnak içinde verilmelidir ve bir referans numarası ile kaynak belirtilmelidir.
• Kaynaklar aşağıdaki formata uygun olarak yazılmalıdır, süreli yayınlarının varsa DOI numaraları belirtilmelidir.

Süreli Yayınlar:
- **Yazar(ların) Soyadı, Adının baş harfi., (Yıl)**, *Çalışmanın Başlığı*, Dergi İsmi, Sayısı, Numarası, Sayfa. *DOI numarası.*

Kitaplar:
- **Yazar(ların) Soyadı, Adının baş harfi., (Yıl)**, *Kitabın Başlığı*, Yayınevi, Basıldığı yer.

Kongreler:
- **Yazar(ların) Soyadı, Adının baş harfi., (Yıl),** *Çalışmanın Başlığı*, Kongre veya Kongre Kitabı Adı. Sayfa, Tarih, Yapıldığı Yer.

İnternet:
- **Yazar(ların) Soyadı, Adının baş harfi.** *Çalışmanın Başlığı*, İnternet Adresi, Erişim Tarihi

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TMMOB TEKSTİL MÜHENDİSLERİ ODASI ÜYE OLUN VE AKTİF KATILIN

Her birimizin gerek mesleğimiz ile ilgili gerekse ülkemizdeki sektörel ve ya genel durum ile ilgili olarak söz söyleme hakkı bulunmaktadır. Mesleki olarak tekstil mühendislerinin bir çatı altında olacağı kurum Tekstil Mühendisleri Odasıdır. Henüz üye olmadıysanız en yakın şubemize başvurun, sözünüzü ve uygulamalarınızı aktif olarak gerçekleştirin.

Türk Mühendis ve Mimar Odaları Birliği (TMMOB) 7303 sayılı yasa, 66 ve 96 sayılı Kanun Hükmünde Kararnamelerle değişik 6236 sayılı yasayla 1954 yılında kurulmuştur. TMMOB tüzel kişiliğe sahip, Anayasanın 135. Maddesinde belirtilen kamu kurumu niteliğindeki bir meslek kuruluşudur. TMMOB çalışmalarını 23 meslek odası ve bu odalara bağlı 160 şube ve 30 İl Koordinasyon Kurulu ile sürdürmektedir. TMMOB'a bağlı odalara 50 kadar mühendislik, mimarlık ve şehir plancılığı disiplininden mezun olan mühendis, mimar ve şehir plancıları üyedir. 6235 sayılı "Türk Mühendis Mimar Odaları Birliği Yasası" uyarınca Türkiye'de özel sektörde mesleki alanlarda çalışan mühendislerin TMMOB çatısı altındaki bağlı bulundukları odaya kayıtlı olarak görevlerini sürdürmeleri zorunludur. (Madde 33). Bu gereği yerine getirmeyen söz konusu mühendisler Türkiye'de mesleki faaliyetten men edilmektedir. (Madde 38).

Bu yasa uyarınca özel sektörde çalışan tüm mühendislerin oda üyesi olmaları gerekmektedir. Türkiye'de yaklaşık 7000 "Tekstil Mühendisi" çalışmaktadır. Ancak bu rakamın %25'i odaya kayıtlıdır. Bu oran Türkiye'deki örgütlenebilme, ekip çalışmasına yatkınlık, birlikte hareket edebilme ve hedef birlikteliği konularına bakış açımızın da açık bir göstergesidir. Kalkınmak, kaynaklarımız ışığında Türkiye'nin hedeflerini daha doğru belirleyebilmek ve ülkemizi hedeflere omuz omuza taşıyabilmek için, tekstil mühendislerini odaya üye olmaya davet ediyoruz.

TEKSTİL MÜHENDİSLERİ ODASI

Tekstil Mühendisleri, örgütlerini 1973 yılında TMMOB tarafından alınan karar gereği "Makine Mühendisleri Odası" içinde sürdürmüşlerdir. TMMOB 32. genel kurul kararıyla 23 Mayıs 1992 tarihinde "Tekstil Mühendisleri Odası" kurularak, birliğin halkasına 21. meslek örgütü olarak katılmıştır. İlk genel kurulunu ise19 Eylül 1992'de Bursa'da gerçekleştirmiştir. Bu gün merkezi İzmir'de olan odamız, Bursa, Denizli, Güney Bölge, İzmir, İstanbul şubeleriyle ve il temsilcilikleriyle faaliyetlerini sürdürmektedir.

Ülke ve toplum yararları doğrultusunda Tekstil Sanayinin ulusal çıkarlara uygun yönden gelişmesini sağlamak amacıyla gerekli inceleme ve araştırmaları yapmak ve bunların "Tekstil ve Konfeksiyon Sektörü"nün ve "Tekstil Mühendisleri"nin yararına sunmayı amaç edinen meslek örgütümüz tarafından sağlanan hizmetler şunlardır:

-Serbest Mühendislik ve Müşavirlik (SMM) Belgesi
-Meslek içi eğitim çalışmaları
-Yayın çalışmaları
-Bilirkişilik hizmetleri
-Sempozyum ve seminerler
-Tekstil proje ve raporlarını denetlemek
-Tekstil mühendisliği alanında teknik çalışmalar yürütmek
-Tekstil ürünlerine kalite belgeleri vermek ve denetlemek
-Tüketicilerin bilinçlendirilmesine ve korunmasına yönelik çalışmalar
-Sosyal ve kültürel etkinlikler

TEKSTİL MÜHENDİSLERİ ODASI ÜYELİĞİ VE ÜYELİK ŞARTLARI

Gelirlerinin büyük bir kısmını üyelerinin ödediği aidatlarla ve yapılan aktiviteler sonucu elde edilen gelirle sağlayan meslek örgütümüz bünyesine katılan her yeni üyeyle gücüne güç katmaktadır. Meslektaşlarımızın, üyelik için aşağıda listelenmiş belgeler ile şubelere başvurmaları gerekmektedir;

-2 adet kayıt formu (Şubelerden veya www.tmo.org.tr adresinden temin edilebilir)
-Diploma fotokopisi (noter tasdikli sureti ya da aslı tarafımızdan görülmek koşuluyla fotokopisi)
-Nüfus cüzdanı fotokopisi
-5 adet fotoğraf (pasaport formuna uygun)
-Evlilik cüzdanı fotokopisi (evli bayanlar için)

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