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INVESTIGATION OF THE DYEABILITY OF COTTON FABRICS WITH BACTERIAL COLORANTS

PAMUKLU KUMAŞLARIN BAKTERİYEL BOYARMADDELERLE BOYANABİLİRLİĞİNİN ARAŞTIRILMASI

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INVESTIGATION OF THE DYEABILITY OF COTTON FABRICS WITH BACTERIAL COLORANTS

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ABSTRACT: Dyestuffs are used in almost every industry. However, due to the negative effects of synthetic dyestuffs on the environment and human health, environmentally friendly natural dyestuffs have gained importance in recent years, especially in the textile sector. Mostly plant and plant waste-based dyes are used in coloring fabrics with natural dyes. However, with the developments in the field of biotechnology, there are also studies in which pigment is produced by microorganisms. Within the scope of this study, 100% cotton woven fabric was dyed using 6 different processes with 3 bio-colors, pink, blue and brown, produced by bacterial fermentation. The dyeings were carried out in the absence of chemicals, in the presence of salt, salt-soda, salt-alum, salt-soda-alum and alum respectively. In order to evaluate the dyeing performance, the CIELab values of the fabrics were measured and their color fastness to washing, water, alkali and acid perspiration and also dry and wet rubbing fastness were checked. As a result of the studies, it was concluded that each dyestuff react in a different way with a different process. While the most suitable process for blue and pink bio-color is that salt used process, the highest K/S value with brown bio-color was obtained as a result of dyeing with salt-soda. All fastness values of the dyed fabrics were quite good. As a result of the trials, it can be said that laboratory-scale studies of bio-colors obtained by bacterial fermentation are promising for the future.

Keywords: Bacterial dyeing, dyeing with microorganisms, textile dyeing, sustainability in textile

PAMUKLU KUMAŞLARIN BAKTERİYEL BOYARMADDELERLE BOYANABİLİRLİĞİNİN ARAŞTIRILMASI

ÖZ: Boyarmaddeler hemen hemen her sektörde kullanılmaktadır. Ancak sentetik boyarmaddelerin çevre ve insan sağlığı üzerinde olumsuz etkilerinden dolayı son dönemlerde özellikle tekstil sektöründe çevre dostu doğal boyarmaddeler önem kazanmıştır. Kumaşların doğal boyalar ile renklendirilmesinde çoğunlukla bitki ve bitki atığı kaynaklı boyalar kullanılmaktadır. Ancak biyoteknoloji alanındaki gelişmeler ile birlikte mikroorganizmalar vasıtasıyla pigment üretilen çalışmalar da mevcuttur. Bu çalışma kapsamında bakteriyel fermantasyonla ile üretilen pembe, mavi ve kahverengi olmak üzere 3 boyarmadde ile 6 farklı proses kullanılarak %100 pamuklu dokuma kumaş boyanmıştır. Boyamalar sırasıyla yalnızca boyarmadde, boyarmadde ile birlikte sırasıyla tuz, tuz-soda, tuz-şap, tuz-soda-şap ve şap kimyasalları varlığında boyanmıştır. Boyama performansını değerlendirmek amacıyla kumaşların CieLab değerleri ölçülmüş, yıkama, su, alkali ve asidik ter ile kuru ve yaş sürtme haslıkları kontrol edilmiştir. Yapılan çalışmalar sonucunda her boyarmaddenin farklı boyama banyolarında farklı davrandığı sonucuna ulaşılmıştır. Mavi ve pembe renk için en uygun proses yalnızca tuz kullanılan proses iken kahverengi boyarmaddede ile en koyu renk tuz-soda ile yapılan boyama sonucu elde edilmiştir. Haslık değerlerinin hepsi oldukça iyidir. Sonuç olarak bakteriyel fermantasyonla elde edilmiş boyarmaddelerin laboratuvar ölçekli çalışmalarının gelecek için umut vaat edici olduğu söylenebilir.

Anahtar Kelimeler: Bakteriyel boyama, mikroorganizmalarla boyama, tekstil boyama, tekstilde sürdürülebilirlik

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1. INTRODUCTION

The textile industry is one of the most polluting industries due to the dyes, chemicals and wastes used during production [1]. In the textile sector, especially dyeing processes have a significant effect on environmental pollution with heavy inorganic chemical, alkali, surfactant, organic matter discharges. In addition to this pollution, it is known that it consumes large amounts of clean water [2]. In order to reduce this environmental impact in the textile sector, either a very large and effective wastewater treatment plant should be built or environmentally friendly alternatives should be selected in the dyes and chemicals used [1].

Compared to synthetic colorants, even if natural colorants have many disadvantages such as higher usage amount, higher costs and low stability, consumers are increasingly moving away from synthetic colorants and prefer harmless natural pigments [3]. Natural pigments that can be produced from plants, animals and microorganisms are known as biodegradable and environmentally friendly products [4]. Natural products are used in many fields in different industries such as textile, pharmacy, cosmetics and food due to their versatile usage areas [5-6]. In recent years, microalgae have been envisioned as living cell factories for the production of biofuels and various useful biochemicals used in the food, aquaculture, poultry and pharmaceutical industries due to the presence of different beneficial compounds, as well as their use as single-cell proteins [7].

The use of natural dyes in the textile industry has a cultural and economic value [8]. In recent years, plant-based dyes have been used instead of synthetic dyes, especially in textile products [9]. Biological pigments obtained from bacteria and microalgae can be considered as an alternative to plant-based dyestuffs, as they are biodegradable and do not harm the environment [10]. Micro-organisms produce a wide variety of stable pigments such as carotenoids, flavonoids, quinones and rubramines, and fermentation has higher yields compared to pigments derived from plants and animals [10-11].

Colorful molecules produced by microorganisms include indigo, melanins, flavins, carotenoids, phenazines, quinones, violacein and prodigiocins [12-13]. Violacein, a natural purple dye, can be obtained from a gram-negative bacterium called Chromobacterium violaceum [14]. The yellow pigment can be extracted by boiling method from Chryseobacterium sp., an isolated gram-negative bacterium [15]. Prodigiosin is a red dye produced by many strains of the bacteria Serratia marcescens and other gram-negative gamma proteobacteria such as Vibrio psychroerythrus and Hahella chejuensis [16-17].

Studies on the use of pigments obtained from bacteria and algae in textile dyeing have gained momentum in recent years. There are different companies that carry out such studies globally, and some of these companies have stated that they will carry their work to a commercial scale in a few years. British origin Colorifix company has produced different colored pigments from genetically modified E. Coli bacteria. Thanks to the technology they have developed, they first obtain a color pigment by bacterial growth in the bioreactor and then obtain a liquid dyestuff that can dye all kinds of fibers [18]. Pili from France is a company that produces microbial pigments in powder form. Its technology is based on redesigned microbial enzymes to produce dyes [19]. The Algaeing company, which was established in Israel, carries out studies that can be suitable for textile printing [20]. Germany-based Blond & Bieber company is investigating the possibilities of using microalgae as pigments in textile printing in the design laboratory of the project they call Algaemy [21].

It is seen that various studies have been carried out in the literature on staining in microorganisms and algae. In these studies, the new species Streptomyces, Vibrio spp. Serratia marcescens bacteria were used. Dyeing was carried out at 80-85ºC in 45-60 minutes. It has been observed that polyamide, acrylic, silk and wool are dyed darker than cotton and viscose. It was observed that the dye color yield decreased as the pH increased [13,22-24].

In this paper, the dyeings of cotton poplin fabric was carried out with different processes by using three different bacterial-based bio-colors. CieLab values of dyeings were compared to find the most suitable dyeing technique and fastness values were checked.

2. MATERIALS AND METHOD

2.1. Materials

100% cotton poplin pre-treated fabric with a weight of 108 g/m^2 was used in the study. Three bio-colors (pink, blue and brown) were used for dyeing fabrics and these bio-colors were obtained by using bacterial fermentation. They were powder form and water-soluble. Trade names were not disclosed for commercial concerns. But blue bio-color belongs to the indole family group, brown bio-color belongs to the alcoholic carotenoid pigment family and pink bio-color belongs to the pyrrole family. The bio-colors were free from the bacterias. All microorganisms worked with have Biosafety Level 1. This shows that they are not pathogenic and safe for human health. Potassium aluminum sulfate dodecahydrate, also known as alum [$KAl(SO_4)_2 \cdot 12H_2O$] mordant material, was used. Sodium chloride (NaCl) was used as salt and sodium carbonate (Na_2CO_3) was used as soda. Washing soap used in washing after dyeing is non-ionic.

2.2. Method

The dyeing process of the fabrics with bacterial dyestuffs was carried out using a TERMAL branded 30 liter water bath. The bath ratio is 1:20. Dyeing was carried out at 85ºC for 45 minutes. Then, the dyed fabrics were rinsed with cold water and then washing were carried out at 60ºC for 30 minutes by using 0,5 g/l washing soap. Dyeing receipts are given in Table 1.

Table 1. Dyeing receipts of bio-colors

Receipt No	Bio-Color Rate (%)	NaCl (g/l)	Soda Ash (g/l)	Alum (g/l)
1P	5	-	-	-
2P	5	25	-	-
3P	5	25	15	-
4P	5	25	-	2,5
5P	5	25	15	2,5
6P	5	-	-	2,5

2.2.1 Color measurements

Color measurements for dyed fabrics were carried out with a Datacolor 1050 model spectrophotometer. Measurements were made according to the CIELab color space under D65 daylight using a 10º standard observer at 6.6 mm aperture.

2.2.2 Color fastness to washing

Washing fastness tests were carried out in James Heal branded gyrowash machine according to ISO 105-C06:2012 A2@40ºC [25] standard. The results were evaluated with a gray scale.

2.2.3 Color fastness to water

Water fastness tests were carried out in Nuve branded oven according to ISO 105-E01:2013 [26] standard. The results were evaluated with a gray scale.

2.2.4 Color fastness to perspiration

Alkali and acidic perspiration fastness tests were carried out in the Nuve branded oven according to ISO 104-E04:2013 [27] standard. The results were evaluated with a gray scale.

2.2.5 Rubbing fastness

Dry and wet rubbing fastnesses were performed by using James Heal branded rubbing device according to ISO 105X12:2006 [28] standard. The results were evaluated according to the gray scale.

3. RESULTS AND DISCUSSION

3.1. Spectrophotometer results

Due to the high environmental impact of synthetic dyestuffs both during production and use, there are some startups working on bacterial dyestuffs obtained by fermentation. In this study, the dyeability of cotton fabrics with bacterial dyestuffs with different recipes was investigated, and the color strength and fastness values were checked. In this way, it will be ensured that a more environmentally friendly approach, which is an alternative to synthetic dyestuffs and will be able to adapt to the commercial market quickly, will be scale-up.

The CIELab values of the trials were given in Table 2. CIE in CIELAB is the abbreviation of Commission Internationale de l'Eclairage, the French name of the International Commission on Illumination. The letters L*, a* and b* represent each of the three values that the CIELAB color space uses to measure objective color and calculate color differences. L* represents lightness from black to white on a scale of zero to 100, while a* and b* represent chromaticity without a specific numerical limit. Negative a* corresponds to green, positive a* to red, negative b* to blue, and positive b* to yellow [29].

When the color strength and K/S value of the pink color were examined in Table 2, it is seen that the deeper color was obtained with the Recipe 2 with a K/S value of 0.30. The lowest value obtained with the pink color was the Recipe 1, which was determined as 0.05. In Recipe 1, only dyestuff was added to the dyeing bath without chemical and it was seen that there was slight staining on that fabric.

Table 2. K/S and CIELab values of dyed fabrics

Recipe no -Color	L	a	b	C	h	K/S
Recipe 1 - Pink	93,13	1,97	4,25	4,69	65,15	0,05
Recipe 2 - Pink	80,93	22,29	-5,79	23,03	345,44	0,30
Recipe 3 - Pink	83,2	20,75	-5,05	21,35	346,32	0,24
Recipe 4 - Pink	84,05	19,08	-4,06	19,51	348	0,22
Recipe 5 - Pink	81,02	22,61	-5,74	23,33	345,76	0,29
Recipe 6 - Pink	85,75	15,25	-2,02	15,38	352,46	0,17
Recipe 1 - Blue	80,5	0,04	-10,05	10,05	270,21	0,21
Recipe 2 - Blue	78,97	0,38	-12,44	12,44	271,75	0,26
Recipe 3 - Blue	91,18	-0,04	1,02	1,02	92,49	0,05
Recipe 4 - Blue	84,71	-0,34	-6,17	6,18	266,81	0,12
Recipe 5 - Blue	89,49	0,38	-0,55	0,67	304,84	0,05
Recipe 6 - Blue	79,96	-0,08	-10,67	10,67	269,57	0,23
Recipe 1 - Brown	89,25	1,68	10,75	10,88	81,1	0,16
Recipe 2 - Brown	81,43	4,03	14,3	14,86	74,27	0,43
Recipe 3 - Brown	67,69	5,89	15,43	16,52	69,1	1,25
Recipe 4 - Brown	92,8	-0,03	6,94	6,94	90,23	0,07
Recipe 5 - Brown	70,79	5,44	14,06	15,08	68,86	0,94
Recipe 6 - Brown	92,95	0,09	6,83	6,83	89,24	0,07

In blue color, the best result was obtained from Recipe 2 and the worst results were obtained from Recipe 3 and Recipe 5. Blue bio-color due to its structure has the best pick-up and affinity. The exhaustion rate was already good for blue color, but adding salt was increased the exhaustion. It was observed that alkaline dyeing baths damaged the blue color chromophore groups. pH values for Recipe 3 and Recipe 5 were 9.93 and 9.58 respectively.

In brown color, the highest K/S value was obtained with Recipe 3. Because these pigments were not naturally soluble in water and alkali was added in the process to improve the solubility of brown bio-color. Salt was added to impove exhaustion. Recipe 4 and Recipe 6 has the lowest K/S value since the alum was in the recipe and it decreased pH. While pH value of Recipe 3 was 10.56, pH values of Recipe 4 and Recipe 6 were 4.2 and 4.1 in these dyeing baths respectively.

3.2. Color fastness results

The fastness values of the dyed fabric are as important as binding a dyestuff to the fabric. For this reason, color fastness to washing , water, acidic and alkaline perspiration and dry and wet rubbing fastness of 18 dyed fabrics were checked. The results were given in Table 3.

When the fastness results were examined in Table 3, no problems were observed in the rubbing fastness, and the results were quite good. The highest color change (CC) values of the pink fabric was taken from Recipe 2 which has the highest K/S value. This shows that the dye was bonded to the fabric properly. In the blue color, the highest fastness results were taken from Recipe 3 and Recipe 5. Because blue dyestuff was not stable in alkali medium and the fabrics were almost colorless. The highest K/S value and the lowest fastness results of blue color was obtained from Recipe 3. The reason for this is thought to be due to high color strength. However, the fastness results obtained are still within acceptable limits.

4. CONCLUSION

In the trials carried out within the scope of this project, it has been observed that each dyestuff has its own characteristic properties since the pigment classes are different. Laboratory scale trials shows that bacterial-based dyes are suitable for cellulosic fabric dyeing. With the widespread use of this practice in the textile industry, the natural resource consumption, high energy requirement and emission of harmful gases required in the production of synthetic dyestuffs will be eliminated, and the waste load of textile waste water will be reduced.

While the darkest color was obtained by using only salt with pink and blue color, the darkest dyeing in brown color was obtained by using salt and soda. It was observed that the chromophore groups of blue color are decomposed in alkaline medium. For Brown color, the solubility of the dyestuff decreases in acidic medium. Considering the other studies in the literature, this study is important because it is the closest study to commercial.

Tablo 3. Fastness results of all dyeings

	Color Fastness to Washing		**Color Fastness to Water**		**Color Fastness to Perspiration (Acid)**		**Color Fastness to Perspiration (Alkali)**		**Rubbing Fastness**	
	ISO 105-B02: 2014		**ISO 105-E01:2013**		**ISO 105-E04:2013**		**ISO 105-E04:2013**		**ISO 105X12:2006**	
	Color Change	Color Staining	Color Change	Color Staining	Color Change	Color Staining	Color Change	Color Staining	Dry	Wet
Recipe 1 Pink	3	4/5	3/4	4/5	3/4	4/5	3/4	4/5	4/5	4/5
Recipe 2 Pink	4	4/5	4	4	4	4	4	4	4/5	4/5
Recipe 3 Pink	3/4	4/5	3	4	3	4	3	4	4/5	4/5
Recipe 4 Pink	3/4	4/5	4	4	4	3/4	4	4	4/5	4/5
Recipe 5 Pink	3/4	4/5	3/4	4/5	3/4	4/5	3/4	4/5	4/5	4/5
Recipe 6 Pink	2/3	4/5	3	4/5	3	3/4	3	4	4/5	4/5
Recipe 1 Blue	4	4	4	4/5	4	4/5	4	4/5	4/5	4/5
Recipe 2 Blue	4	4	4	4/5	4	4/5	4	4/5	4/5	4/5
Recipe 3 Blue	4/5	4/5	4/5	4/5	4/5	4/5	4/5	4/5	4/5	4/5
Recipe 4 Blue	4	4/5	4	4/5	4	4/5	4	4/5	4/5	4/5
Recipe 5 Blue	4/5	4/5	4/5	4/5	4/5	4/5	4/5	4/5	4/5	4/5
Recipe 6 Blue	4	4	4	4/5	4	4/5	4	4/5	4/5	4/5
Recipe 1 Brown	3	4/5	3/4	4/5	3/4	4/5	3/4	4/5	4/5	4/5
Recipe 2 Brown	3/4	4/5	4/5	4/5	4/5	4/5	4/5	4/5	4/5	4/5
Recipe 3 Brown	3/4	3/4	4	4/5	4	4	4	3	4/5	4/5
Recipe 4 Brown	3/4	4/5	3/4	4/5	3/4	4/5	3/4	4/5	4/5	4/5
Recipe 5 Brown	4	4/5	4/5	4/5	4/5	4/5	4/5	4/5	4/5	4/5
Recipe 6 Brown	4	4/5	4/5	4/5	4/5	4/5	4/5	4/5	4/5	4/5

In future studies, these colors can be dyed as combinations among themselves. Salt should be added to the recipe while dyeing pink and blue together. Salt and soda ash should be added to the recipe while dyeing brown and pink combination. Salt alone should be used when dyeing blue with brown even if solubility of brown is better in alkaline medium; because alkaline medium will degrade the blue bio-color. If triple combination is used to get different color, dyeing should be performed using salt alone. In this study, the amount of salt and soda was kept constant. In future studies, it can be examined how the increase and decrease in the amount of salt and soda affect the dyeing efficiency.

As a result, in the coming years it is seen that bacterial dyeing will be commercialized rapidly since the dyestuffs are powder and water soluble and easy to adapt to production.

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