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THE INFLUENCE OF ENZYMATIC PRE-TREATMENT ON THE ADSORPTION OF COTTON-POLYESTER BLENDED FABRIC

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Thermophysiological comfort, which is crucial for the overall satisfaction of the wearer, depends largely on effective heat and moisture regulation. Cotton-polyester blends offer a balanced solution due to the hydrophilic and hydrophobic properties of the respective fibers, improving moisture absorption and the ability to dry quickly. However, the conventional alkaline pretreatment with NaOH is ecologically questionable. In this study, an environmentally friendly alternative by enzymatic pretreatment of 50/50 cotton-polyester fabric with pectinase and esterase enzymes was investigated. The effects on water adsorption were evaluated using vertical wicking (AATCC TM 197-2022), and the subsequent adsorption of fluorescent whitening agents (FWAs), Uvitex® BHT and Uvitex® NFW, was analyzed at three concentrations (1%, 2%, and 10% owf). The results showed that both enzymes improved the adsorption properties, with esterase and its combination with pectinase significantly increasing the whiteness of the fabric due to the higher uptake of Uvitex BHT. The optimal whiteness was achieved with 2% Uvitex BHT, while higher concentrations were required for comparable results with Uvitex NFW. The study shows that enzymatic pretreatment is a sustainable method to improve both sorption and optical properties of cotton-polyester fabrics.

Keywords: cotton-polyester blend, pectinase, esterase, FWA, degree of whiteness.

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INTRODUCTION

Thermophysiological comfort, which includes heat and moisture regulation, has a major influence on wearer comfort. Adsorption properties maintain thermal balance and dryness, especially under conditions of high physical activity or thermal stress, where the accumulation of sweat can lead to discomfort, skin irritation, or even thermal fatigue. Textiles facilitate moisture transfer from the skin to the environment mainly by two mechanisms: liquid transfer (by wetting and wicking) and vapor transfer (by diffusion and evaporation). The effectiveness of these processes depends on the fiber type (hydrophilic vs. hydrophobic), yarn structure, fabric construction, and surface treatment. Common blends such as cotton-polyester blended fabric, which account for over 15 % of global textile production, combine the best properties of both fibres. Cotton contributes to wearer comfort due to its hydroxyl groups, which improve hydrophilicity, wettability, and antistatic properties, while polyester offers strength and durability as well as easy care, crease resistance, dimensional stability, and quick drying. In order to improve the wearing comfort of garments, especially blends with a higher polyester content, the inherent hydrophobic properties of polyester need to be modified to improve moisture absorption and the adsorption of textile auxiliaries. Various surface modification processes are available for cotton-polyester blended fabrics, usually targeting the polyester fibers in the blend, including plasma treatment, alkaline processing, chitosan functionalization, and enzymatic pre-treatment. Given the environmental concerns associated with chemical treatments, enzymatic pre-treatments are increasingly favoured as an environmentally friendly alternative [1-7].

Enzymes from the hydrolase group are mainly used in the textile industry, e.g., α-amylases in desizing, pectinases in scouring. Various enzymes, such as lipase, esterase, and cutinase, can be used for the pretreatment of polyester materials. Both esterase and lipase perform surface hydrolysis, and the cleavage of the polymer chains leads to an increase in the number of terminal hydroxyl (-OH) and carboxyl (-COOH) groups. Lipases and some esterases are able to hydrolyse the waxes of cotton fibres as well. When used under optimal conditions, esterase and lipase can improve the hydrophilicity of polyester fibers, facilitate further textile finishing processes, and at the same time maintain good mechanical properties. Pectinases are a heterogeneous group of related enzymes that hydrolyse pectin substances of plant origin in scouring and retting processes [6-9].

To achieve a high degree of whiteness, textiles must be treated with fluorescent whitening agents (FWAs). The effect of FWAs is based on fluorescence; molecules absorb ultraviolet light (300-400 nm) and emit it as visible light, usually in the blue range of the spectrum (400-500 nm), which neutralises the yellow tint of the fabric and creates the impression of a high degree of whiteness. Due to the cotton and polyester content in the blend, different FWAs must be used depending on the chemical composition of the fabric. FWAs for cotton fabrics are mainly stilbene derivatives, mostly diaminostilbene derivatives, which differ in the substituents and the number of sulphonate groups. Distyrylbiphenyl derivatives and triazolylstilbene derivatives can also be used for cellulose, but also for blended fabrics with cellulose. In polyester fabrics, FWAs are usually benzoxazole derivatives that have no affinity to cellulose. In addition to the degree of whiteness of the fabric, FWAs also contribute to UV protection [10-13].

Since most of the studies on surface modification of cotton-polyester blended fabrics were aimed at the polyester fibers in the blend, the enzymatic pretreatment of cotton-polyester blended fabrics in this work was aimed at both cotton and polyester, so that two commercially available enzymes – pectinase for the cotton and esterase for the polyester - and their mixture were used. The influence of the enzyme treatment on the adsorption of water and fluorescent whitening agents (FWAs) was determined before and after the enzymatic pretreatment.

MATERIALS AND METHODS

A 50/50 cotton-polyester blend fabric produced by Čateks d.o.o. was used in this research. The fabric was woven in a basket weave (Panama) 2/2, having a mass per unit area of 170 g/m^2.

The enzymatic pre-treatment of cotton-polyester blended fabric was carried out with two commercially available enzymes – pectinase (Biosol PRO, CHT-Bezema) and esterase (Texazym PES, Inotex), and their mixture. The pretreatment was carried out with 2 % owf (over weight of fabric) of each enzyme (or 1% Beisol PRO + 1% Texazym PES) by the exhaustion method at 60°C for 1 h in the drum of Polycolor Turbomat P4502 (Mathis) at LR 1:10.

Since the influence of enzymatic pre-treatment of cotton-polyester blended fabric on the adsorption of fluorescent whitening agents (FWAs) was investigated, fabrics were treated with two different FWAs for cellulosic fibers and their blends by Huntsman, Uvitex® brand: Uvitex BHT (C.I. Fluorescent Brightener 113) - diamino stilbene disulphonic acid derivative, and Uvitex NFW (C.I. Fluorescent Brightener 351) - distyryl biphenyl derivative. FWAs were used in a wide concentration range: 1, 2, and 10% owf by batch-wise method having LR 1:30 at 80°C for 30 min in stainless-steel bowls (Linitest, Hanau). After treatment, fabrics were air-dried.

Labels and treatments are listed in Table 1.

Table 1. Pre-treatments and Labels

Label	**Treatment**
N	Cotton-polyester blend – start fabric
T	Fabric pre-treated with commercial lipase Texazym (2% owf)
BP	Fabric pre-treated with commercial pectinase Beisol PRO (2% owf)
BPT	Fabric pre-treated with commercial lipase and pectinase
…_BHT_...	Treatment with Uvitex BHT
…_NFW_...	Treatment with Uvitex NFW
…_conc.	Concentration of FWA - 1, 2, 10% owf

The changes in water adsorption of the fabric were determined according to AATCC TM 197-2022 *Vertical wicking of textiles*, Option B - length direction. The wicking rate was calculated for the short and long periods according to:

$$W = \frac{d}{t} \qquad (1)$$

where: W is wicking rate [mm/s], d is wicking distance [mm], and t is wicking time [s]. The short-period rate was calculated from the distance measured in 2 min, and long-period rate from the distance in 10 min.

The adsorption of fluorescent whitening agent was monitored through spectral characteristics and whiteness of the fabrics. Spectral remission (R [%]) was measured using a remission spectrophotometer Spectraflash SF 300 (Datacolor). The whiteness degree of fabrics (W_{CIE}) according to ISO 105-J02:1997 *Textiles – Tests for colour fastness – Part J02: Instrumental assessment of relative whiteness*, Tint value (TV), Tint Deviation (TD), and their coloristic meanings according to Griesser [14] were calculated automatically.

RESULTS AND DISCUSSION

The influence of the enzymatic pretreatment of cotton-polyester blended fabrics on the adsorption properties was investigated. For this purpose, the enzymatic pretreatment of cotton-polyester blended fabrics with two commercially available enzymes – pectinase for the cotton and esterase for the polyester - and their mixture was carried out. The adsorption of water and fluorescent whitening agents (FWAs) was determined before and after the enzymatic pretreatment.
The water adsorption of the cotton-polyester blend fabric was determined according to AATCC TM 197-2022. This test method evaluates the vertical wicking rate of fabrics, i.e. the ability of a fabric to transport liquid upwards along its surface due to its capillary forces [3,15]. The distance a liquid travels up a vertically oriented fabric sample over a given time was measured, and the vertical wicking rate was calculated for a short (2 min) and a long (10 min) time using equation (1). The results are summarized in Table 2.

Table 2. Vertical wicking rate of polyester/cotton blend fabric before and after enzyme pretreatment

Option B	Short period (t = 2 min)		Long period (t = 10 min)	
Sample	d [mm]	W [mm/s]	d [mm]	W [mm/s]
N	45.0	0.375	100.0	0.167
T	59.0	0.492	118.5	0.198
BP	58.5	0.488	120.0	0.200
BPT	55.0	0.458	121.0	0.202

The results of the vertical wicking rate of the cotton-polyester blended fabrics, shown in Table 2, demonstrate the changes in water absorbency after enzymatic pretreatment. It can be seen that the start cotton-polyester blend fabric reaches 45 mm in 2 minutes with a wicking rate of 0.37 mm/s, while this distance is >55 mm after the enzyme pretreatment. Cotton fibers have polar binding sites for water molecules; they can absorb large quantities of liquid and therefore have a high absorption rate. Polyester fibers, on the other hand, have a high crystallinity, so they do not adsorb water, but have better capillary transport of liquid upwards. Blended together, both fibers show their effect, while the enzyme pretreatment changes this ability. The polyester component hydrolyzed with esterase increases the wicking rate to 0.49 mm/s, and a longer distance has been achieved. This is due to the surface changes on the fibers, which also enable better absorption in the polyester component, as the water binds to the new chemical groups formed during pretreatment. The results of the FWA adsorption confirm these findings.

For the research of FWA adsorption, fabrics were treated with two different FWAs from Huntsman brand Uvitex®: Uvitex BHT, a stilbene derivative with high affinity to cotton (2 sulfonate groups), and Uvitex NFW, a distyrylbiphenyl derivative in three concentrations: 1, 2, and 10 % owf. The spectral remission of cotton-polyester blended fabrics before and after FWA treatment was measured, and the coloristic parameters were automatically calculated. The spectral remission results are shown in Figures 1 and 2, and the whiteness degree (W_{CIE}), the maximum of remission (R_{max}) at a certain wavelength (λ_{max}), Tint value (TV), Tint deviation (TD), and its coloristic meaning are listed in Tables 3-6.

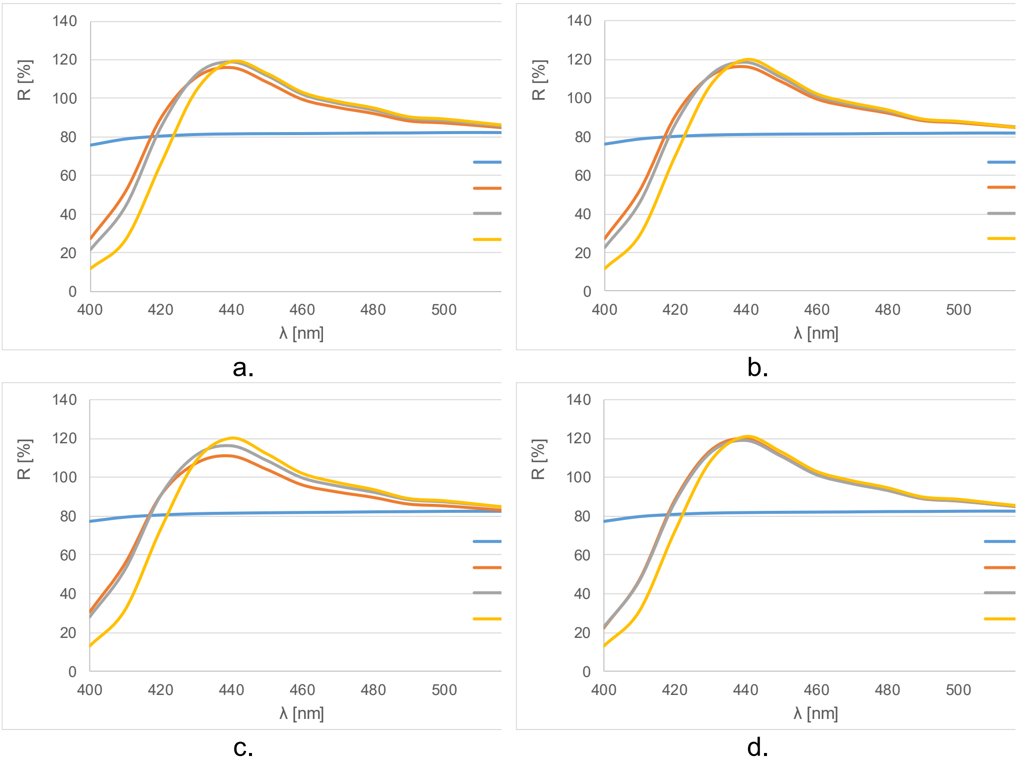

Figure 1. Spectral remission of cotton-polyester blended fabrics after enzyme pre-treatment and FWA treatment with Uvitex BHT

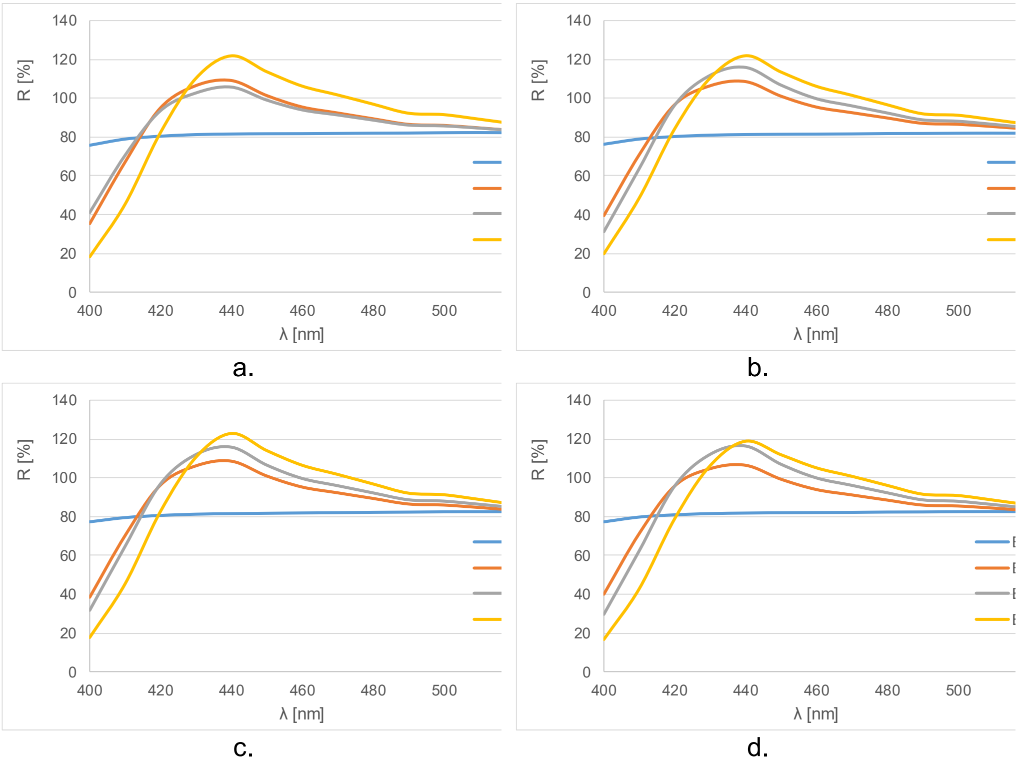

Figure 2. Spectral remission of cotton-polyester blended fabrics after enzyme pre-treatment and FWA treatment with Uvitex NFW

Table 3. Whiteness degree (W_{CIE}) of cotton-polyester blended fabrics before and after FWA treatment, maximum of remission (R_{max}) at a certain wavelength (λ_{max}), Tint value (TV, Tint deviation (TD), and its coloristic meaning

Fabric	W_{CIE}	R_{max}	λ_{max} [nm]	TV	TD	Coloristic meaning
N	78.9	84.88	700	-0,6	R1	Trace redder than the white scale
N_BHT_1	136.0	115.85	440	-1	R1	Trace redder than the white scale
N_BHT_2	140.3	118.61	440	0.1		
N_BHT_10	133.2	119.26	440	1.2	G1	Trace greener than the white scale
N_NFW_1	123.7	105.73	440	-0.8	R1	Trace redder than the white scale
N_NFW_2	128.6	108.97	440	-0.9	R1	Trace redder than the white scale
N_NFW_10	142.5	121.61	440	1.2	G1	Trace greener than the white scale

Table 4. Whiteness degree (W_{CIE}) of pretreated cotton-polyester blended fabrics with Texazym PES, and after FWA treatment, maximum of remission (R_{max}) at a certain wavelength (λ_{max}), Tint value (TV, Tint deviation (TD), and its coloristic meaning

Fabric	W_{CIE}	R_{max}	λ_{max}[nm]	TV	TD	Coloristic meaning
T	78.6	84.64	700	-0.6	R1	Trace redder than the white scale
T_BHT_1	136.8	113.92	440	-0.7	R1	Trace redder than the white scale
T_BHT_2	139.6	116.06	440	-0.4		
T_BHT_10	136.6	119.81	440	0.6	G1	Trace greener than the white scale
T_NFW_1	127.6	108.58	440	-1.1	R1	Trace redder than the white scale
T_NFW_2	138.0	115.75	440	-0.8	R1	Trace redder than the white scale
T_NFW_10	143.5	121.67	440	1	G1	Trace greener than the white scale

Table 5. Whiteness degree (W_{CIE}) of pretreated cotton-polyester blended fabrics with Beisol PRO, and after FWA treatment, maximum of remission (R_{max}) at a certain wavelength (λ_{max}), Tint value (TV, Tint deviation (TD), and its coloristic meaning

Fabric	W_{CIE}	R_{max}	λ_{max}[nm]	TV	TD	Coloristic meaning
BP	78.6	84.96	700	-0.5	R1	Trace redder than the white scale
BP_BHT_1	131.9	110.98	440	-1.1	R1	Trace redder than the white scale
BP_BHT_2	138.6	116.23	440	-0.5		
BP_BHT_10	137.8	120.08	440	0.4		
BP_NFW_1	129.0	108.61	440	-0.9	R1	Trace redder than the white scale
BP_NFW_2	138.4	115.73	440	-0.8	R1	Trace redder than the white scale
BP_NFW_10	144.7	122.84	440	1.2	G1	Trace greener than the white scale

Table 6. Whiteness degree (W_{CIE}) of pretreated cotton-polyester blended fabrics with a mixture of Texazym PES and Beisol PRO, and after FWA treatment, maximum of remission (R_{max}) at a certain wavelength (λ_{max}), Tint value (TV, Tint deviation (TD), and its coloristic meaning

Fabric	W_{CIE}	R_{max}	λ_{max}[nm]	TV	TD	Coloristic meaning
BPT	79.2	85.04	700	-0.6	R1	Trace redder than the white scale
BPT_BHT_1	142.5	119.84	440	-0.6	R1	Trace redder than the white scale
BPT_BHT_2	141.1	119.28	440	-0.5		
BPT_BHT_10	138.6	121.11	440	0.6	G1	Trace greener than the white scale
BPT_NFW_1	125.0	106.51	440	-1.3	R1	Trace redder than the white scale
BPT_NFW_2	139.4	116.28	440	-0.8	R1	Trace redder than the white scale
BPT_NFW_10	139.0	118.68	440	1.6	G2	Slightly greener than the white scale

The results shown in Table 3 indicate that the untreated cotton-polyester fabric has a remission at 700 nm and a whiteness of 78.9, and is a trace redder than the white scale. The enzyme pretreatment (Tables 4-6) does not change the whiteness. When both enzymes are applied, the whiteness is slightly higher, 79.2, but the fabric is still a trace redder than the white scale.

Regardless of the chemical composition of the FWA used and its affinity, treatment with the lowest concentration of Uvitex BHT and Uvitex NFW, 1 % owf, results in a significantly higher degree of whiteness (W_{CIE}>120) due to fluorescence emission at 440 nm.

From the spectral remission results shown in Figure 1 and Tables 3-6, it can be seen that the highest degree of whiteness and excellent brightness was achieved at a concentration of 2 % Uvitex BHT. All fabrics, regardless of the pretreatment, achieve the desired degree of whiteness with no appreciable deviation in tint from the white scale. It also shows that a concentration of 1 % is sufficient to achieve excellent whiteness, especially for the cotton-polyester fabric pretreated with both enzymes.

The spectral remission curves (Figure 1) show that the remission at λ_{max} = 440 nm for the fabrics treated with Uvitex BHT increases with the increase in the concentration. At the highest concentration of 10 % owf Uvitex BHT, the remission values are the highest ($R_{N\_BHT\_10}$ = 119.26 %, $R_{T\_BHT\_10}$ = 119.81 %, $R_{BP\_BHT\_10}$ = 120.08 %, $R_{BPT\_BHT\_10}$ = 121.11 %), but the whiteness is lower. The reason for the lower whiteness is the quenching of the fluorescence phenomenon by the FWA concentration [11]. The peak of the curve for a concentration of 10 % is slightly shifted from 440 nm, and this shift to higher wavelengths is characteristic of quenching. Layering of FWA molecules in high concentration prevents excitation of molecules in all layers, and therefore, there is no fluorescence that directly affects the reduction of whiteness. Additionally, FWA molecules at high concentrations build dimers that do not have the ability to fluoresce. This layering of FWA led to a change in tint; the tint is a trace greener than the white scale. Pretreatment with enzymes, esterase, and/or pectinase, individually or in combination, increases the whiteness of the fabric. The reason for this improved whiteness is the higher adsorption of Uvitex BHT. If both enzymes are used in the pretreatment, a higher number of active groups is available, so that a higher FWA adsorption is achieved, as it is a stilbene derivative with a high affinity to cotton cellulose.

In fabrics treated with Uvitex NFW, the spectral remissions also increase with increasing concentration (Figure 2). In contrast to Uvitex BHT, the degree of whiteness achieved with 1% Uvitex NFW is lower. The reason for this is the lower affinity to cellulose, since Uvitex NFW is a distyrylbiphenyl derivative but also has an affinity to polyester, so that with increasing concentration, the affinity is better and the adsorption is higher. Therefore, the highest remission and the highest degree of whiteness are achieved with 10 % Uvitex NFW. However, the degree of whiteness achieved with 10 % Uvitex NFW shows a green tinting.

Pretreatment with the enzymes increases the adsorption of Uvitex NFW. When the combination of enzymes, esterase and pectinase, was used in the pretreatment, quenching was observed in fabrics. Due to the highest adsorption, Uvitex NFW was layered, and the whiteness is lower, while the fabric itself has the color of FWA. The tint deviation confirms this finding, as the fabric is slightly greener than the white scale.

CONCLUSION

As the conventional alkaline pretreatment with NaOH is ecologically questionable, an environmentally friendly alternative by enzymatic pretreatment of cotton-polyester fabric was investigated. Enzymatic pretreatment with esterase and/or pectinase, individually or in combination, increases the adsorption of cotton-polyester blended fabrics. The wicking effect is faster and the fabrics achieve a higher degree of whiteness after FWA treatment. However, the adsorption of Uvitex BHT and Uvitex NFW is different due to the affinity to cotton. The adsorption of Uvitex BHT is higher, resulting in a higher degree of whiteness of the fabric, especially if it has been pretreated with esterase and its mixture with pectinase. 2% Uvitex BHT is sufficient for the highest degree of whiteness, while a higher concentration is required for Uvitex NFW. The study shows that enzymatic pretreatment is a sustainable method to improve both sorption and optical properties of cotton-polyester fabrics.

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Izvod

UTICAJ ENZIMSKE PREDOBRADE NA ADSORPCIJU TKANINE OD MEŠAVINE PAMUKA I POLIESTRA

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U ovom radu je ispitan uticaj enzimske predobrade obrade tkanine od mešavine pamuka i poliestra na adsorpciju fluorescentnih sredstava za izbeljivanje (FWA). U tu svrhu, izvedena je enzimska predobrada tkanine od mešavine pamuka i poliestra (50%/50%) sa dva komercijalno dostupna enzima – pektinazom za pamučnu komponentu i esterazom za poliestarsku komponentu, i njenom smešom. Promene u adsorpciji vode tkanine određene su vertikalnim upijanjem (AATCC TM 197-2022). Za adsorpciju FWA, u zavisnosti od hemijskog sastava tkanine, korišćena su dva različita FWA od Huntsman-a, marke Uvitex®: Uvitex BHT, derivat stilbena sa visokim afinitetom prema pamuku (2 sulfonatne grupe) i Uvitex NFW, derivat distirilbifenila. FWA su primenjene u tri koncentracije: 1, 2 i 10%, u odnosu na masu tkanine. Spektralna remisija pre i posle obrade sa FWA merena je pomoću remisionog spektrofotometra Spectraflash SF 300, Datacolor. Stepen beline je izračunat prema ISO 105-J02:1997, a odstupanja nijanse i njihovih kolorističkih parametara određena su prema Griseru. Iako esteraza i pektinaza deluju na različite komponente tkanine, obe doprinose povećanoj adsorpciji mešavine pamuka i poliestra. Što se tiče adsorpcije FWA, postoji razlika između adsorpcije Uvitex BHT i Uvitex NFW. Adsorpcija Uvitex BHT je veća, što rezultira većom belinom tkanine, posebno ako je prethodno obrađena esterazom i njenom mešavinom sa pektinazom. 2% owf Uvitex BHT je dovoljno za najveću belinu, dok je za Uvitex NFW potrebna veća koncentracija.

Ključne reči: mešavina pamuka i poliestra, pektinaza, esteraza, FWA, stepen beline.