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SCIENTIFIC ARTICLES/ *Znanstveni članki*

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Introducing the Methodology of 'Critical Fashion Practice' into Fashion Design Studies in Croatia
Uvajanje metodologije Kritične modne prakse v študij modnega oblikovanja na Hrvaškem

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Abstract
Since the advent of mass production, where the quantity of clothing reflects the consumption habits of society, fashion has become a reflection of the capitalist atmosphere. The reciprocity of society and fashion begin to occupy and initiate all the intense theoretical discussions that lead to the emergence of new branches of scientific research in the social-humanist field. The two most important scientific field are the ***history of fashion*** and ***fashion theory***, whose analyses focus on the role of clothing as part of material culture conditioned by the political, social, economic and religious context. These two branches of science are increasingly becoming the focus of fashion design students in the education system. As a result, the above disciplines are included as separate compulsory subjects in the fashion design programme, developing strong theoretical skills at the expense of practical production and collection making. This approach represents a significant departure from the curricula of previous fashion design programmes, where the conditioning of the profession by political, economic, technological and social impulses was evident. In 2014, the former Centre for Fashion Studies at the Stockholm College highlighted the problem of a strong dichotomy between theoretical and fashion design courses in fashion design programmes and organised a symposium entitled 'Fashion Issues: Critical Fashion Studies'. Based on his guidelines, the project 'Critical Fashion: Reflections in Theory and Practice' was developed as part of the degree programme at Beckmans College of Design in Stockholm, resulting in a highly discursive internet platform with the symbolic name 'Critical fashion practice'. The aim of the new approaches was to rethink the importance of theoretical approaches in observing fashion production based on reflection of social relations, media images and personal experiences. This paper analyses the contribution of the platform 'Critical fashion practice' in the context of theoretical-practical teaching for fashion design students at the Faculty of Textile Technology, University of Zagreb.
Keywords: fashion design, education, critical fashion practice, concept, fashion theory, fashion practice

Izvleček
Z začetkom serijske proizvodnje, pri kateri količina oblačil odraža potrošniške navade družbe, je moda postala odraz kapitalističnega vzdušja. Kot takšna je vplivala na čedalje intenzivnejše teoretične razprave, ki so pripeljale do novih znanstvenih vej na področju teorije in zgodovine mode. Pri njih so analize, osredinjene na vlogo oblačenja kot dela materialne kulture, pogojene s političnim, družbenim, ekonomskim in verskim kontekstom. Navedeni znanstveni

veji sta tudi v središču pozornosti študentov modnega oblikovanja. Posledično sta disciplini vključeni kot ločena obvezna predmeta v študijski program modnega oblikovanja na Hrvaškem, kjer dajeta izrazito teoretične podlage za praktično proizvodnjo in izdelavo kolekcij. Ta pristop je pomemben odmik od učnih načrtov dosedanjih programov modnega oblikovanja. Leta 2014 je Center za modne študije Univerze v Stockholmu opozoril na močno dihotomijo med teoretičnimi in praktičnimi predmeti modnega oblikovanja ter v okviru študijskega programa predstavil projekt za vzpostavitev diskurzivne spletne platforme Kritične modne prakse. Cilj novega pristopa je bil sprožiti razmislek o pomenu teoretičnega pristopa za izvedbo in interpretacijo modne produkcije, ki pa je temeljila na refleksiji družbenih odnosov, medijskih podobah in osebnih izkušnjah. Prispevek predstavlja metode pri uvajanju Kritične modne prakse v poučevanje študentov modnega oblikovanja na Tekstilno-tehnološki fakulteti Univerze v Zagrebu.
Ključne besede: modno oblikovanje, izobraževanje, kritična modna praksa, koncept, modna teorija, modno usposabljanje

1 Introduction

The first school for fashion design was the Parisian private school *École supérieure des arts et techniques de la mode* (ESMOD), founded by Alexis Lavigne in 1841 [1]. The educational programme focused on the acquisition of knowledge in manufacturing techniques. After the Second World War, the *School of Fashion* was founded in 1948 at the Royal College of Art in London to train students with new skills dictated by the increased demands of the industry. At the aforementioned educational institution, graphic and industrial design were introduced at the same time as the fashion programme. The training includes not only all phases of garment production, but also courses in art history and literature to improve the future fashion designer's communication and presentation skills needed to deal with a prestigious clientele [2].

Over the past decade, major fashion design educational institutions have recognised the need to revise fashion design degree programmes [3]. They have thus organised a series of public forums and discussion groups to address the problems and find new solutions, training methods and pedagogical approaches. Business changes on the fashion market and increasingly strong synergies between design and society, design and politics, and design and culture require academic institutions to rethink their curricula to adapt them to the demands of the market and society. Comparing the American and European fashion design education systems, the American system ('Parsons The New School of Design' and 'Fashion Institute of Technology' in New York) focuses on 'design thinking and process' in its programmes. Their aim is to train a fashion designer who understands the broader social and market context and is able to design innovative products that are subordinate to the dictates of the market. The English model of education ('Central Saint Martin's' and 'The London College of Fashion') bases its educational tradition on the social and historical study of fashion as a cultural phenomenon and a key to creative inspiration. The other model is found in European study programmes. Analytical research approaches are developed mainly during doctoral studies. In Denmark, for example, the programme of the state Kolding Design School is funded by the Ministry of Culture, with the requirement that one third of teaching is focused on market research, with the aim of finding new solutions subordinate to the progress and development of the Danish fashion industry. The director of this school explains that the system trains fashion designers who are sensitive to social issues, so-called 'social fashion entrepreneurs', and not just the suppliers of fashion collections subordinated to a commercial purpose [4].

The education system at the world's leading academic institutions for fashion design is undergoing a paradigm shift in which preference is being given to a curriculum that focuses on 'analytical thinking' rather than a programme that is subordinate to the 'act of shaping and sewing'. In order to achieve a new orientation, the programme is conducted in the spirit of interdisciplinarity, but in such a way that the theoretical and practical courses, which were previously separate, are linked. The curriculum of the course will set a theme each year, while at the same time teachers from contrasting fields (scientific and artistic) will jointly advise and stimulate individual students to rethink and deepen the concept. The courses aim to develop the skills of collaboration, communication, empathy, the articulation of ideas and strategic planning. To foster such a creative atmosphere, educational institutions and their programmes train fashion designers who are prepared to operate in the global marketplace, where different business rules apply depending on the country of origin. After their education, future fashion designers are able to design an innovative product, a product of conceptual and critical thinking, subordinated to economic and increasingly significant environmental influences.

Also in Croatia, at the Faculty of Textile Technology, there is a growing need to reflect on the changes and challenges in the education of future fashion designers. Study programmes are determined by the uncertain future of the fashion industry and the new demands of the global market. Interdisciplinary experiences with scientific and artistic practice, and the comparison of fashion design education with education in other design fields (industrial design, product design, visual design communication and interactive design) are of great importance for the formulation of methodological positions and possible orientations in the search for new solutions. At the Faculty of Textile Technology in Zagreb, the five-semester 'Textile and Clothing Design' course was introduced in 1983, while the four-year 'Design and Projecting of Textiles and Clothing' university course was introduced during the 1993-1994 academic year [5]. In the two-and-a-half-year 'Textile and Clothing Design' course, most of the teachers were painters who were trained at the Academy of Fine Arts. They therefore developed their fashion design courses based on their artistic background and skills. A smaller number of teachers came from the social sciences and humanities. In contrast, the four-year 'Design and Projecting of Textiles and Clothing' course was more focused on synergetic knowledge from technical and natural science subjects, and had a small proportion of courses from the artistic field and the social sciences and humanities. In accordance with the principles of the Bologna Declaration and study reform at European universities, the Faculty of Textile Technology introduced a new study procedure from the 2005/2006 academic year on, according to which the study of fashion design includes an undergraduate study programme (duration of three years) and a graduate study programme (duration of two years) under the uniform name 'Textile and Fashion Design' [6, 7]. In the above-mentioned study programmes, especially in the undergraduate study programme, the art courses and the study of drawing and painting techniques still dominate, while fashion production is neglected due to the potential of small realised collections. The production of costumes and small fashion collections is the focus of the graduate study programme, especially in the 'Fashion Design' and 'Costume Design' courses. Starting from the first undergraduate course entitled 'Textile and Fashion Design', which is characterized by a strong separation of artistic and technical subjects, fashion theory and fashion history have also been developed more intensively since the Bologna reform. While the synergy of the theoretical and practical merging of the courses has been well under way for the last five years at the Faculty of Textile Technology in Zagreb (additional attention will be given to that merging in the next section), it is also necessary to highlight the increasingly intensive efforts of the teaching staff towards a personalized approach. Taking into account the cognitive characteristics of the student, especially prior knowledge, as well as other characteristics of learning and the student's personality, the teaching staff relies on the theory of experiential learning (the so-called Kolb model) to achieve the more frequent synergy of theoretical approaches and production processes. Contemporary media culture, which prescribes physical beauty as a social imperative, has a powerful influence on students' creative perceptions. To their detriment, the power of analytical thinking, observation and reasoning is neglected and not encouraged. In today's modern culture, nothing is controversial or unusual; everything is accepted under the pretext of political correctness. The 2007 historical analysis of the concept of ugliness by the Italian philosopher and medievalist Umberto Ecco [8] is no longer at the centre of contemporary aesthetic-philosophical debates. Media culture also accepts everything and feeds on accelerated visual impressions, to the detriment of promoting critical discussions among the younger population. The theme of 'ugly' was therefore the impetus for the student work of the undergraduate programme at the Faculty of Textile Engineering in Zagreb in 2019.

2 Materials and methods

2.1 Methodology of the synergy of theory and practice in fashion design

As fashion projects become more conceptual, the history and theory of fashion provide a quality paradigm for discussion and analytical reflection, opening up new fields for students' creative productions. There is thus a need for joint courses or projects in which professors from theoretical and practical work closely together to impart knowledge and translate it into project assignments.

The concept of fashion critical practice helps them in this regard. But what is critical thinking? In the book 'Critical Design in Context: History, Theory, and Practice', which deals primarily with industrial design, Matt Malpass describes how critical design preserves the intellectual and creative power of the product, as opposed to the usual purpose-driven product design [9]. It stimulates thought and influences new discourses and perspectives on social reality. Today it is the focus of discussions and the starting point for fashion, but also for environmental and social criticism. It stimulates thought and influences new discourses and perspectives on social reality, and is the centre of discussions and the starting point for fashion, but also for environmental and social criticism. Beckmans College of Design (Stockholm, Sweden) has excelled in this direction of implementing theoretical knowledge, i.e. critical reflection in fashion practice. In their case, the current fashion design course is structured through projects that contrast essays with personal critical assessments of fashion, supported by visual images and commentary on the problems the student faces. In addition, a significant number of former students and foreign guest lecturers are involved in the delivery of the study programme to stimulate discussion on current and private issues, but in an international context. The new methodological content for the duration of the project of the synergy of theory and practice through critical reflection has been publicly available on the 'Critical Fashion Practice' platform since 2020 [10]. To date, Adam Geczy and Vicki Karaminas, Peter Jakobsson, Andreas Nobel, Marco Pecorari and Mathilda Tham have presented their reflections on critical fashion practice in the form of essays, while Ann-Sofie Back and Göran Sundberg, Caroline Evans and Susanna Stroemquist have presented themselves in the form of a conversation between a fashion designer and a theorist.

Emil Balesic, Josef Forselius, Matilda Ivarsson/ Jeremiah Whitmore, Alexander Krantz, Alecsander Rothschild, Ada Swärd exhibited their creative reflections through photography. The most important factors for a critical fashion practice were presented by lecturer and curator Maria Ben Saad, who stated that "without the connection between theory and practice, it will be difficult to connect design practice with critical thinking" [11]. The first synergy projects from 2014 focused on the current issue of *gender identity*. Over the years, critical engagement with social issues began to include a more intimate perspective of the author. For example, the project 'Freedom; Isolated' (2017) by Emil Balesic, a visual communications student at Beckmans, explored gender expression through moving portraits of people behaving independently of norms regarding masculinity and femininity. In this project, he decided to explore queer masculinity from his own perspective, focusing on the bulge, a well-known symbol in this context. For him it represents an all-encompassing masculinity and he was looking for a way to invite the viewer to see what he sees [12]. Fashion designer Ann-Sofia Back's next project, for example, explores the concept of ugliness and is presented in conversation with Göran Sundberg, a theorist, journalist and designer [13]. Ann-Sofie Back explored issues of failure in practice, then cracks and misunderstandings in the construction of women's identity. She gave new value to certain garments that she considered ugly or too ordinary, transforming them into a fashion commentary on societal expectations of women and the dictates of perfection that suppress the possibility of weakness. In her reflections, Sundberg applies French sociologist Pierre Bourdieu's theory of the intertwined cultural spheres (politics, economics, religion, sport, art, etc.) that make up society to her collections, combining elements of street fashion with reflections on social issues, such as the consequences of climate change, questions of identity and consumerism.

However, the issue of 'ugliness' in contemporary culture, which is dominated by the dictates of beauty and perfection, is a very challenging topic. This was also evident in the assignments given to students of the undergraduate programme in Textile and Fashion Design at the Faculty of Textile Technology in Zagreb (2019–2020 academic year, winter semester). The students were asked to choose three 'beautiful' fashion items (clothes, textiles, fashion accessories, etc.) from the everyday life surrounding them according to personal criteria. They were then asked to select three 'ugly' items. They found it very easy to name 'beautiful' items, while it was difficult for them to identify 'ugly' ones. They tended to say that "nothing is ugly to them, that everything is acceptable to them" instead of identifying certain fashion

adjectives as ugly. It is as if the term is already ugly and inappropriate, and they only apply it with difficulty and a little embarrassment to the object they have designated by their choice.
This raises the question of the source of influence and impetus on perceptions and attitudes towards the concept of ugliness. Is it due to familial, socio-cultural, ideological, media or educational influences? Ugly is a term that has not been accepted as a paradigm for research concepts, nor is it a common starting idea for creative projects. It is a term that is avoided because it evokes negative feelings, such as squeamishness, and it arouses in us the need to criticise it and distance ourselves from its use. However, the task was designed to make students think about the feelings of disgust and the aesthetics of ugliness that garments, fashion accessories or decorations evoke in them. After choosing an 'ugly' object, they tried to become aware of the influences and sources of their own aesthetic canon. The next step was to give the object a new discourse and presentation value in a practical-creative approach with the help of the medium of photography, transferring the object from the category of the ugly to the category of the 'acceptable' for the author. At the same time, the object was not allowed to be cut or painted. By playing with styling and photography, changing the purpose or juxtaposing it with other trends, accessories, textiles or garments, a 'new image' of tolerable aesthetics emerges for the author (Figures 1 to 6).

3 Results and discussion

3.1 The results of the assignments from 'ugly' to 'acceptable':

First example: starting point Capri trousers in fluorescent yellow-green colour, a trend from the 1980s. 90% polyamide, 10% elastane, 60 dtex.
Second example: brown socks, a common assortment for older women. 100% polyamide, 40 dtex.

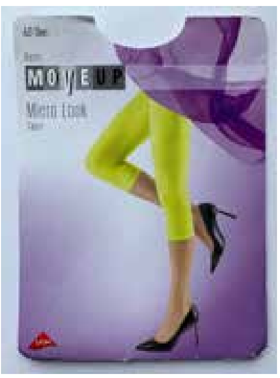

Figure 1: The original state of the object – repulsive to the author

Figure 2: A new value proposition: fashionable, highly visible and reflective accessory for crossing a tunnel, walking in the dark or protesting (inspired by the "Yellow Vests" revolution in France 2018)

Figure 3: The original state of the object – repulsive to the author

Figure 4: A new value proposition: play with shapes in a sock. The result is a piece of jewellery.

Figure 5: The original state of the object – repulsive to the author

Figure 6: A new value proposition: in the context of the prevailing issue of gender identity in fashion, the author proposes a female beard as a fashion accessory

Third example: knitted potholders by grandmother from the 1970s, cotton and wool thread.

The exercise presented here is part of a series in the theoretical course of the undergraduate programme 'Textile and Fashion Design' at the Faculty of Textile Technology in Zagreb, with the aim of confronting and solving repulsive tasks and breaking the aesthetic canon imposed by contemporary media culture. The exercises develop the senses necessary for critical observation and the identification of current social issues, conflicts, tensions and doubts, which are the starting points for conceptual approaches to fashion projects at the graduate level of fashion design studies at the Faculty of Textile Technology in Zagreb. In the graduate course 'Theory and Culture of Fashion', methodological approaches to the study of contemporary fashion phenomena are deepened, while in the course 'Fashion Design', creative production is imbued with theoretical background.

3.2 Results with discussion: 'critical fashion practice' of the graduates of the Faculty of Textile Technology in Zagreb

Just as 'fashion critical practice', which analyses historical turns and contemporary productions, draws attention to discourses on fashion, sexuality and identity, so too has the 'Polari' collection by Dominik Brandibur, who graduated from the Faculty of Textile Technology in 2020. Brandibur critically examined clothing as a medium of non-verbal language, focusing on the symbolism and dress dialect of the LGBT community throughout history. He captures the fragmentary echoes of this identity and translates them into his collection. In doing so, he explores the subversive charge of the language of dress and the act of dressing as an act of costuming that transforms the body into a performative medium. To stimulate a discursive dialogue with the viewer, he builds the collection from striking fetish elements, combining contrasting materials (gentle cotton, camouflage military fabrics, etc.) and patterns (classic lines, pop art motifs, etc.), but also deconstructing classic dress forms. He plays with gender identity (body and clothes) in a fascinating way, but also with the ideal body canon imposed by the media, using models whose appearance does not correspond to the standard look of mannequins. In addition to manipulating classic dress forms, Brandibur does not omit textile patterns. He uses the historical reference of the paisley motif and transforms it into an eggplant motif, a symbol (emoticon) of fertility and male sexuality in the virtual world of social applications. These woven diminutive codes, which include peach and drop symbols, become a new fashion language called 'Polari' (Figure 7) [14].

In contrast to Brandibur, Josipa Fostač's collection, also a final project at the Faculty of Textile Technology in 2021, critically examines the contemporary potential of a fashion item that has an element of national identity woven into it. Can the fashion signature of autochthonous expression still be maintained in the broad spectrum of contemporary trends? On this path of critical reflection, Fostač draws inspiration from the Zagreb football fan group 'Bad Blue Boys' of the Dinamo club and specifies the name of the men's collection with the diminutive 'Blubači' (Figure 8). It retains the symbolic blue colour of the group's identity, and plays with other signs and the graphic style of the fan signs. The group, very warlike and territorial, but at the same time modern in their humanity (during the earthquake in Zagreb on 22 March 2020, they were the first to appear in front of the KBC Zagreb hospital to help pregnant women and newborns during the evacuation), expresses their belonging with a visual identity. In the spirit of globalisation and accelerated changes in fashion trends, the wearer's spatial affiliation or signature woven into the hem of clothing no longer has national characteristics. However, smaller groups with common goals and values cultivate analogous clothing expressions, in which the already forgotten historical role of clothing can be found, which was not only a status symbol, but also reflected national identity, especially in the period from the 16th century to the Industrial Revolution, i.e. mass production in the 19th century. In the sea of Croatian street trends adapting to Western dictates, the 'Blubači' men's collection explores the role of clothing as a distinctive sign of spatial belonging and thus as an autochthonous fashion expression. While the role of the bearer of autochthonous expression fell to the man as a modern warrior, the female body apostrophises its fragility with the 'Become Human' collection and critically engages with the limits of technology's influence on human existence and production as a medium of historically conditioned roles [15]. Clothing as a second skin, or more precisely as a litmus paper of social reality and change, with the surface inscription of a topological network of cuts of organic forms as a motif and in a range from soft tonalities to intense colours, updates the question of humanity in the age of digital technology and virtual reality (Figure 9).

4 Conclusion

With this paper, we have tried to show current approaches in the education of fashion designers, motivated by fashion critical practices, and informed by theoretical and creative considerations. In contrast to the early 20th century, which was based

Figure 7: Dominik Brandibur, models from the Polari collection, 2020. Mentor: Jasminka Končić and Duje Kodžoman. Photo Donovan Pavleković

Figure 8: Josipa Fostač, models from the 'Blubači' collection, 2021. Mentor: Jasminka Končić and Duje Kodžoman. Photo: Zvonimir Ferina

Figure 9: Josipa Fostač, model from the 'Become Human' collection, 2021. Mentor: Jasminka Končić and Duje Kodžoman. Photo: Mina Pavlović/Fotosofia 16

on collaboration between artists and craftsmen (Wiener Werkstatte), today's aspects of education focus on collaboration between fashion theorists and fashion designers. At the same time, the process of insight into the sources of inspiration and creative stimulation begins with a concept that focuses on delicate and problematic social phenomena that indirectly affect the individual. In today's society, the space for free, unconditional and critically grounded action is lacking in the prevailing media culture, which is confronted with strong visual, ideological, economic and technological stimuli that are woven into the human mind at an unconscious level. Through the process of deeper questioning (of social fractures, i.e. current issues) via the critical practice of fashion woven into the educational process, we sensitise future fashion designers to an activist, creative response that brings progress in a personal, social and market context.

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The Stability of the Chitosan Coating on Polyester Fabric in the Washing Process
Stabilnost hitozanskega nanosa na poliestrski tkanini pri pranju

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Abstract
The sensitivity of chitosan to environmental conditions and processing conditions can stress its structure and cause degradation of this polymer on various application carriers. The stability of chitosan in a designed textile structure of standard polyester fabric with chitosan was analysed in a multiple washing process with a standard detergent by studying the properties before and after 10 washing cycles. The chitosan was coated on standard and alkali treated polyester fabrics. Washing was performed with an ECE A reference detergent at 60 °C according to the Standard protocol HRN EN ISO 6330 in 10 cycles. The washing stability of chitosan onto polyester fabrics was monitored by a staining test, zeta potential, breaking force, breaking elongation, pilling propensity, touch, whiteness, moisture transport, antimicrobial activity and morphological features. The staining test confirmed the wash stability of chitosan coated on alkali hydrolised polyester fabrics, while the chitosan coated on standard polyester fabric disappeared. Zeta potential proved to be the significant parameter for determining chitosan` stability. The tensile properties of fabric samples were harmonised with other characterisation parameters. Coating of polyester fabric with chitosan increased the elasticity of all samples. The antimicrobial activity of polyester fabrics coated with chitosan against Staphylococcus aureus was reduced by 20% after 10 washing cycles. All the characterisation parameters proved that polyester fabric as a chitosan carrier should be surface modified for designing a stable bioactive textile structure of chitosan and polyester.
Keywords: polyester fabric, chitosan, washing, stability

Izvleček
Hitozanski nanosi na različnih nosilcih so izpostavljeni tako okoljskim kot tudi procesnim pogojem. Le-ti vplivajo na strukturo hitozana in lahko povzročijo njegovo degradacijo. Proučevali smo stabilnost hitozanskega nanonsa na poliestrski tkanini pri večkratnem pranju s standardnim detergentom, pri čemer smo analizirali lastnosti obdelane

tkanine pred pranjem in po desetih ciklih. Hitozan smo nanesli na standardne poliestrske tkanine in poliestrske tkanine po alkalni obdelavi. Prali smo z referenčnim detergentom ECE A pri 60 °C po standardnem protokolu HRN EN ISO 6330 v desetih ciklih. Stabilnost hitozanskega nanosa na poliestrskih tkaninah smo spremljali s testom obarvanja, zeta potencialom, določitvijo pretržne sile in pretržnega raztezka, nagnjenostjo k luščenju, dotikom, belino, transportom vlage, protimikrobno aktivnostjo in morfološkimi značilnostmi. Preskus obarvanja je potrdil stabilnost hitozankega nanosa na poliestrski tkanini, predhodno obdelani z alkalno hidrolizo po pranju, medtem ko hitozanskega nanosa na standardni poliestrski tkanini po pranju nismo zaznali. Zeta potencial se je izkazal kot pomemben parameter za določanje stabilnosti hitozanskega nanosa. Natezne lastnosti vzorcev tkanine so bile usklajene z drugimi karakterizacijskimi parametri. Vsem poliestrskim tkaninam s hitozanskim nanosom se je povečala elastičnost. Antimikrobna aktivnost poliestrskih tkanin s hitozanskim nanosom proti Staphylococcus aureus se je po desetih ciklih pranja zmanjšala za 20 %. Vsi karakterizacijski parametri so pokazali, da je treba poliestrski nosilec predhodno površinsko modificirati, da je dosežena stabilna bioaktivna tekstilna struktura hitozana in poliestra.
Ključne besede: poliestrska tkanina, hitozan, pranje, stabilnost

1 Introduction

Chitosan is a natural, multifunctional polysaccharide, which, due to its exceptional biological and physicochemical properties, is used in various fields of application, such as the medicine, biomedicine, pharmacy, cosmetics, textile, chemical and paper industries, as well as in agriculture [1–3].
Chitosan, along with some other polymers, has been shown to be a useful dye transfer inhibitor in the wash bath. Its hydrogelling property provides a suitable physical form for the adsorption of dyes, which makes it a suitable material for the treatment of wastewater contaminated with dyes [4,5]. Such a wide range of applications demands the development of effective bioactive chitosan products. Numerous studies and results show the activity and added value of using chitosan in textiles, where it is used for its non-toxicity, biocompatibility, biodegradability, microbicidal activity, antistatic activity, complexing (chelating) properties, deodorising properties, film-forming ability, chemical reactivity, ability to improve the dyeing process, thickening properties, accelerated wound healing, etc. [6].
This cationic polymer consists of (1-4)-2-amino-2-deoxy-β-D-glucan, which is, as a derivative, more important than the chitin, the main component of the cell wall of fungi, skeletal shells of crustaceans and insects and fish scales [7].
The chitin source, as well as preparation methods, make chitosan available in a range of deacetylation grades and molecular weights, which are important factors in the type and quality of the polymer. One of the main disadvantages of chitosan is its low solubility in water [8]. It is soluble in dilute inorganic and organic acids with a lower pH than chitosan (pKa ≈ 6.3), and forms a non-Newtonian liquid [9]. Free amino groups are protonated at low pH, which leads to electrostatic repulsion between the polymer chains, and, consequently, to dissolution.
The sensitivity of chitosan to environmental conditions and processing conditions (e.g., heating or freezing) can stress its structure and cause degradation of this polymer. Factors affecting the stability of chitosan can be internal (purity, molecular weight, polydispersity index, degree and method of deacetylation, moisture content) and external (environment – temperature and humidity and process – dissolution in acid, sterilisation, thermal treatments, physical methods) [10].
Its stability in formulations can be achieved by controlling environmental factors and process conditions (e.g., temperature), introducing stabilising compounds, combining with other polymers, and modifying chitosan with chemical or ionic compounds. Molecular weight, polydispersity, degree of deacetylation, purity and moisture content play an important role in determining the mechanism and rate of polymer degradation [10]. A decrease in average molecular weight and an increase in the degree of deacetylation were observed as a result. Simultaneously with the breaking of the chitosan chain, there is a degradation and/or destruction of the functional groups (amino, carbonyl, amido and hydroxyl groups), and, in addition, the depolymerisation of chitosan can lead to the formation of free radicals. Strong intermolecular interactions between the formed chitosan fragments (interchain cross-linking) change the structure of the polymer, leading to irreversible loss of its physicochemical properties. Therefore, the problem of low stability of

systems developed with chitosan can be a limiting factor for their application.

In this research, the stability of chitosan in a differently designed textile structure with chitosan in a multiple washing process with a standard detergent was analysed by studying the properties before and after 10 washing cycles.

Considering the partial compatibility of the biopolymer chitosan with the synthetic polymer polyester, the modification of the polyester fabric by alkaline hydrolysis, which can be considered as a preparatory phase for the adhesion of various substances, was also included in the research [11–14].

2 Materials and methods

2.1 Materials

A standard white polyester fabric (PN-01) from the supplier Centre for Testmaterials (CFT) B.V., The Netherlands, and Chitosane (low molecular weight-LMW with an 85% degree of deacetylation), from Aldrich® was used for the design of the polyester and chitosan biopolymer textile structure. Chitosan of LMW was selected as suitable for textiles, food, photography, medical and environmental applications [15].

The polyester fabric (PES) used, with a unit per surface area of 156 g/m^2, was woven in plain weave with a density of 27.7 threads/cm in the warp direction and 20 threads in the weft direction, using a warp yarn fineness of 30.4 tex and a weft yarn fineness of 31.9 tex.

Design of chitosan-PES textile structure

Prior to coating with chitosan, the standard polyester fabric was modified by alkaline hydrolysis with a sodium hydroxide solution, 2% NaOH (aq.), purchased from Ivero d.o.o., Croatia, and by alkaline hydrolysis with the addition of a cationic promoter, benzalkonium chloride, contained in the product BarquatTM50 from the supplier QuatChem, England, at a concentration of 3 g/L. Both modifications were carried out under the same process conditions, bath ratio (BR) 1:5, 98 °C for 30 min in a W. Mathis apparatus. After alkaline hydrolysis, the fabrics were washed twice with hot water at 98 °C, and rinsed twice with cold water at 20 °C and air dried.

Untreated and alkaline hydrolysed polyester fabrics and chitosan at a concentration of 0.5%, prepared with 0.1 mol/L hydrochloric acid (HCl), whose pH was adjusted to 3.6, were used for the design of the chitosan-PES textile structure. These fabrics were impregnated with a chitosan solution in a Benz stenter with a pressure of 12.5 kg/cm, and then dried at 90 °C for 40 s and cured at 130 °C for 20 s in the same apparatus to achieve a better fixation of the chitosan on the textile material in the impregnation process

Washing process

The washing process was performed using a standard ECE A detergent with a concentration of 1.25 g/L in a Rotawash laboratory washing machine, SDL Atlas at 60 °C with BR 1:8 according to the Standard protocol HRN EN ISO 6330 in 10 cycles, except for the samples after 5 cycles to monitor the degree of changes and the stability of chitosan on the designed chitosan - PES structures. The identifications of all the analysed samples are described in Table 1.

Table 1: Description of polyester fabrics and chitosan-PES fabrics

Description	PES fabric	Chitosan-PES fabric
Untreated	U	Ch-U
Untreated washed 5 times	U-5	Ch-U-5
Untreated washed 10 times	U-10	Ch-U-10
Alkali hydrolysed	AH	Ch-AH
Alkali hydrolysed washed 5 times	AH-5	Ch-AH-5
Alkali hydrolysed washed 10 times	AH-10	Ch-AH-10
Alkali hydrolysed with promoter	AH_C	Ch-AH_C
Alkali hydrolysed with promoter washed 5 times	AH_C-5	Ch-AH_C-5
Alkali hydrolysed with promoter washed 10 times	AH_C-10	Ch-AH_C-10

2.2 Methods

Staining test

Identification of chitosan in the designed chitosan-polyester textile structure before, after 5 and 10 washing cycles was performed qualitatively and quantitatively. The samples were subjected to the dyeing process with the reactive dye Remazol Red RB (C.I. Reactive Red 198) at the concentration 1% (o.w.f.) from the manufacturer DyStar in a W. Mathis laboratory apparatus with BR 1:50 at 60 °C for 30 min. After dyeing, the fabrics were washed with cold water, followed by post-treatment with Kemopon 50 supplied by Kemo, Croatia, in the same apparatus, at a concentration of 2 g/L at 90 °C for 10 min. The composition of this washing agent is a mixture of anionic and nonionic surfactants suitable for removing of dye non-fixed to the fabric.

After washing the samples were air dried, and then analysed microscopically and spectrophotometrically.

Microscopic examination

A DinoLite digital microscope, Premier IDCP B.V., Almere, The Netherlands, was used to analyse the surface of the dyed samples at 50× and 230× magnification.

The fabric surface before and after the design of the chitosan-polyester structure and 10 washing cycles was observed with a Scanning Electron Microscope, Tescan, MIRA /LMU, Czech Republic, under a magnification of 1,500x. Prior to observation, the samples were sputtered with gold and palladium for 90 s (Quorum Technologies, Q150T ES Plus, UK).

Spectrophotometric measurements

Quantitative evaluation of the hue of the chitosan-polyester textile structure before, after 5 and after 10 washing cycles was performed spectrophotometrically by determining the colour strength (K/S value) measured according to the Kubelka–Munk equation using the DataColor 850, a Swiss instrument with a constant instrument aperture, standard illumination D65 and d/8° geometry.

The whiteness degree according to Ganz Griesser (W_{GG}), tint deviation (TD) and tint value (TV) of all the fabrics were determined using the DataColor 850, with the aperture size of 20 mm, under the standard illumination D65. The whiteness degree (W) was calculated automatically according to ISO 105-J02:1997 Textiles—Tests for colour fastness—Part J02: Instrumental assessment of relative whiteness and expressed as medium values of four individual measurements [16].

Streaming potential method

The zeta potential, determined by the streaming potential method, was chosen as a parameter to characterise the fabric before, after 5, and after 10 washing cycles, to monitor the stability of chitosan during cyclic washing. The analysed samples placed in the Adjustable Gap Cell were subjected to the measurement of the streaming potential in 1 mmol/L KCl by a titration procedure, starting from alkaline (adjusted with 1 mol/L NaOH) to acidic (adjusted with 1 mol/L HCl) in the SurPASS electrokinetic analyzer, A. Paar GmbH, Austria. During the measurement, in addition to the streaming potential in mV, the parameters are also recorded from which the zeta potential was calculated as a function of pH according to the Helmholtz-Smoluchovsky equation [17, 18].

In addition, the control samples and the samples washed 10 cycles were analysed by other applied methods.

Breaking force and breaking elongation

The breaking force and breaking elongation of the unwashed and 10-cycle washed samples were selected, to evaluate the tensile properties and elasticity, considering that the properties change with the modification of polyester fabric by alkaline hydrolysis, the treatment with chitosan and the washing process. The tensile properties were determined in accordance with the Standard HRN EN ISO 13934-1:2013: Textiles -- Tensile properties of fabrics -- Part 1: Determination of maximum force and elongation at maximum force by the strip method using a Tensolab 3000 dynamometer, Mesdan s.p.A., Italy.

Tendency to pilling generation

The surface propensity of the samples before and after 10 washing cycles to produce pilling was analysed after 125, 500, 1000, 2000, 5000 and 7000 cycles according to HRN EN ISO 12945-2:2003: Textiles – Determination of the tendency of textiles to surface fuzzing and pilling – Part 2: Modified Martindale method.

Moisture management

The dynamic transfer of moisture through the samples from the front and back surfaces was measured using the MMT 290 Moisture Management Tester from SDL Atlas.

By choosing the wetting time (WT), the similarities and differences between each sample, before and after the design of the chitosan- PES structure and after 10 washing cycles, were determined by HCA-Hierarchical Cluster Analysis using Minitab software and Ward's dendrograms [19]. HCA is an advanced mathematical and statistical method used to classify samples in groups by similarity and dissimilarity. In this research, it was used as an additional method for mathematical confirmation of the obtained differences of the samples before and after the washing process.

Tactile properties

The alkali modified and chitosan-polyester fabrics, before and after washing, were characterised by a Fabric Touch Tester, FTT M293 from SDL Atlas, USA. The properties are specified by smoothness, softness, warmness, total hand and total touch [20].

The antimicrobial activity

The antimicrobial activity (AMA) of chitosan was analysed before and after 10 wash cycles according to the ASTM E 2149-01 method: Standard Test Method for Determining the Antimicrobial Activity of Immobilised Antimicrobial Agents Under Dynamic Contact Conditions. The bacterial species defined in the Standard is *Klebsiella pneumoniae*, American Type Culture Collection (ATCC) No. 4352, and one gram-positive bacteria, found commonly on skin, *Staphylococcus aureus* ATCC 29213, was used as well, in order to broaden the spectrum of antimicrobial activity of the examined chitosan-polyester fabrics.

The 2 g test samples were cut into 1 × 1 cm pieces, divided in two and autoclaved, and then placed in suspensions. A suspension with a volume of 25 mL and a density according to the Standard used of 2.0×10^5 of one culture and the other was transferred to Falcon tubes and then incubated for 1 h under rotational mixing. Then, 0.01 mL from each vial was diluted serially 10x into microtiter plates, these dilutions were applied to nutrient agar, and the plates were incubated for 24 h at 35 °C. The results are expressed as the percentage of reduction of microorganisms in contact with the sample according to Equation 1:

$$Reduction = \frac{(B - A)}{B} \times 100\ (\%) \quad (1)$$

where:

A is CFU per mL of treated sample after contact in a certain time,

B is "0" time of contact CFU per mL before placement of the sample.

3 Results and discussion

Chitosan is positively charged in the neutral conditions, and can be used for adsorption of anionic substances due to electrostatic interactions [4]. Accordingly, the identification of chitosan on the designed chitosan - PES textile structure (untreated, alkaline hydrolysed and alkaline hydrolysed with a cationic promoter) was performed before, and after 5 and 10 wash cycles, after dyeing with Remazol Red RB reactive dye. According to the literature, this is a dye with excellent light, perspiration and soaping fastness [21]. The single azo reactive bifunctional dye Remazol Red RB (C.I. Reactive Red 198) [22] (Figure 1) contains two different reactive systems in the same molecule. The first reactive centre (RC. 1) is a 2-sulphatoethyl sulphone precursor of the vinysulphone reactive system, and the second (RC. 2) is based on nitrogen-containing heterocyclic ring, bearing a halogeno substituent undergoing nucleophilic substitution [21, 23].

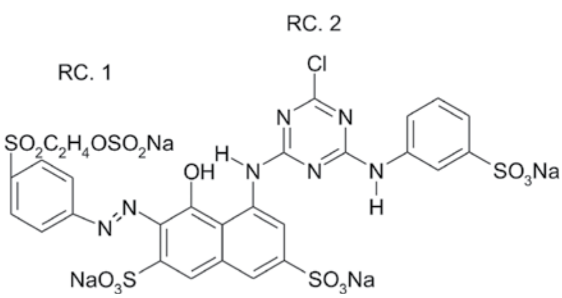
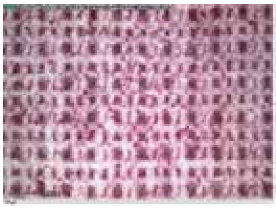
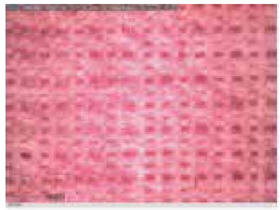
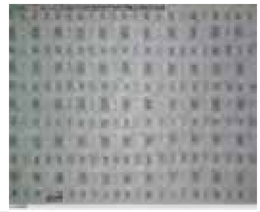
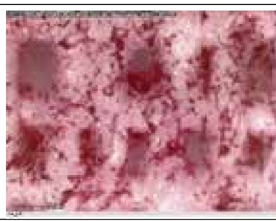
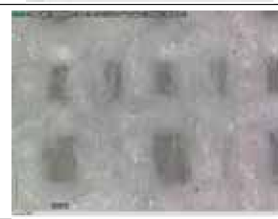
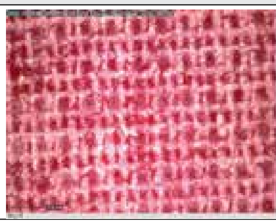
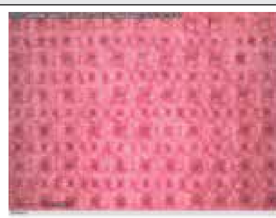
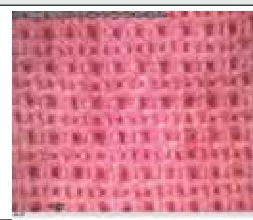
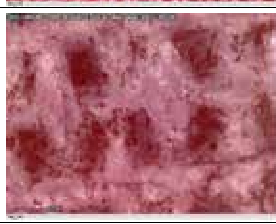
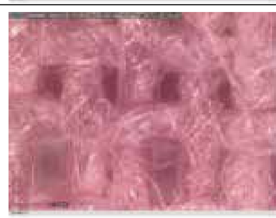
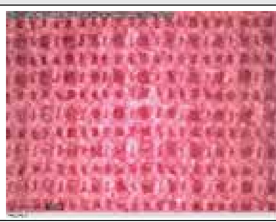
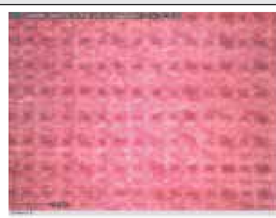
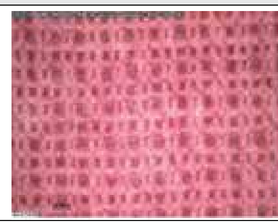
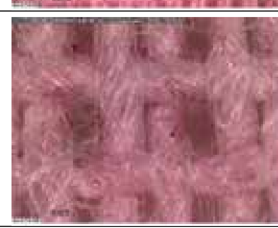


Figure 1: Chemical constitution of the reactive dye Remazol Red RB (C.I. Reactive Red 198) [21, 23]

The vinysulphone reactive system (RC. 1) reacts via a nucleophilic addition mechanism. In this system the carbon–carbon double bond is polarised by the powerfully electron-attracting sulphone group. This polarisation imparts a positive character on the terminal carbon atom, and favours the nucleophilic addition of the chitosan anion.

The reactive centre, based on a nitrogen-containing heterocyclic ring (RC. 2) bearing a halogen substituent, undergoes nucleophilic substitution. The heteroatoms (-Cl) in the aryl ring activate the system for nucleophilic attack of a chitosan anion due to their electronegativity [24]. The red shade of the colour proves the presence of the biopolymer chitosan. The intensity of the staining shows the degree of saturation of the polyester fabric with this biopolymer [25–28]. A digital image of the surface of the examined samples with a magnification of 50 and 230 times is shown in Table 2.

Table 2: Digital micrographs of the chitosan-PES fabrics before and after washing cycles dyed with Remazol Red RB under magnification of 50x and 230x

Magnification	Ch-U	Ch-U-5	Ch-U-10
50×			
230×			
Magnification	Ch-AH	Ch-AH-5	Ch-AH-10
50×			
230×			
Magnification	Ch-AH_C	Ch-AH_C-5	Ch-AH_C-10
50×			
230×			

An image of the red-stained surface of the control sample before (Ch-U) and after 5 wash cycles (Ch-U-5) confirms the stability of the chitosan during the wash cycles. However, the 230x magnification shows clearly that this stability is not permanent, as the chitosan particles visible on the control samples (Ch-U) have disappeared on sample ChU5. A snapshot of the sample (Ch-U-10) shows an unstained surface, confirming that no chitosan was present on the sample after 10 wash cycles, indicating the instability of the adhered chitosan on this sample. This is due to the weaker compatibility and interreactivity of the natural and synthetic polymer on the studied structure. The intensity and uniformity of staining of each sample differed before and after 5 and 10 cycles.

The multifunctional properties of polyester, identified as compatibility with chitosan, increase in reactivity and enhanced hydrophilic character, were the result of modification by alkaline hydrolysis [29]. Visual inspection confirmed that the best effect was obtained with the biopolymer textile structure chitosan-alkaline hydrolysed PES fabric (Ch-AH). However, the red colouration of the samples chitosan-alkaline hydrolysed PES fabric after 10 washing cycles (Ch-AH-10 and Ch-AH_C-10) confirms the good stability of chitosan. This proves that it is necessary to modify the surface of polyester fabric to develop a stable bioactive textile structure of chitosan and polyester. The stability results obtained are consistent with previous studies, even though these were carried out under different processing conditions [30].

The dyed textile structures with chitosan were evaluated spectrophotometrically, and the results of the colour strength (K/S) of the samples are shown in Table 3.

Table 3: Colour strength (K/S) of the control and washed chitosan-PES fabrics dyed with Remazol Red

Fabric	K/S
Ch-U	1.5056
Ch-U-5	1.6378
Ch-U-10	1.1517
Ch-AH	2.9824
Ch-AH-5	1.6101
Ch-AH-10	1.5208
Ch-AH_C	3.2686
Ch-AH_C-5	1.5913
Ch-AH_C-10	1.4995

The colour strength shows the stability of coated chitosan on PES fabric before and after modification numerically. It can be seen that alkaline hydrolysis affects the coating potential of chitosan favourably. The analysis shows that the unmodified chitosan coated fabric had the best stability after 5 wash cycles (Ch-U-5), while, after 10 wash cycles (Ch-U-10), the chitosan was lost, due to poor compatibility between the two polymers, polyester and chitosan. This proves the need for an increase in the compatibility of chitosan with polyester, e.g. by alkaline hydrolysis, or some other chemical or physical methods. The colour strength of the alkaline hydrolysed samples was almost twice that of the unmodified samples. However, the results show that chitosan is not completely stable, but some of it is lost under the alkaline conditions of the washing process. The values shown indicate the highest loss over 5 cycles. Further wash cycles up to the analysed 10 did not result in significant changes in colour strength, indicating that the chitosan had stabilised through 5 washing cycles.

Benzalkonium chloride as a cationic compound promoted alkali hydrolysis of polyester fabric and improved compatibility between chitosan and polyester. The presence of free quaternary ammonium groups of the cationic promoter and protonated amino groups of chitosan on the surface of the sample Ch- AH _C improved its colour strength. This effect of quaternisation of polyester fabric modified with chitosan did not improve wash fastness, as the K/S values of the alkaline hydrolysed samples (Ch-AH and Ch- AH _C) were comparable after 5 and 10 washes. Considering the fact that surface properties change with the modification and functionalisation of textiles, the surfaces of all the studied samples were analysed before and after 5 and 10 washing cycles. The characterising parameter is the zeta potential, which is determined as a function of the pH of the 1 mmol/L KCl solution, Figures 2–7.

It is well known that the most hydrophobic synthetic fibres, including polyester, have a highly negative value of zeta potential. Esterified carboxylic groups of polyester result in negative zeta potential values from -40 mV to -80 mV, depending on the structural parameters and modification/functionalisation process [31]. The zeta potential values of the standard polyester fabric (U) are due to preparations [11] lower throughout the pH range than the values shown in other research findings [31,32]. After 5 and 10 washing cycles, the zeta potential of the washed

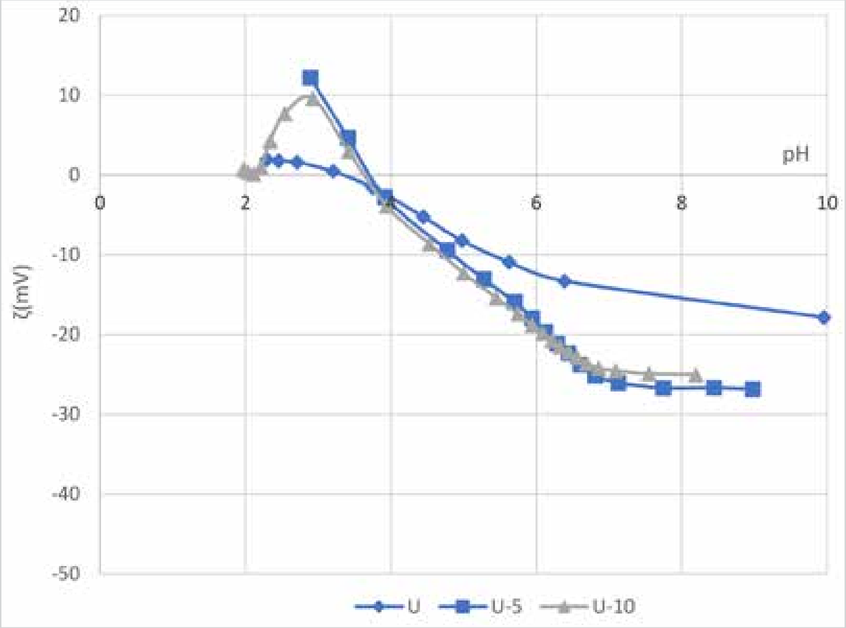


Figure 2: Zeta potential of untreated fabrics before and after washing cycles in variations of pH 1 mmol/L KCl

standard polyester fabric (U-5 and U-10) was more negative compared to the control sample (U). This relationship shows that the washing process had a purifying effect, although the values obtained were still lower compared to those characterising polyester textiles.

Figure 3 shows that the designed chitosan-polyester structure (Ch-U) has positive values of zeta potential throughout the studied pH range, which is in agreement with the results of zeta potential of chitosan, which is 12 mV at pH 7 [4, 33]. The zeta potential curves of the washed chitosan-polyester fabric are negative in the whole pH range. The shape of the titration curves depends on the surface changes caused by the number of washing cycles. The curve of the 10-cycle washed sample (Ch-U-10) is flatter than the curve describing the electrokinetic behaviour of the Ch-U-5 sample, which means that the 5-cycle washed sample has a more negative zeta potential than the 10-cycle washed sample. A possible reason for the less negative surface of the 10 times washed fabric (Ch-U-10) than the 5 times washed (Ch-U-5) can be accumulation of detergent ingredients, e.g. insoluble zeolites, or inorganic substances from hard water.

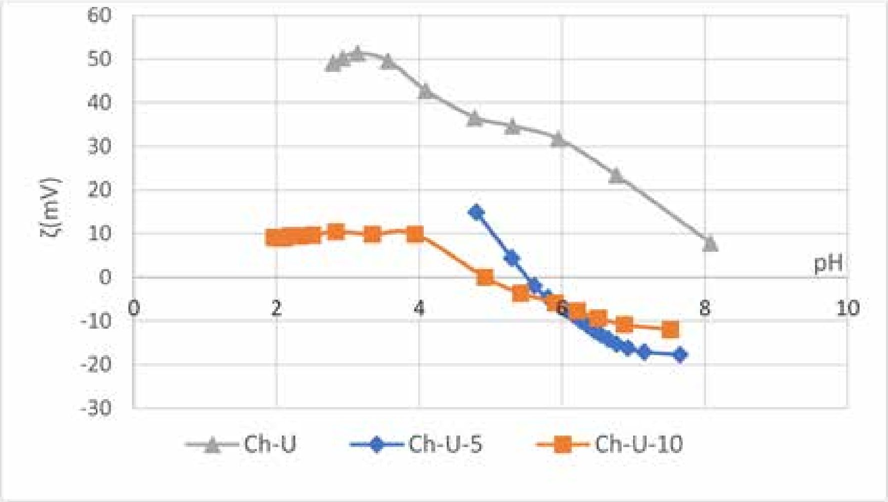


Figure 3: Zeta potential of chitosan-PES fabrics before and after washing cycles in variations of pH 1 mmol/L KCl

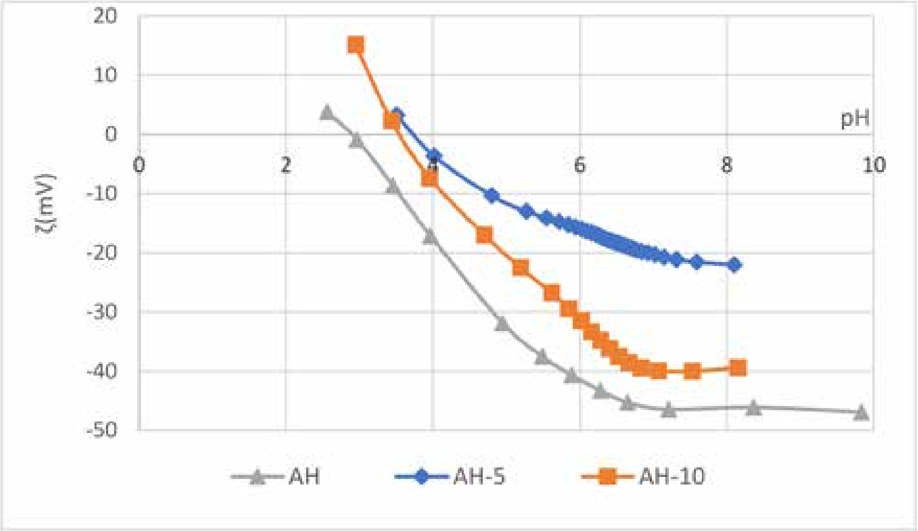


Figure 4: Zeta potential of alkali hydrolysed PES fabrics before and after washing cycles in variations of pH 1 mmol/L KCl

Modification of the polyester fabric by alkaline hydrolysis (AH) resulted in a decrease in zeta potential compared to the control sample (U), Figure 4. The modification of polyester in alkali hydrolysis should be observed as a preparation process, where a surface was purified and peeled to a certain degree. The zeta potential curves show that the zeta potential of the washed fabrics continued to decrease, with the decreasing trend following the patterns described previously, where 5 cycles (AH-5) resulted in more negative zeta potential values compared to 10 cycles (AH-10). The Isoelectric points (IEPs) of the 5 and 10 times washed alkali hydrolysed samples are very close, despite a difference in the negative zeta potential values. The influence of the number of washing cycles on the state of the modified surface cannot be compared with untreated polyester fabric (U), which is covered with impurities (Figure 2).

The zeta potential curve of the alkaline hydrolysed polyester fabric treated with chitosan (Ch-AH) as a function of pH is completely in the positive range, Figure 5. The size and stability of the titration curve indicates the presence of chitosan on the surface. After 5 and 10 wash cycles, it can be seen that the curves of the washed samples (Ch-AH-5 and Ch-AH-10) go completely into the negative range, with

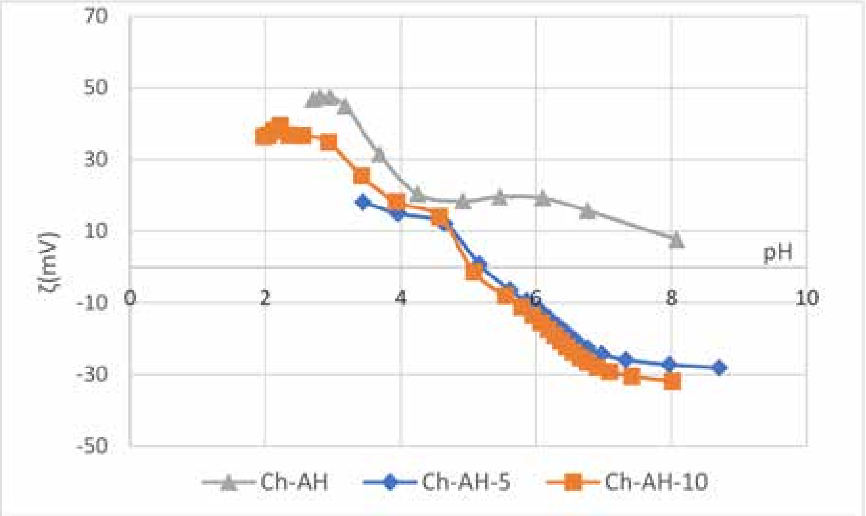


Figure 5: Zeta potential of chitosan-alkali hydrolysed PES fabrics before and after washing cycles in variations of pH 1 mmol/L KCl

the values of the 10 wash cycles being slightly more negative than those of the 5 wash cycles. The comparison of the alkaline hydrolysed sample treated with chitosan after 10 washing cycles (Ch-AH-10) with the alkaline hydrolysed sample after 10 cycles (AH-10) shows that the values were less negative This confirms that chitosan is still present on the surface of the polyester fabrics after 10 washing cycles. The results are in agreement with the identification by the staining results and the colour strength values.

The zeta potential curves of the alkaline hydrolysed samples with the addition of a cationic surfactant, before and after 5 and 10 wash cycles, overlap, Figure 6. The alkaline hydrolysed control fabric with cationic surfactant (AH_C) shows a typical curve of polyester textiles [31,32]. This process of alkaline hydrolysis with the addition of a promoter caused the removal of the existing preparations and the pilling of the surface, which changed the surface properties completely compared to the control fabric (U).

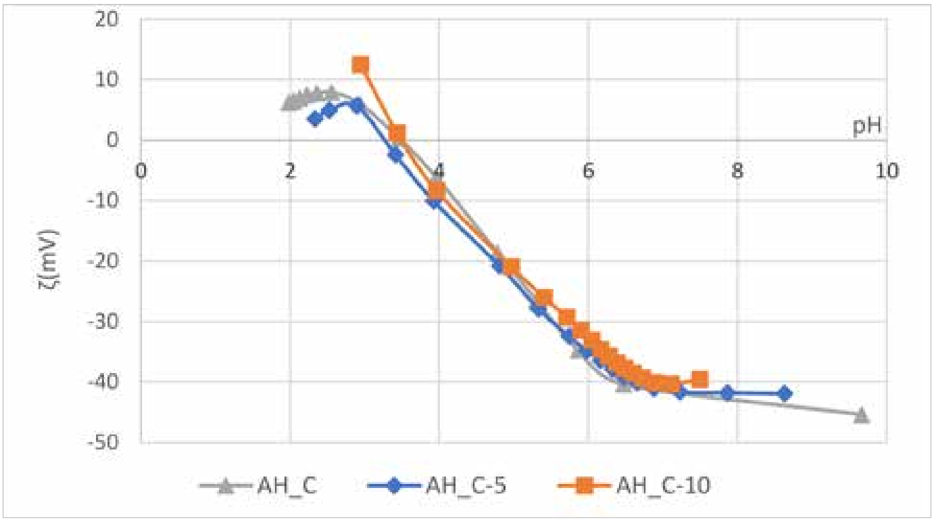


Figure 6: Zeta potential of alkali treated with promoter fabrics before and after washing cycles in variations of pH 1 mmol/L KCl

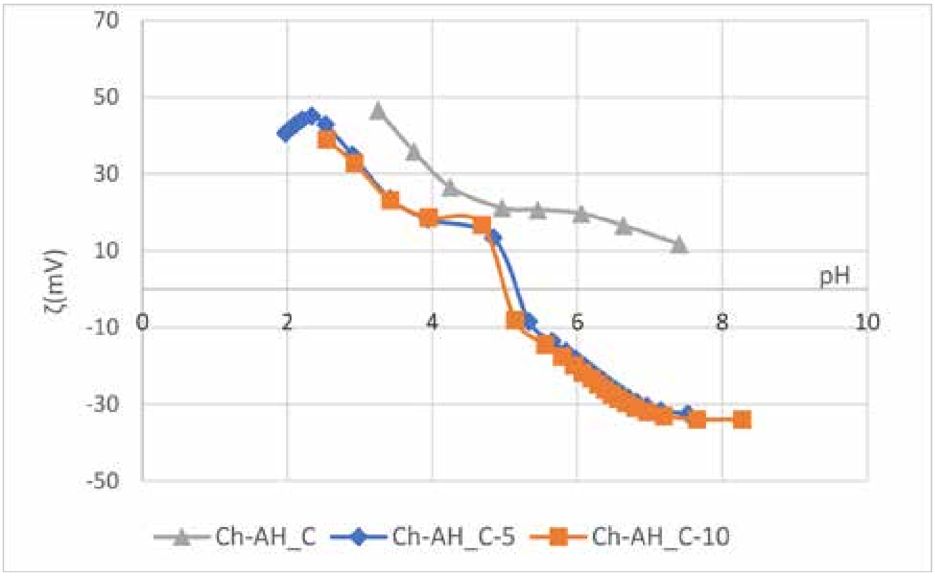


Figure 7: Zeta potential of chitosan-alkali hydrolysed with promoter PES fabrics, before and after washing cycles in variations of pH 1 mmol/L KCl

The zeta potential of the chitosan-polyester sample alkaline hydrolysed with the promoter is positive throughout the pH range, confirming a complete coating that is stable over the entire studied range, Figure 7. Washing this fabric changes the surface, the zeta potential values are negative, and their size shows that some chitosan remains on the surface. The differences between 5 and 10 cycles of the washed samples (Ch-AH_C-5 and Ch-AH_C-10) are insignificant.

The tensile properties of textile materials are an important structural characteristic, and it is important to monitor them and evaluate the appropriateness of the modification and functionalisation process based on the values obtained. In this research, the tensile properties of all control samples of a standard polyester fabric and the same after 10 washing cycles, were analysed by measuring the breaking force and the breaking elongation, Figure 8 and Table 4.

Figure 8 shows data of the breaking force of the analysed samples before and after 10 washing cycles.

The breaking forces (Fp) of the washed samples after 10 cycles compared to certain control groups of samples before washing show a decrease and an increase in tensile properties, depending on the degree of modification and functionalisation of each fabric sample.

According to these data, the influence of 10 washing cycles is shown by a decrease in tensile properties of fabric samples (AH, Ch-U, Ch-AH), while the tensile properties of fabric samples (U, AH_C, Ch-AH_C) improved. The indexes of increase and decrease indicate the structural characteristics of the studied structures. The approximate value of increase (about 25%) is characteristic for alkaline hydrolysed PES fabrics with the addition of a cationic surfactant before (AH_C) and after chitosan coating (Ch-AH_C). This increase can be attributed to the compactness of the polyester fabric, weakened by alkaline hydrolysis due to the chitosan coating and washing process. This increase in the breaking force of the sample during washing (Ch-AH_C-10) can be attributed partially to the more uniform surface coverage of the chitosan-coated fabric, as confirmed by the uniform colouring of this sample, Table 2 and Table 3.

The elasticity of the analysed samples was compared by breaking elongation and statistical indicators, Table 4.

Table 4: Elongation (ε) and statistical indicators of the tested fabrics

Fabric	ε (%)	σ (%)	CV (%)
U	18.66	0.457	2.451
U-10	21.35	1.4569	6.82
AH	18.24	0.567	3.110
AH-10	20.35	0.4822	2.37
AH_C	11.37	0.707	6.216
AH_C-10	13.30	1.8755	14.10
Ch-U	19.32	0.652	3.38
Ch-U-10	20.75	0.6245	3.010
Ch-AH	19.53	2.149	11.002
Ch-AH-10	19.35	0.7500	3.88
Ch-AH_C	11.88	1.389	11.689
Ch-AH_C-10	13.34	1.2388	9.28

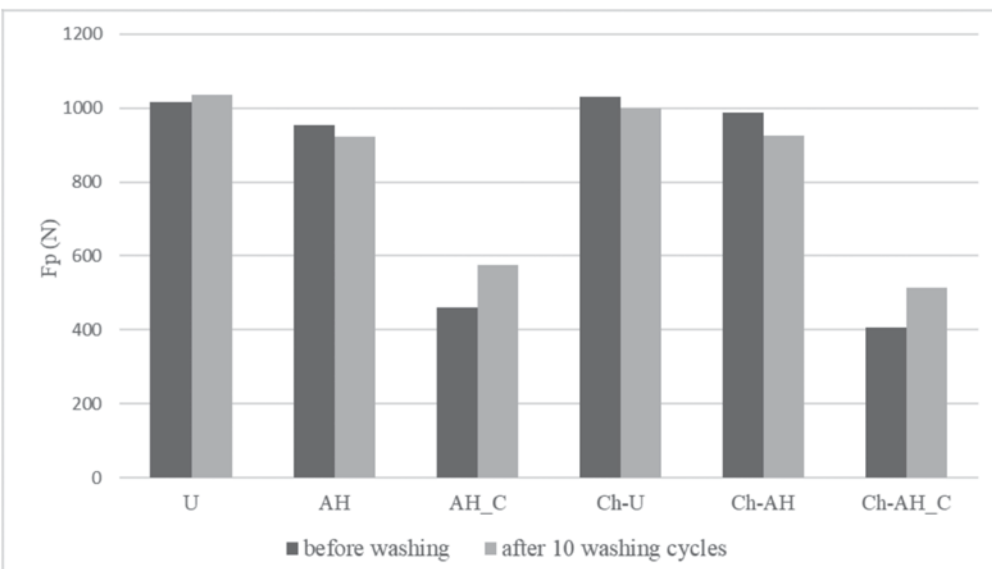


Figure 8: Breaking force of the tested fabrics before and after washing

The results in Table 4 show a significant decrease in the elastic properties of polyester fabrics when modified by alkaline hydrolysis with the addition of a cationic surfactant. The decrease in the tensile and elastic properties of AH_C are the result of modification of the polyester fabric by alkaline hydrolysis with a promoter, leading to a polyester fabric of different structural features. Coating polyester fabrics with chitosan increases the elasticity of all samples by about 1 unit.

The tendency of the textile surface to pilling is a property that must be monitored for synthetic textiles that exhibit this tendency. Accordingly, the surface of PES fabric samples was evaluated before and after 10 washing cycles with a different number of rubs (125 - 7000 cycles), Table 5.

Table 5: Pilling grades

Fabric	Cyclic rubs					
	125	500	1000	2000	5000	7000
U	5	5	5	5	4-5	3-4
U-10	5	4	3-4	3	3	3
AH	5	5	5	5	4	3
AH-10	5	4	3-4	3-4	3-4	3
AH_C	5	5	5	5	4	3-4
AH_C-10	5	5	5	4-5	4	3-4
Ch-U	5	5	5	5	4-5	3-4
Ch-U-10	5	5	4-5	4-5	4	3-4
Ch-AH	5	5	5	5	4-5	3-4
Ch-AH-10	5	4-5	4-5	4-5	3-4	3-4
Ch-AH_C	5	5	5	5	4	4
Ch-AH_C-10	5	5	5	5	4-5	4-5

Grade 1 - very heavy pilling; grade 5 - no pilling

From the evaluations of the appearance of the surface after cyclic abrasion of PES fabric samples before and after 10 washing cycles, it is clear that the washing process affects the tendency of samples to form pilling, which is evident at 125 cycles, 500 cycles, 1000 cycles, 2000 cycles, and 5000 cycles. However, at 7000 cycles, almost no significant differences were observed between the unwashed and washed fabrics.

Since the standard polyester fabric is white, the effect of modification and functionalisation on whiteness was investigated in the research, Table 6. From the values listed in the Table, the whiteness (W_{GG}) of the original control fabric (U) increased

Table 6: Whiteness degree (W_{GG}), tint deviation (TD) and tint value (TV) of PES and Chitosan-PES fabrics before and after 10 washing cycles

Sample	W_{GG}	TD	TV
U	58.36	G2	1.96
U-10	71.78	G2	1.83
AH	58.98	G2	1.83
AH-10	78.76	G2	1.98
AH_C	58.35	G2	1.63
AH_C-10	75.52	G1	1.46
Ch-U	55.98	G1	1.33
Ch-U-10	61.47	G2	1.90
Ch-AH	52.25	G2	1.75
Ch-AH-10	58.48	G2	1.75
Ch-AH_C	52.92	G2	1.57
Ch-AH_C-10	58.93	G2	1.66

through 10 washing cycles. The standard detergent does not contain optical brightener, so the whiteness increases in proportion to the effect of the other detergent ingredients. Alkali modifications and chitosan treatment reduced the whiteness of all samples by several units. The slightly yellowish hue of the chitosan solution and the thermal processes of drying and cure affected the slight yellowing of all chitosan-treated fabrics. On washing, the whiteness of chitosan treated fabrics increased somewhat, but did not reach the values of modification after 10 wash cycles. The whiteness decrease is not valorised by tint deviation (TD) and tint value (TV).

The surface of the polyester fabric samples before and after modification and functionalisation with chitosan was analysed structurally by Scanning Electron Microscopy at a magnification of 1,500x, Figures 9–10.

The micrographs show clearly the roughness upon the influence of sodium hydroxide as an alkali in both variants (AH, AH_C) on the surface appearance of the polyester fabric. The formation of micro sized craters is caused by the action of hydroxyl ion to the ester bonds of polyester, that is in line with previous findings [34]. The addition of the promoter, together with sodium hydroxide during alkaline hydrolysis, caused a change in the surface, which detached partially and no longer showed irregularities. After 10 washing cycles with standard detergent, the surface of all samples was loaded with solids, due to zeolite and other silicate formations.

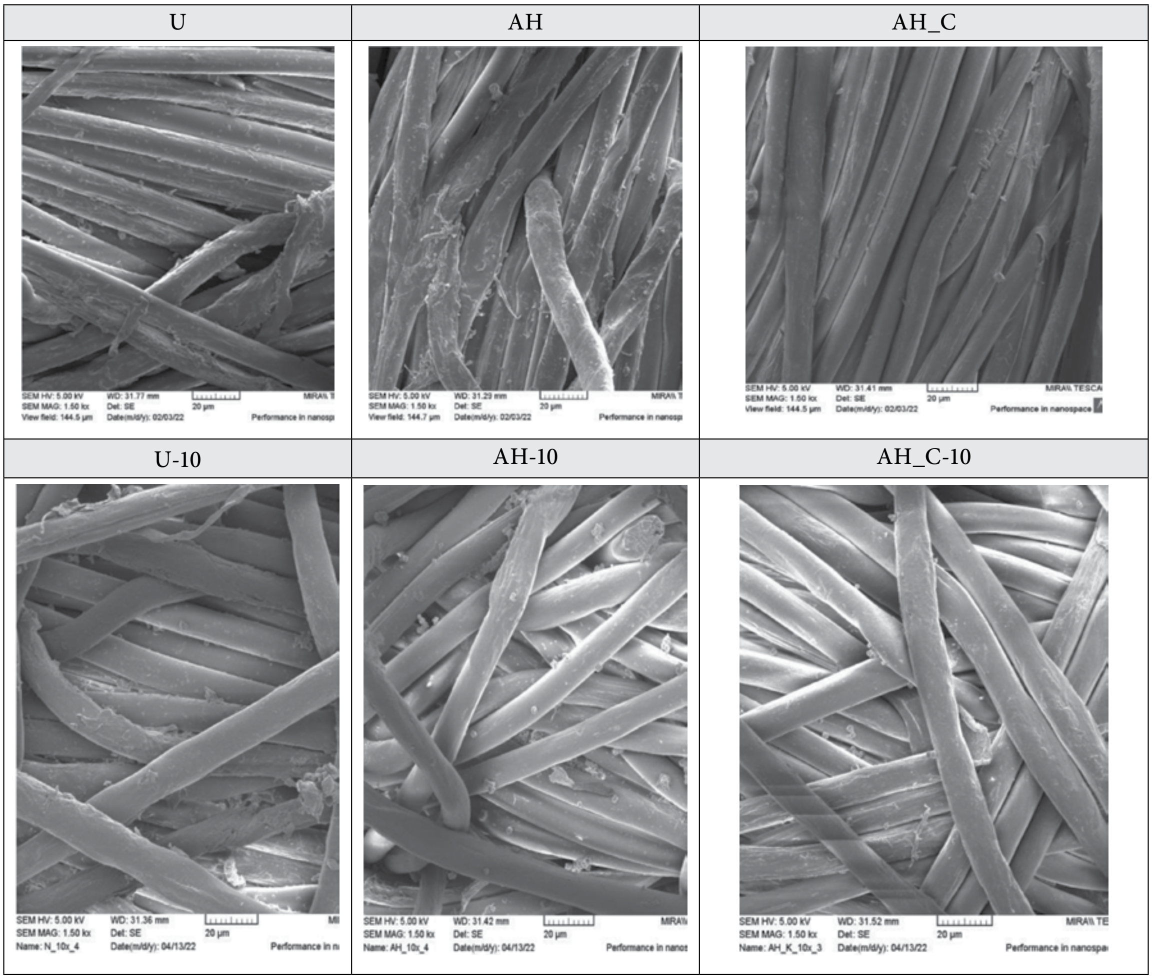


Figure 9: Micrographs of control (U) and modified polyester fabrics (AH, AH_C) before and after washing (U-10, AH-10, AH_C-10) magnified 1,500-×

The microscopic images of the chitosan-polyester fabric show changes in the morphological properties of the polyester structure due to the coating of the individual fibres by the chitosan [29], although no significant differences are visible between the individual samples, Figure 10. However, after 10 washing cycles, differences became visible between the individual samples. The surface of the sample (Ch-U-10) was loaded with agglomerates, which is due to the complete loss of the chitosan, as confirmed by the digital images of the stained samples. The distribution and proportion of similar agglomerates on the surface of the samples (Ch-AH-10 and Ch-AH_C-10) was significantly lower than for the Ch-U sample. The reason for this is the remaining protective layer of chitosan on the surface, which prevents the deposition of substances from the washing baths on the surface of the fabrics.

MMT wetting time is considered as a time when top surface and bottom surface of textile sample begins to wet accordingly [35]. The wetting time (top surface and bottom surface) of untreated and modified polyester fabrics was analysed by HCA analysis, Figure 11.

The values of MMT wetting time of polyester fabrics are slightly lower on the bottom side than on the top surface. Results of determining the MMT wetting time of polyester fabrics top surface before and after modification is in the range of 3.5 s to 2.2 s respectively. Modification of the fabric by alkaline hydrolysis and alkaline hydrolysis with promotor increases the hydrophilicity, which is reflected in a decrease of the wetting time. Washing process of polyester fabrics with alkaline detergent medium affects the mild hydrolysis of the surface and the further reduction of the wetting time between 1.2 and 2.0 s.

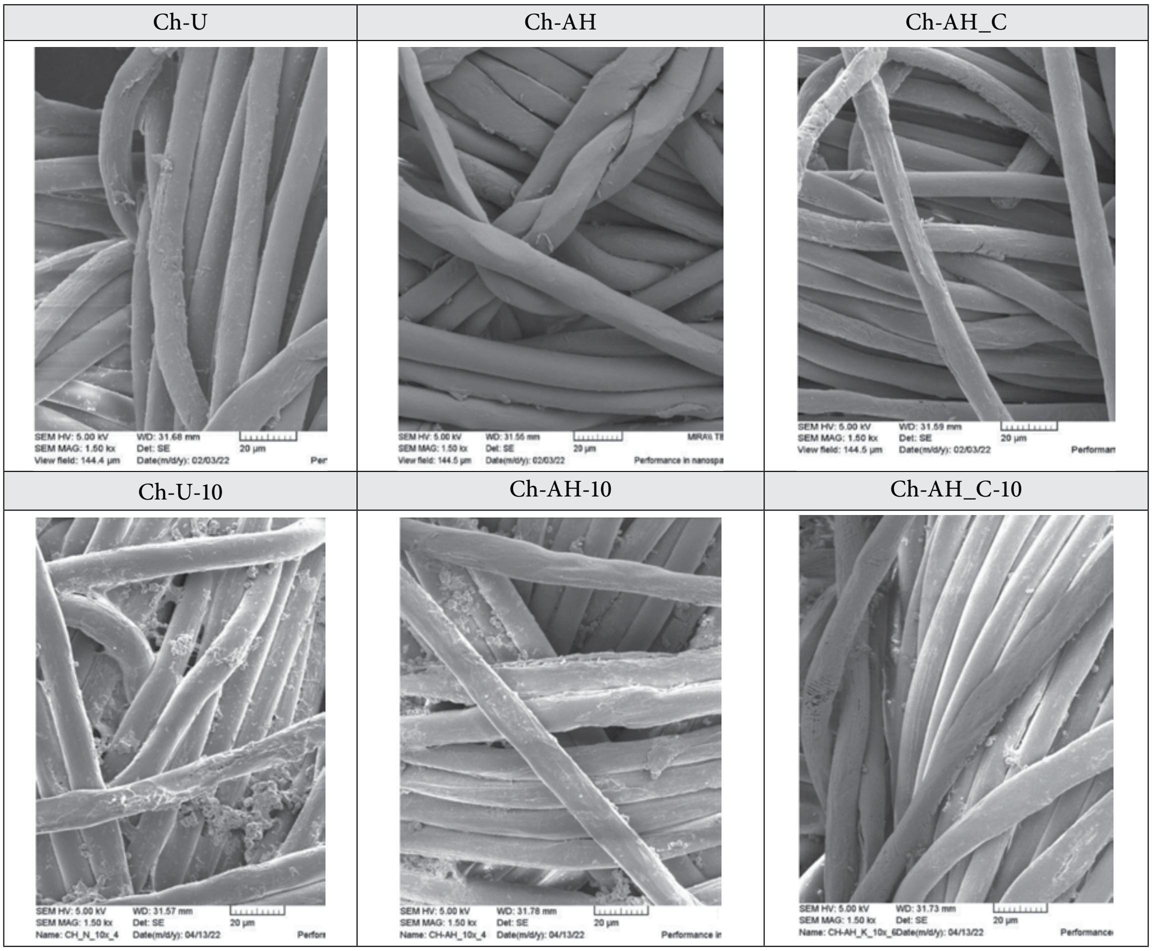


Figure 10: Micrographs of polyester fabrics coated with chitosan (Ch) before and after washing (Ch-U-10, Ch-AH-10, Ch-AH_C-10) magnified 1,500-×

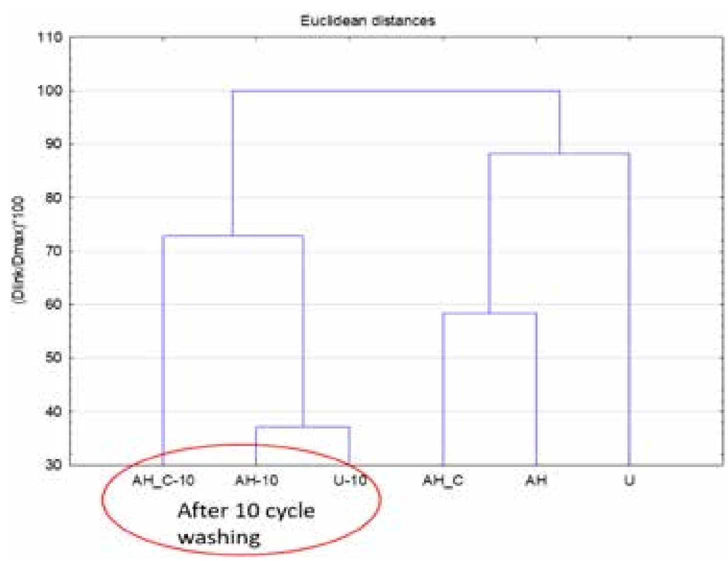


Figure 11: Dendrogram of the Euclidean distance for 6 variables (control standard fabric before and after 10 washing cycles, alkali hydrolysed and alkali hydrolysed with a promotor before and after 10 cycles) according to the MMT wetting time data (top surface and bottom surface)

Hydrophobic surfaces require a longer time for wetting than hydrophilic ones. MMT wetting time proves that modified surfaces before and after washing are hydrophilic, considering that it is less than 3 s. In Figure 11 is visible a distribution by groups obtained by applying HCA analysis, where one group includes samples that have been washed 10 times, while modified samples before washing form another group. The level of grouping in the samples washed 10 times shows the similarity of U-10 and AH -10 and the difference with AH _C-10, but still belonging to the same group. On the other hand, in the group of samples before washing, the similarity of the treated samples AH _C and AH is visible, while a significant difference is visible with respect to the untreated sample, but also belonging to the same group.

The moisture transport of the chitosan-polyester structures (top surface and bottom surface) before and after 10 washing cycles was also analysed by HCA analysis, Figure 12.

Treating the polyester samples with chitosan shortens the wetting time, and the differences between the top and bottom surfaces are smaller. The untreated chitosan sample has a shorter wetting time compared to the samples of chitosan alkaline hydrolysed polyester, while the sample alkaline hydrolysed with a promotor has a longer wetting time than the alkaline hydrolysed one. Washing these chitosan-treated samples results in minor differences in wetting time within this group of samples. Figure 12 shows a distribution by group for the washed and unwashed samples of chitosan-polyester fabrics. Group formation of the 10 cycles washed chitosan polyester samples is visible. The level of grouping shows small differences in the samples of washed chitosan polyester structure treated with AH and AH _C belonging to the same group. The next level belongs to an untreated chitosan structure, but with great similarity of samples, so they can be grouped together, and this is marked on the graphical representation. The unwashed samples are placed on the following levels, where the difference is between untreated and samples treated with AH and AH _C, while untreated Ch-U is placed on the highest level, which is an indicator of a big difference compared to the other samples.

The surface of the standard polyester fabric was modified by alkaline hydrolysis and the process of coating with the biopolymer chitosan, which is expected to change the tactile properties. Accordingly, the characterisation of the fabric samples was performed before and after 10 washing cycles with the device FTT, Fabric Touch Tester, Table 7.

From the results in Table 7 it can be seen that the standard control fabric (U) had the highest smoothness, which may be related to the preparations, especially the silicone product [11]. It can be seen that the smoothness is disturbed by the surface treatments with alkaline hydrolysis, and additionally by the treatment of all samples with chitosan.

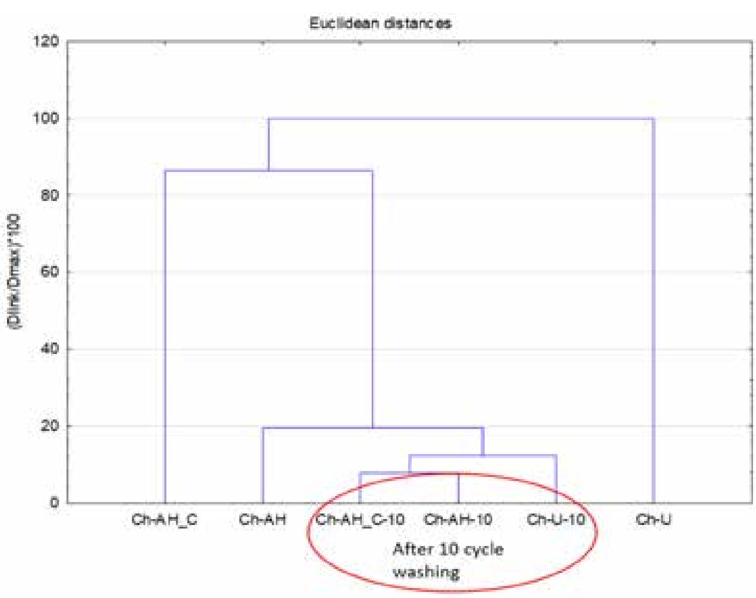


Figure 12: Dendrogram of the Euclidean distance for 6 variables (chitosan - polyester structures before and after 10 washing cycles) according to the MMT wetting time (top surface and bottom surface)

Table 7: FTT evaluation parameters of the tested fabrics

Fabric	Smoothness	Softness	Warmness	Total touch
U	4.0	2.0	2.0	3.0
U-10	3.0	3.0	3.0	3.0
AH	3.0	3.0	4.0	3.0
AH-10	3.0	3.0	4.0	3.0
AH_C	3.0	4.0	4.0	3.0
AH_C-10	3.0	4.0	3.0	3.0
Ch-U	2.0	1.0	3.0	1.0
Ch-U-10	3.0	3.0	4.0	3.0
Ch-AH	1.0	1.0	4.0	1.0
Ch-AH-10	3.0	2.0	4.0	3.0
Ch-AH_C	2.0	1.0	4.0	1.0
Ch-AH_C-10	3.0	3.0	4.0	3.0

The softness of the fabric changes with the degree of treatment, and it is obvious that the alkaline hydrolysed samples with the addition of a cationic surfactant have better softness compared to the other samples. The samples treated with chitosan have worse tactile properties (total touch) compared to the control samples, and the values obtained are the same (value 1) in Table 7.

The total touch of the modified fabrics before and after 10 washing cycles was the same (total touch = 3), which was not expected given the fact that the samples were not soiled. It is known that detergent components can settle on the surface of textiles if they are not used to remove stains [36], which is not the case in this study. This may be explained in part by the fact that the washing process was performed in hard water, and that certain components of the detergent, particularly zeolite, were focused on the process of water softening rather than on loading the fabric surface.

Chitosan applied to the surface of the polyester fabric stiffened it partially and reduced the total touch (grade 1). In the chitosan-polyester samples, an increase in total touch (grade 3) was observed after 10 wash cycles compared to the total touch of chitosan-polyester (grade 1). This increase can be attributed to the loss of chitosan through 10 wash cycles due to its instability. The released chitosan has a tendency to combine with the zeolite from the detergent, and the improvement in touch can be attributed to the prevention of scaling (chitosan/zeolite). This synergistic effect of chitosan and zeolite from different sources is consistent with the literature [37]. The added value of the chitosan/zeolite composite is evident in the reduction of the chemical oxygen demand (COD) value from the water, since the absorption capacity of the composite is greater compared to the individual structural elements, zeolite and chitosan [38].

As chitosan is recognised and used as an antifungal and antibacterial agent [39–45], the antimicrobial activity (AMA) of chitosan- polyester fabric samples before and after 10 washing cycles against selected gram-positive (*Staphylococcus aureus* ATCC 29213, SA) and gram-negative (*Kebsiella pneumoniae* ATCC, KP) bacteria was analysed, and the effect was expressed through CFU and % in reduction, Tables 8–9

As the experiments were performed in triplicate, the statistical parameters were integrated in both Tables.

All chitosan-polyester fabrics before and after 10 washing cycles possess antimicrobial activity against gram-positive bacteria *Staphylococcus aureus ATCC 29213* (SA). The antimicrobial efficiency of chitosan-polyester fabrics after 10 washing cycles (Ch-U-10, Ch-AH-10, Ch-AH_C-10) in comparison to samples before washing (Ch-U, Ch-AH, Ch-AH_C) was preserved partly. The reduction in AMA depends on the pretreatment phase, so the chitosan-polyester fabric showed 17.5%, chitosan-alkali hydrolised polyester 25.7% and chitosan-alkali hydrolsed polyester with promoter 15.7%.

The obtained results indicate leaching of the chitosan during 10 washing cycles and a certain instability. The best effect was achieved by the alkaline hydrolysed sample with the addition of the promoter, benzalkonium chloride – a known quarternary

Table 8: Antimicrobial activity (AMA) of chitosan in polyester fabric before and after 10 washing cycles against Staphylococcus aureus ATCC 29213

Sample	Staphylococcus aureus ATCC 29213			
	Reduction (%)	CFU	σ	CV (%)
Ch-U	80.00	6.00×10^3	5.66×10^3	94.3
Ch-U-10	66.60	6.66×10^4	4.71×10^4	70.7
Ch-AH	90.00	1.10×10^4	1.27×10^4	116.0
Ch-AH-10	66.80	6.63×10^4	4.70×10^4	71.0
Ch-AH_C	100.00	0.00	0.00	0.00
Ch-AH_C-10	84.34	1.85×10^5	1.91×10^5	103.0

Table 9: Antimicrobial activity (AMA) of chitosan in polyester fabrics before and after 10 washing cycles against Klebsiella pneumoniae ATCC 4352

	Klebsiella pneumoniae ATCC 4352			
Sample	Reduction (%)	CFU	σ	CV (%)
Ch-U	No	3.30×10^6	2.40×10^6	72.9
Ch-U-10	No	9.99×10^6	7.06×10^6	70.7
Ch-AH	55.5	65.0×10^6	35.4×10^6	54.4
Ch-AH-10	98.0	5.10×10^6	6.93×10^6	136.0
Ch-AH_C	No	55	63.6	116.0
Ch-AH_C-10	96.6	3.10×10^5	4.10×10^5	132.0

ammonium compound with antimicrobial properties against bacteria, fungi, and viruses [45].

The results of the antimicrobial activity of chitosan-polyester fabrics (Ch-U, Ch-AH_C) against gram-negative *Klebsiella pneumoniae* ATCC 4352 (KP) were absent, while the fabric (Ch-AH_C-10) showed a high reduction level. The absence of antimicrobial activity of the samples treated with chitosan before washing was not to be expected. The results of AMA against gram-negative *Klebsiella pneumoniae ATCC 4352* were not consistent and require further experiments and tests with other methods.

4 Conclusion

The stability of the differently designed textile structures with chitosan in the multiple washing process with a standard detergent was analysed based on the modification protocol and the number of washing cycles. Modification of the standard polyester fabric was performed with sodium hydroxide and sodium hydroxide and a cationic surfactant.

The absence of chitosan on the standard polyester fabric-chitosan after 10 washing cycles proved the weak stability of the biopolymeric chitosan-PES textile structure during washing and the need to implement a chitosan on modified polyester fabric.

The Remazol Red staining test is a suitable qualitative method for the identification of chitosan. The staining and uniformity of the red colouration of the chitosan - treated alkaline hydrolysed PES fabric after 5 and 10 washing cycles confirmed the presence of chitosan on the surface, i.e. the washing stability of these structures during washing. The zeta potential has been useful to monitor the stability of chitosan as a function of pH and other environmental impacts. Other methods, Scanning Electron Microscopy, pilling propensity, touch, whiteness, breaking force and breaking elongation and MMT wetting time, are also suitable for monitoring the washing stability in a designed chitosan-polyester structure. Hierarchical cluster analysis confirmed the differences in the MMt wetting time of the chitosan-polyester structure with chitosan designed by different methods and washing. All the chitosan-polyester fabrics, before and after 10 washing cycles, possessed antimicrobial activity against the gram-positive bacteria Staphylococcus aureus. The obtained results indicate the leaching of chitosan during multiple washing cycles.

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Awareness of the Environmental Impact of Clothing Production and Consumption among Slovenian Female Customers

Zavedanje glede okoljskih vplivov proizvodnje in potrošnje oblačil

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Abstract
The textile industry, where clothing industry accounts for an important share, is one of the most polluting industries in the world. As a result, clothing consumption has a significant impact on the environment. The consumption of clothing has been increasing rapidly in line with growth in the middle classes in developing nations and the fast-fashion business model. At the same time, consumers are becoming increasingly aware of the importance of sustainability, and have been changing their behaviour accordingly. In this study, we focused our attention on awareness of the environmental impact of clothing production and consumption from the point of view of consumer knowledge, as it relates to different generations, marital statuses, living environments, household income and type of purchasing store. The study reveals a high-level of consumer-evaluated knowledge regarding the effects of clothing production and consumption, as well as the purchasing preference in fast-fashion stores.
Keywords: clothing consumption, customer behaviour, sustainability, contemporary environment, waste pollution logistics

Izvleček
Industrija tekstila, kjer predstavlja industrija oblačil pomemben delež, je izmed najbolj onesnažujočih industrij na svetu, posledično pa ima potrošnja oblačil pomemben vpliv na okolje. Z naraščanjem srednjega razreda v državah razvojem in vzpon modela hitra mode, potrošnja oblačil raste izjemno hitro. Hkrati se potrošniki vse bolj zavedajo pomena trajnosti in temu primerno spreminjajo svoje potrošniško vedenje. V raziskavi smo se osredotočili na zavedanje vplivov proizvodnje in potrošnje oblačil na okolje z vidika znanja oz. poznavanja v povezavi z različnimi generacijami, zakonskim statusom, življenjskim okoljem in družinskim dohodkom. Raziskava razkriva oceno visoke ravni potrošnikovega znanja o vplivih proizvodnje in potrošnje oblačil, a sočasno tud visokoi naklonjenost nakupom v trgovinah z modelom hitre mode.
Ključne besede: potrošnja oblačil, vedenje potrošnikov, trajnost, sodobno okolje, logistika odpadkov

1 Introduction

The amount of clothes bought in the European Union per person has increased by approximately 40% in just a few decades. The main reasons are low prices and the increased rates at which fashion is delivered to consumers [1]. In this regard, fast fashion is an applied business model that is based on the rapid production of cheap clothing following the latest fashion trends. Consequently, the lifespan of clothing has shortened significantly in recent years as rapidly changing fashion guidelines encourage customers to change clothes more often than ever before.

The rapid rise of brands selling cheap and trendy clothing has led to major changes in consumer behaviour. Many consumers consciously buy clothes that quickly become outdated, both physically and aesthetically. Nevertheless, others still prefer clothes that are characterised as sustainable. The number of those has been also increasing.

Moreover, less than half of used clothes are collected for reuse or recycling when they are no longer needed, and only approximately 1% are recycled into new clothes, since technologies that would enable the recycling of clothes into virgin fibres are only starting to emerge [1].

The greatest cost of mass clothing consumption is increased waste and environmental pollution. In Slovenia, every resident threw away 12.3 kilograms of clothes, on average, in 2019. The European average is lower, at 11 kilograms per inhabitant, although that figure also takes into account other separately collected textile waste [2].

This article aims to improve general understanding about the impact of clothing production and consumption, as well as consumer clothing behaviour related to sustainability, with a focus on awareness and knowledge, as it relates to different generations, marital statuses, living environments, household income and store preferences.

1.1 Consumer behaviour

Many authors have written about consumer behaviour [3–11]. In contrast to contemporary theories, which are based on empirical data, traditional theories are based on economic concepts or marketers' experiences [10].

Consumer behaviour is the process through which people or groups choose, acquire, utilize and discard goods, services, concepts or experiences in order to meet their needs and desires [5]. On the other hand, there are authors who define it as a study. In this manner, consumer behaviour is the study of people and the activities they undertake to satisfy their realized needs [3].

Some authors strongly believe consumer behaviour should be defined more broadly in accordance with contemporary trends, as it involves a wide range of consumer activities. Consumer behaviour entails all consumer activities associated with the purchase, use and disposal of goods and services, including the consumer's emotional, mental and behavioural responses that precede, determine or follow these activities [4]. By understanding how consumers behave and what affects them, businesses can better manage their marketing mix, brand management and customer communication [7].

Consumer behaviour is an interdisciplinary concept that derives from four disciplines: psychology as a study of the human mind and the mental factors that affect it, sociology as a study of the development, structure, functioning and the problems of human society, anthropology as human societies' culture and development, and communication as the process of imparting or exchanging information personally or through media channels and of using persuasive strategies [6].

Consumer behaviour can help companies of all sizes to understand consumption patterns more clearly, as well as the internal and external influences that have effect on customers [3]. It is essential that companies comprehensively understand consumer behaviour in order to develop the best possible business strategy.

Nevertheless, some believe studying consumer behaviour can also have a dark, negative side. Experts who criticize it are concerned that an in-depth understanding of consumer behaviour can enable unethical marketers to exploit human vulnerabilities in the marketplace and engage in other unethical marketing practices to achieve business goals [6].

1.2 Sustainable consumer behaviour in the clothing industry

The consumer behaviour related to sustainability in the clothing industry has been the research subject of many distinguished authors in recent years [12–20]. The term sustainability in consumer clothing behaviour describes the capacity to satisfy current needs without compromising the quality of living for future generations.

Clothing business models have gone through an immense transformation in recent decades. Instead of waiting for the conventional fashion seasons, companies now continuously offer new designs at lower prices. It is becoming more common for people to wear clothing just a few times before discarding it [21]. Fashion leaders are becoming more receptive to overconsumption. Nevertheless, they are also perceptive of new trends. One of them is certainly sustainability, which they incorporate into their strategy and influence others through their tastes and preferences [15].

Some studies partly explore certain areas of sustainable clothing consumption. One of the studies researched young adult consumers and the main reasons participants engage or do not engage in sustainable clothing consumption [22]. Another emphasizes a gap between consumers' awareness, their positive attitude toward sustainable fashion and a lack of action in that direction when making purchasing decisions [19]. That study revealed a significant change in students' knowledge of social and environmental issues relevant to the clothing and textile industry. On the other hand, the study found no significant adjustments in clothing purchasing behaviour and no significant relationship between students' knowledge and their reported purchasing behaviour [13]. The next study pointed out that it was clear among fashion-oriented participants that disposable fashion is a prevailing custom that is tied to emotional satisfaction, symbolism, etc. [23].

Customers' purchasing behaviour is not necessarily consistent with their principles [21]. One of the reasons is that sustainable clothing consumption is perceived as expensive [23]. Nevertheless, an increase in awareness can be noted regarding the negative effects of mindless fashion production and consumption [14].

The fact is that the topic of consumer behaviour in the clothing industry related to sustainability has become an important discussion in the academic and business environment.

1.3 Impact of the clothing industry on the environment

The clothing industry has an immense impact on the environment. The fast-fashion business model has fuelled growth in the multi-trillion-dollar clothing sector [24].

It is estimated that the global textile industry produces 150 billion pieces of clothing and generates 93 million tons of waste annually. However, only 1% of all the fabric used for clothing is recycled [2]. Between 2000 and 2015, the average consumer increased the purchase of clothing by more than 60% [24].The number of times an article clothing is worn has declined by 36 per cent in the last 15 years [25]. Moreover, data shows that European households consume huge amounts of clothing. In 2018 and 2019, Europeans spent an average of 600 euros per year on clothing, 150 euros on footwear, and 70 euros on household textiles [26–27]. The greatest cost of this unlimited increase in consumption comes in waste and environmental pollution.

The clothing industry uses immense amounts of water, energy and chemicals in all process phases, from production and the processing of raw materials to disposal. Because the quantities of produced and purchased clothing have been constantly growing, the problem of textile waste and the logistics of its disposal have are becoming increasingly more burdensome [2].

Water use and pollution are important factors during clothing production. Approximately 20% of industrial water pollution is caused by the manufacture of clothing. Numbers show that the world uses 5 trillion litres of water each year for fabric dyeing alone [24]. Moreover, the UNEP estimates that the clothing industry produces between 2 to 8% of global carbon emissions. If changes are not made, the fashion industry will use up a quarter of the world's carbon budget by 2050 [25].

Global environmental concern also addresses the production of waste and its proper disposal. The challenge of optimizing marketing channels, including the disposal of the clothing, is immense. Consequently, this has become an important issue in all phases of marketing channels [28]. The main opportunities lie in readjusting the disposal of clothing waste through the reuse and commercialization of the waste generated by the companies in the cluster [29].

1.4 Impact of the clothing industry on the environment in Slovenia

Consumers have been becoming more environmentally conscious in Slovenia, as well. The trend of wearing environmentally friendly clothing has evolved as a result of our culture's evolving consciousness [30]. Various methods of addressing these issues have been proposed, including the development of new business models, designing products in a way that would make re-use and recycling easier (circular fashion), convincing consumers to buy fewer clothes of better quality (slow fashion), and generally steering consumer behaviour towards choosing more sustainable options [31].

The latest Slovenian study shows that Slovenians throw away clothing mostly due to long-term wear and tear. One of the main reasons that clothes become threadbare or change their shape faster than in the past is the poor quality of materials used to make the clothing sold by fast-fashion stores. The number of fast-fashion stores has been increasing in Slovenia, as well [2].

In 2019, Slovenia imported the most clothing from European nations, such as Germany, Austria and Italy, and from non-European nations, most notably from China and Bangladesh. The average price per kilogram of imported clothing was 25 euros, while the average price of exported clothing was 45 euros. The numbers indicate that Slovenia exports high-quality clothing products and imports lower-quality products [2].

In reality, however, consumers still rarely choose options that are defined as sustainable. Consumers may have high level of environmental awareness, but they rarely take environmental impacts into account when purchasing clothing. Slovenian consumers prioritize, when purchasing clothing, factors such as fashion trends and place of origin, while they still place less value on factors such as environmental sustainability [31]. The share of used, second-hand clothing sales compared to the purchase of new clothes was only 0.62% in Slovenia in 2019, while the share of clothing rental was even lower. On the other hand, a positive trend has been noticed [2]. Purchasing used clothing is still not a typical practice in Slovenia [31]. One of the studies in Slovenia suggest that overall positive attitudes toward environmentally friendly clothing products should be reinforced, as consumers can be influenced through advertising [32].

2 Methodology

2.1 Methods

The main objective of this study, conducted in 2022, was to examine women's decision-making in the selection and purchase of sustainable clothing. Among other things, we addressed their level of knowledge as it relates to sustainable clothing and their preferred clothing store options. An in-depth analysis of collected data was carried out, using selected demographic characteristics.

The survey was performed on convenience samples of female clothing customers born between 1945 and 2005. They were classified into four age groups: Baby Boomers (1945–1964), Generation X (1965–1980), Generation Y (1981–1994) and Generation Z (1995–2005). Our research focused solely on women, as one of the studies found out that women consider their own awareness to be higher than men's [19].

2.2 Questionnaire and hypotheses

The study was conducted using a web-based structured questionnaire, which was pilot-tested in advance. The number of respondents participated in pilot testing was 24 (six respondents from each generation). The pilot testing confirmed that the questions were clearly articulated and the response options are relevant.

The questionnaire tackled: awareness and preferences related to clothing consumption, the effect of the clothing industry on the environment, and sustainable consumer behaviour in the past and future. We noted many possibilities for further research on consumer behaviour related to sustainability. Based on a theoretical review, limitations and suggestions from previously conducted research, we defined three hypotheses.

Many studies partly tackle consumer behaviour awareness and sustainability [13, 19–22]. One of the studies confirmed a generally low awareness about environmental issues and attitudes [21]. Another study discussed positive awareness and attitude toward sustainable fashion [19]. Based on different research results, we aimed to verify whether Slovenian female consumers consider themselves as well-informed, and if they feel they know a lot about the issue and feel that they are experts in the field.

Hypothesis 1

We assumed that those who consider themselves as well-informed also feel that they know a lot about the topic and are experts in the field.

One recently conducted research regarding consumer behaviour found that a lack of knowledge and skills is one of the reasons young adults are not engaged in purchasing sustainable clothing [22]. Taking into account the research results, we defined a hypothesis to explore the difference in knowledge between generations of Slovenian women (baby boomers, X, Y and Z).

Hypothesis 2
We assumed that members of the older generations are more confident in their knowledge and expertise than members of the younger generations.

One research project that emphasised clothing purchasing behaviour in the area of sustainable behaviour focused on the analysis of demographic data, such as age, education and status [31]. In this way, we defined a broader hypothesis to analyse the clothing purchasing behaviour of Slovenian women consumers using other demographic data to ensure comprehensive understanding.

Hypothesis 3
We assumed that clothing purchasing behaviour differs according to demographic data, such as age, marital status, living environment and household income.

2.3 Representativity of the sample

Our plan was to collect 400 completed questionnaires, with at least 100 responses from each generation (Baby boomers, Generation X, Generation Y and Generation Z).
The study was conducted during the first half of 2022. Our objective was achieved and exceeded, as we collected 505 fully completed questionnaires (100 Baby boomers, 129 Generation X, 133 Generation Y and 143 Generation Z) In this way, we obtained some perspective on the research subject for all four generations.

3 Results

The aim of the survey was to gather data about the respondents' awareness about the environmental impact of clothing production and consumption. We asked them three questions to find out how informed they are about the topic, how they rate themselves in terms of knowledge about the topic and whether they consider themselves novices or experts. Respondents answered on a scale of 1 to 7.
First, they rated how informed they are about the topic, ranging from "I am not informed" to "I am well-informed". In the next step, they rated their knowledge of the topic from "I know very little" to "I know a lot". Then they rated their belief on whether they know a lot or a little about the topic. In the third option they rated themselves on a scale from "I am a novice" to "I am an expert".
Table 1 shows that respondents evaluated themselves the highest on a scale from 1 to 7 when these extremes correlated to "I know very little" and "I know very much", respectively. The mean score was 4.53. However, respondents were less confident when choosing between "I am a novice" and "I am an expert". The mean score was 4.22.
In the next step, we took a closer look at the consistency of the answers and compared whether respondents' ratings of how much they know were logically related to their ratings of how well-informed they are. Those who rated themselves as being poorly informed would not be expected to rate themselves as knowing a lot about the topic in question, and vice versa. Those who are well-informed are also expected to know a lot about the topic.
In most cases, we see that respondents who consider themselves well-informed also feel that they know a lot about the environmental impact of clothing production and consumption.
However, cross-tabulating how much they know and how informed they are can reveal some discrepancies. As many as 12.3% of respondents who consider themselves poorly informed claim to know a lot about this area. Moreover, as many as 35.7% of those who stated that they are only moderately well-informed think that they know a lot about the environmental impact of clothing production and consumption, as shown in Table 2. A statistically significant difference was found at Chi-Square 388.8 and p = 0.001.

Table 1: Descriptive statistics for the question "What is your awareness of the impact of clothing production and consumption on the environment?" Answers were given on a scale of 1 to 7.

	1. I know very little" to "I know very much"	2. "I am a novice" to "I am an expert"	3. "I am uninformed" to "I am well-informed"
Number	505	505	505
Mean score	4.53	4.22	4.34

Table 2: Cross-tabulations of respondents' scores of how much they know, linked to their scores of how well-informed they are

How well-informed are they?	How much do they know? (%)		
	Very little	Intermediate amount	Very much
Poorly informed (%)	71.6	16.1	12.3
Moderately well-informed (%)	10.2	54.1	35.7
Well-informed (%)	2	7.9	90.1

Even when showing how the variables cross-tabulate (i.e. how informed the respondents are and their opinions on their level of expertise in this field), the result is similar. Those who stated that they were poorly informed are slightly less likely to be considered experts. However, in the group of respondents who stated that they were moderately well-informed, as many as 20% consider themselves to be experts in the field. The results are shown in Table 3. A statistically significant difference was found at Chi-Square 405.7 and $p = 0.001$.

We also examined how much each generation knows about the environmental impact of clothing production and consumption. The results presented in Table 4 show that the youngest group of respondents, Generation Z, are more reserved in their statements about their knowledge of the topic. They are more likely than the other generations to say that they know a moderate amount. A statistically significant difference was found at a Chi-square of 16.8 and $p = 0.01$.

Table 3: Cross-tabulation of the variables of how informed they are and what kind of experts they are in the field

How well-informed are they?	What kind of experts they are in the field? (%)		
	Inexperienced	Has some experience	Is an expert
Poorly informed (%)	81.3	12.3	6.5
Moderately well-informed (%)	20.4	59.2	20.4
Well-informed (%)	5.6	10.7	83.7

Table 4: Cross-tabulation of variables of age groups with respect to knowledge about the environmental impact of clothing production and consumption

Generation	Knowledge about the environmental impact of clothing production and consumption (%)		
	Knows very little	Knows a moderate amount	Knows very much
Baby boomers (%)	30	12	58
Generation X (%)	20.2	16.3	63.5
Generation Y (%)	20.3	21.1	58.6
Generation Z (%)	30.1	25.8	44.1

Table 5: Comparison of experience concerning the environmental impact of clothing production and consumption between different age groups

Generation	Is inexperienced (%)	Has some experience (%)	Is an expert (%)
Baby boomers (%)	37.0	13.0	50.0
Generation X (%)	24.0	21.7	54.3
Generation Y (%)	23.3	23.3	53.4
Generation Z (%)	42.6	22.4	35.0

We also checked which option best describes their preferences when it comes to the purchase of clothes. The respondents had five options to choose from:

- **Option 1**

The latest fashion trends, as offered by large clothing chains, which often change their store assortments (daily, weekly). Design is important, quality is diverse and the origin of the material is not a key factor. Women who shop there often leave a store with many pieces that they wear only a few times or even never (e.g., H&M, Zara, Reserved, C&A, Orsay and Takko).

- **Option 2**

Clothes offered in smaller shops and boutiques located near the customer's place of residence or employment, or in smaller e-shops that are not widely known. They have a relatively stable and sufficient selection of goods that does not change too frequently. They offer reasonable quality (e.g., Icona, Anna and Broadway).

- **Option 3**

Clothes in second-hand shops, bazaars and/or online platforms. The clothes are of basic quality; have previously been worn by someone else or the clothes on offer are completely new and unworn but belong to previous years' collections. The clothes are offered at a lower price (e.g., Humana, Dajadaja, Krama and Moja tvoja omara).

- **Option 4**

Clothes designed and/or made by local designers or manufacturers. The pieces are timeless and classic, and do not go out of fashion quickly. The quality and origin of the material are very important in this case (e.g., BooPacks, Wearelena, Goodwill, Ihavenofocus, Oblak and By Andraž).

- **Options 5**

Second-hand and/or upcycled clothes that are exceptional, authentic, original and made of natural and ecological materials. The clothes were previously worn, but nevertheless are and appear in very good condition. Not only can those clothes be bought, they can also be rented (e.g., Krinolina, Sanjska obleka, Maja's closet, Naturaland, Terrasleep and Bombažek).

Analysis shows that most respondents (55.6%) still purchase clothes in large fashion clothing chains, where fashion trends change rapidly. In second place (30.3%), respondents placed smaller shops and boutiques located near their place of residence or employment. The other three options combined account for less than 15% (second-hand shops, local stores with classic clothes, rental stores, etc.).

We cross-tabulated the data to determine whether there were significant differences in shopping behaviour between groups of respondents who thought they knew a lot about the environmental impact of clothing and those who knew little or nothing about it.

As evident from Table 7, no one from the groups that know nothing or little about the environmental impact of clothing in the Option 5 group buys second-hand clothing or clothing made from organic materials. Only those who know a lot about the impact buy such clothing. A statistically significant difference was found at a Chi-square of 29.1 and $p = 0.01$ (the zeros in the table have been treated with some caution in the statistical calculation).

Similarly, the purchasing behaviour of groups who identify themselves as experts regarding the environmental impact of clothing is only slightly less pronounced. Those who deem themselves as novices do not buy clothes in the way described in Option 5. Experts, however, stand out again, as can be seen in Table 8.

Table 6: Descriptive statistics on respondents' preferences on where to purchase clothes

Options		Frequency	Valid (%)	Cumulative (%)
Valid	Option 1	281	55.6	55.6
	Option 2	153	30.3	85.9
	Option 3	35	6.9	92.8
	Option 4	21	4.2	97
	Option 5	15	3	100
	Total	505	100	

Table 7: Chi-Square tests on the question "Which one of the following options best describes your preferences when it comes to the purchase of clothes?"

Knowledge about the environmental impact of clothing production and consumption	Option that best describes preference (%)				
	Option 1	Option 2	Option 3	Option 4	Option 5
Knows very little (%)	29.9	21.6	20	9.5	0
Knows a moderate amount (%)	22.8	18.3	8.6	14.3	0
Knows very much (%)	47.3	60.1	71.4	76.2	100

Table 8: Cross-tabulation on the question "Which one of the following options best describes your preferences when it comes to the purchase of clothes?" (the second option from "I am a novice" to "I am an expert")

How identify themselves as experts on the environmental impact of clothing	Option that best describes preference (%)				
	Option 1	Option 2	Option 3	Option 4	Option 5
Is a novice (%)	37.4	28.8	20.0	19.0	0.0
Has some experience (%)	21.4	22.2	11.4	19.0	13.3
Is an expert (%)	41.3	49.0	68.6	61.9	86.7

A statistically significant difference was found at a Chi-square of 24.0 and $p = 0.01$ (the zeros in the table have been treated with some caution in the statistical calculation).

We also tested the hypothesis of whether demographic characteristics influence purchase behaviour. In the first case, we crossed age groups data with purchasing behaviour.

Second-hand and/or recycled clothing is increasingly popular among baby boomers. The data shown in Table 9 give us statistically significant differences at a Chi-square of 29.2 and $p = 0.01$. We can confirm thus our hypothesis about various age groups' purchasing behaviour.

However, in the case of crosses between single and married people, there is no difference in purchasing habits, as shown in Table 10, so we must reject the hypothesis.

Similarly, there is no statistically significant difference between urban and rural residents, as shown in Table 11.

We also checked whether purchasing behaviour differs according to household income. We took a threshold of 2,000 euros per month and divided the respondents into those who have an income below this threshold and those who have an income above this threshold. In this case, as shown in Table 12, we conclude that there are no statistically significant differences, so we must reject the hypothesis.

Table 9: Preferences of different age groups and purchasing clothing options

Generation	Option that best describes preference (%)				
	Option 1	Option 2	Option 3	Option 4	Option 5
Baby boomers (%)	40	42	8	3	7
Generation X (%)	47.3	35.7	7	7.8	2.3
Generation Y (%)	58.6	25.6	8.3	4.5	3
Generation Z (%)	71.3	21.7	4.9	1.4	0.7

Table 10: Comparison of marital status in relation to consumers' purchasing behaviour

Status	Option that best describes preference (%)				
	Option 1	Option 2	Option 3	Option 4	Option 5
Single (%)	2.4	29.3	56.6	3.9	7.8
Married (%)	5.3	31	55	2.3	6.3

Table 11: Comparison of purchasing behaviour of residents

Residence	Option that best describes preference (%)				
	Option 1	Option 2	Option 3	Option 4	Option 5
Rural (%)	5.1	26.4	59.1	3.7	5.7
Urban (%)	2.9	35.9	50.7	1.9	8.6

Table 12: Purchasing behaviour in relation to household income

Household income (EUR)	Option that best describes preference (%)				
	Option 1	Option 2	Option 3	Option 4	Option 5
2,000 or less (%)	3.6	32.5	52.6	3.2	8
more than 2,000 (%)	4.9	27.3	56.6	3.5	7.7
N/A (%)	4.4	29.2	61.1	1.8	3.5

4 Discussion

Consumer behaviour explains why people choose to spend their money, time and effort on the products that companies are trying to sell them [6]. In our contemporary environment, such decisions are increasingly influenced by product sustainability. Consumer behaviour and environmental protection are closely related [31].

However, there has been noted a rise in public awareness of the harmful consequences of senseless clothing production and consumption [14]. Our study clearly highlighted, *inter alia*, the issue of awareness and knowledge about sustainability, which is necessary to change consumer behaviour. The issue has not yet been addressed in this dimension in Slovenia. The results show that respondents generally believe they are knowledgeable about the impact of clothing production and consumption. Moreover, they assessed that they are mostly well-informed and mostly consider themselves experts. Nevertheless, respondents gave themselves the highest scores when assessing their options on a scale from “I know very little” to “I know very much”, and the lowest when assessing themselves as “I am a novice” and “I am an expert. The results were at a relatively high level for both formulations.

Additionally, we examined preferences in terms of purchasing clothes. The number of fast-fashion stores has been increasing in Slovenia [2]. Our study clearly shows that women’s consumption behaviour in Slovenia is based on short-term decision making. Slovenian women prefer to buy a large amount of cheap clothes in large clothing chains, which has long-term negative consequences on the environment.

Furthermore, more detailed analyses were conducted for a more in-depth understanding of clothing purchasing preferences as they relate to knowledge, generations, material status, living environment and household income. In short, below are a few of the main findings. The group that buys second-hand clothing or clothing made with organic materials assessed themselves as knowing a lot about environmental impacts. Second-hand and/or recycled clothing stores are the most popular among baby boomers. In the case of crosses between single and married people, and rural and urban respondents, there is no difference in purchasing behaviour.

5 Conclusion

During the 21st century, we have witnessed an increase in discussions regarding the importance of sustainable growth. The clothing industry has a significant and detrimental impact on the environment. Globalization has widened the industry’s boundaries. Sustainability is undoubtedly one of the factors that influences consumer behaviour. This study investigated customers’ awareness and knowledge concerning the purchasing of clothing in Slovenia. Despite widespread knowledge, there is an urgent need for more education and information-sharing regarding the importance of sustainability in daily life. There are numerous opportunities today to promote sustainability. One is certainly through education [18], another through advertising [31]. The study also examined the contemporary consumption of clothing as it relates to different store types, generations, material statuses, living environments, and household income levels.

Overall, the results of these studies provide a better understanding of Slovenian women's perception of awareness of clothing sustainability and various related factors, as well as difference and similarities related to different demographics.

Despite the fact that this study has made contributions to understanding the issue in question, there are many opportunities for future research. In the study, we limited ourselves to studying Slovenian women's behaviour in purchasing clothing. Moreover, we analysed knowledge and customer preferences using selected demographic segmentation. Future studies should pay greater attention to the motivational elements that influence clothing consumption and gauge how to change behaviour toward more environmentally friendly clothing purchasing and consumption.

It is nevertheless evident that the trend of sustainable fashion is here to stay, despite the powerful and lingering fast-fashion trend. We strongly believe that more studies should be conducted on consumer sustainability behaviour in terms of consumer awareness linked to fostering attitudes and the willingness to buy sustainable clothes.

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Antimicrobial Active Chitosan-Based Cotton Yarns: Effect of Chitosan Solution Concentration

Protimikrobno aktivna s hitozanom obdelana bombažna preja: vpliv koncentracije raztopine hitozana

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Abstract
Using the exhaustion-pad-dry-rinse method, chitosan was applied to alkaline-scoured and bleached cotton yarns in a solution with concentrations ranging from 0.2–1% to achieve good antimicrobial activity against the bacteria *Escherichia coli* (Gram-negative) and *Staphylococcus aureus* (Gram-positive). Studied samples were also assessed by measuring the amount of introduced chitosan, amount of accessible amino groups, mechanical properties, whiteness index and the *b** colour coordinate. Alkaline-scoured and bleached cotton yarns treated with all concentrations of the chitosan solution showed good antimicrobial activity against *Escherichia coli* and *Staphylococcus aureus*. Better antimicrobial activity was achieved against *Escherichia coli*. Increasing the concentration of chitosan solution deteriorated the mechanical properties of chitosan-treated cotton yarns. The optimal concentration of chitosan solution incorporated in the exhaustion phase to obtain chitosan-treated yarns with good antimicrobial activity and mechanical properties was 0.6%. The best antimicrobial treatment should minimise potential economic costs while providing functionality.
Keywords: cotton, chitosan, antimicrobial activity, *Escherichia coli* bacteria, *Staphylococcus aureus* bacteria

Izvleček
Hitozan je bil v raztopini s koncentracijo od 0,2–1 % nanesen na alkalno izkuhano in beljeno bombažno prejo z izčrpalno-impregnirnim postopkom z naknadnim sušenjem in spiranjem, da bi dosegli dobre protimikrobne aktivnosti proti bakterijama Escherichia coli (Gram negativna) in Staphylococcus aureus (Gram pozitivna). Vzorce smo preučevali z merjenjem količine uporabljenega hitozana, količine dostopnih aminoskupin, mehanskih lastnosti, indeksa beline in barvne koordinate b. Kljub temu, da je alkalno izkuhana in beljena bombažna preja v vseh koncentracijah raztopine hitozana pokazala dobro protimikrobno aktivnost proti bakterijama Escherichia coli in Staphylococcus aureus, je bila protimikrobna aktivnost boljša proti bakteriji Escherichia coli. Mehanske lastnosti bombažne preje, obdelane s hitozanom, so se poslabšale, ko smo povečevali koncentracijo hitozana v raztopini. Optimalna koncentracija raztopine*

hitozana, ki je bila vključena v fazo izčrpavanja, da bi pridobili s hitozanom obdelano prejo, ki ima dobro protimikrobno aktivnost in mehanske lastnosti, je bila 0,6 %. Dobra protimikrobna obdelava bi morala zmanjšati morebitne stroške in hkrati zagotavljati funkcionalnost.
Ključne besede: bombaž, hitozan, protimikrobno delovanje, Escherichia coli, Staphylococcus aureus

1 Introduction

The need for environmentally justified antimicrobial textiles is particularly interesting, especially in the medical sector [1, 2]. The increase in the world's population, the interest in a safer, healthier and more comfortable environment, awareness and expectations regarding hygiene and healthcare standards (protection from microorganisms) significantly influence the daily development of bioactive materials [3]. Textile materials in the course of application in healthcare institutions, especially in operating rooms, for medical staff and hospital patients, represent a significant source of bacteria and infections [4]. Microbiologically contaminated textiles represent a potential opportunity for a further deterioration of patient's health status and disruption of medical personnel's health status.
An antimicrobial textile is a textile material that acquires antimicrobial properties after being treated with an agent which carries antimicrobial properties. Textiles made of cotton fibres are in constant contact with microorganisms from the environment, especially in healthcare institutions. Due to their surface area and ability to retain moisture, they are an ideal substrate for developing microorganisms that reproduce and grow [5]. Textiles of natural origins, e.g. cotton, are more susceptible to the action of microorganisms than textiles of synthetic origin due to their porous hydrophilic structure that retains water, oxygen, and nutrients that represent ideal conditions for their growth and development. To date, various types of antimicrobial agents can be found on the market, e.g. inorganic salts and salts of organic compounds, iodoform, phenols, thiophenols, antibiotics, triclosan, polyhexamethylene biguanide (PNMB), quaternary ammonium compounds, derivatives of formaldehyde and amines [5, 6]. However, many of these agents are toxic and non-biodegradable; therefore, efforts are being made to replace them with agents with antimicrobial activity of natural origin. Natural antimicrobial agents can be of animal (chitin, chitosan, lysosomes and lactoperoxidase), vegetable (essential oils, aldehydes, esters, plants) and microbiological (nisin) origin [7].
As one of the antimicrobial agents of animal origin, chitosan has several advantages over other natural antimicrobial agents. These are high antimicrobial activity, a broad spectrum of action, a high degree of inhibition of microorganisms and low toxicity to human cells [8].
Sources of chitosan, with high economic justification, are the secondary products of the seafood processing industry [5]. It is produced on a large scale in different parts of the world (Japan, North America, Poland, Russia, Italy, Norway and India) [8]. Chitosan is obtained from chitin with its deacetylation. Structurally, chitin is a polysaccharide composed of N-acetyl-D-glucosamine, GlcNAc ($C_8H_{15}NO_6$) repeating units linked by β-(1→4) glycosidic linkages, while technically, the structure of chitin is similar to cellulose and can be considered as cellulose in which the hydroxyl group (-OH) of the C-2 atom is replaced by an acetamido group ($-NHCOCH_3$). Chitosan is a derivative of chitin, obtained with the deacetylation of chitin (40–45% NaOH, 120 °C, 1–3 h), and a linear polycationic heteropolysaccharide composed of N-acetyl-D-glucosamine, GlcNAc, and D-glucosamine, GlcN, linked by β-(1→4) glycosidic bonds. The reactivity of chitosan is due to the amino group on the C-2 atom and the two hydroxyl groups on the C-3 and C-6 atoms [9]. The ratio between GlcNAc and GlcN units in chitosan represents the degree of deacetylation and depends on the deacetylation conditions. It increases by increasing the NaOH concentration, deacetylation temperature and time, and decreasing molecular weight. Chitin solvents are toxic and corrosive; thus, chitosan is used for commercial use. Chitosan is obtained by deacetylating chitin above 60%, which dissolves in dilute acids. Chitosan is insoluble in water, alkalis and organic solvents, and forms water-soluble salts with organic (acetic, formic, lactic, glutamic and maleic) and inorganic (hydrochloric) acids. The solubility of chitosan is a consequence of amino groups [10] and is pH dependent. Chitosan forms a viscous solution depending on the degree of deacetylation, molecular mass,

concentration and type of solvent, pH environment and temperature [9]. Using chitosan in any physical form depends on its physicochemical properties, e.g. colour, degree of polymerisation, degree of deacetylation, crystallinity, molecular weight, solubility and chemical reactivity. The biological properties of chitosan arise from its polycationic nature, which depends on the degree of deacetylation and molecular weight.

Research groups have outlined the antimicrobial activity of chitosan and its derivatives, and the mode of antimicrobial action and application of chitosan and its derivatives [8–11]. Many studies have focused on the bonding of chitosan with cellulose, and the discussion on antimicrobial textiles has been primarily focused on defining the type of bond and condition for their formation [12–14]. For instance, several published studies have focused on viscose, lyocell and modal fibre to analyse and evaluate their antimicrobial activity after being treated with chitosan [15–17]. In that, mainly the tests with a 1% concentration of chitosan solution for treatment were performed [13, 15–18]. To properly inform the evaluation and selection of chitosan solution concentration for textiles, it should be noted that an adequately selected concentration of chitosan solution is desirable for achieving the required antimicrobial activity. Therefore, an optimal concentration of chitosan solution incorporated in the cotton yarns treatment bath needs to be obtained that will yield higher percentage of bacteria reduction while minimising potential economic costs.

The present work aimed to study the antimicrobial activity of alkaline-scoured and bleached cotton yarns treated with different concentrations of chitosan solution incorporated in the application method. In addition to the antimicrobial activity, the tested samples were also examined for the amount of introduced chitosan, the amount of accessible amino groups, mechanical properties, whiteness index and the *b** colour coordinate. The surface of examined samples was also monitored with SEM and FTIR-ATR techniques.

2 Materials and methods

2.1 Materials

Piled, ring-worsted cotton yarns with 30 × 2 tex linear density and 330 twists/m were used. Commercially available chitosan samples with low molecular weight of 50000–190000 Da (g/mol) and deacetylation degree (DD) of 75–85% (denoted as ChL) were used to treat cotton yarns. Chitosan was used without further purification. *Escherichia coli* (ATCC 25922) and *Staphylococcus aureus* (ATCC 29219) bacteria obtained from American Type Culture Collection (ATCC) were used for the antibacterial activity test. The acetic acid and C.I. Acid Orange 7 were analytical grades purchased from Sigma-Aldrich (USA). Cotoblanc HTD (N-anionic surfactant) and Kemonecer NI (nonionic surfactant) were purchased from CHT and Kemo (Croatia), respectively.

2.2 Treatment Process

Pre-treatment of cotton yarns

Cotton yarns were pre-treated with alkaline scouring and bleaching processes before being treated with chitosan [19, 20]. Scouring was conducted in a bath with 30 : 1 LR using 20 g/dm^3 NaOH in the presence of 2 cm^3/dm^3 Cotoblanc HTD-N and 1 cm^3/dm^3 Kemonecer NI at 95 °C for 90 min. Bleaching was done in a bath with 30 : 1 LR, using 6 cm^3/dm^3 H_2O_2 (30%), 1 cm^3/dm^3 Kemonecer NI, 2 cm^3/dm^3 Na_2SiO at pH 11.2 at 95 °C for 30 min.

Chitosan treatment

The chitosan solution with 0.2, 0.6, and 1% (w/v) concentrations was prepared in 1% (v/v) CH_3COOH for 60 min at 60 °C followed by constant stirring; pH was adjusted to 4–4.5 by adding 95% acetic acid. The prepared chitosan solution was applied to the pre-treated cotton yarns using the exhaustion-pad-dry-rinse (EPDR) application method. A pre-treated sample (10 g) was immersed in the 300 cm^3 chitosan solution with stirring at 60 °C for 120 min. After the exhaustion phase, the sample was padded at 80% on a padding machine, dried at 60 °C for 12 h, rinsed five times at 20 °C for 10 min and dried at room temperature.

2.3 Methods

Determination of weight add-on

Before the testing, all samples were conditioned in a standard atmosphere (temperature 20 °C and 65% relative humidity) for 24 h to be identically acclimatised. The percentage add-on of cotton yarns after the chitosan treatment (i.e. the increase in sample weight relative to original weight) was determined with the gravimetric method with equation 1.

$$\Delta W\ (\%) = \frac{(W_2 - W_1)}{W_1} \times 100 \quad (1)$$

where: ΔW is weight add-on, W_1 is sample weight before the treatment with chitosan, and W_2 is sample weight after the treatment with chitosan.

Spectrophotometric C.I. Acid Orange 7 method

This method is based on the absorption of the dye C.I. Acid Orange 7 with the principle of reducing the dye concentration in the dye bath following the Lambert-Beer Law [16]. Sulfonic groups (SO_3^-) of the dye form within the acidic medium ionic bonds in the ratio 1 : 1 with the positively charged amino groups of chitosan (NH_3^+); therefore, the amount of the dye bound to fibres corresponds to the amount of accessible amino groups [16]. A 0.2 g sample was soaked in 100 cm^3 acetate buffer at pH 4 (0.5 g/dm^3 CH_3COONa+0.5 g/dm^3 CH_3COOH glac.) in the presence of 0.02 g/dm^3 C.I. Acid Orange 7 at 30 °C for 3 h. The maximum wavelength of absorbency (λ_{max} = 484 nm) of C.I. Acid Orange 7 dye solution was measured using a Perkin Elmer Lambda 2 UV-VIS spectrophotometer. For the calibration of standard solutions, a dye stock solution was prepared.

Measurement of colour strength (K/S)

The colour strength (K/S) of samples dyed with C.I. Acid Orange 7 was measured by using X-Rate Color i7 at maximum wavelength of absorbency (λ_{max}). It was calculated using the built-in software of the computer colour matching system according to the Kubelka-Munk equation given in equation 2.

$$\frac{K}{S} = \frac{(1 - R)^2}{2R} \quad (2)$$

where: K is the absorption coefficient, S is the scattering coefficient and R is the reflectance value of the dyed sample at the wavelength at maximum absorption.

Fourier transform infrared spectroscopy-attenuated total reflectance (FTIR-ATR)

The FTIR-ATR spectroscopy was performed on a FTIR-ATR Perkin Elmer Spectrum GX 69876 spectrometer. 16 scans at the resolution of 4 cm^{-1} were recorded for each sample between 4000 cm^{-1} and 650 cm^{-1}.

Scanning electron microscopy (SEM)

The characterization of surface morphology with scanning electron microscopy (SEM) was conducted on a JEOL JSM-6060 LV (Japan) electron microscope operating at an accelerating voltage of 10 kV and magnification of 5000× on samples previously coated with gold in a scatter coater.

Antimicrobial activity

The antimicrobial activity of samples against *Escherichia coli* ATCC 25922 (Gram-negative bacteria) and *Staphylococcus aureus* ATCC 29219 (Gram-positive bacteria) was quantitatively determined according to the standard AATCC Test Method 100:2004. A 2 g sample was soaked in 57 cm^3 nutrient broth inoculated with the bacterium (1.5–3.0 × 10^5 CFU/ml) and incubated at 37 °C for 60 min. After a series of dilutions of the bacterium, the plates were inoculated and incubated at 37 °C for 24 h. Later, surviving cells were counted. The average values of duplicates were converted to CFU/ml in flasks by multiplying by the dilution factor. The antimicrobial activity was expressed in the percentage reduction of organisms after contact time with the test specimen compared to the number of bacterial cells surviving after the contact with the control according to equation 3.

$$Reduction\ (\%) = \frac{B - A}{B} \times 100 \quad (3)$$

where: A is CFU/ml after contact (end test), and B is CFU/ml at zero contact time.

Mechanical properties

Tensile strength (F_a), elongation at break (ε) and work of rupture (A) were measured on a Tinus Olsen (SDL ATLAS) instrument according to the EN ISO 2062:2009 standard using the test speed of 100 mm/min and gauge length of 300 mm. The presented results are the mean value of 10 measurements at a confidence level of 95%.

Whiteness index and b^* colour coordinate

The whiteness index and b^* colour coordinate (yellowness) were measured according to the ISO 105-J02:1999 and ISO 105-J01:1997 standards, respectively, on an XRate 7i spectrophotometer under illuminant D65 and using the 10° standard observer. For each fabric sample, 10 measurements were performed at a confidence level of 95%, and the mean value (M) and standard deviation (SD) were presented as the result.

3 Results and discussion

The pre-treatment process removed non-cellulose components from cotton yarns and influenced their surface functional group; therefore, it was proven that alkaline-scoured cotton yarns possess lower carboxyl and aldehyde group amounts than enzymatic-scoured cotton yarns [21, 22]. Thus, to remove all non-cellulosic components from cotton yarns, rigorous alkaline scouring and bleaching processes were conducted, and the amount of carboxyl and aldehyde groups of these yarns determined with the calcium acetate method was 60 and 10 mmol/kg, respectively [19, 20]. The alkaline-scoured and bleached cotton yarns used in our previous research were employed in the present work for monitoring the effect of chitosan solution concentration incorporated in the exhaustion phase on the antimicrobial activity of chitosan-treated cotton yarns. The exhaustion phase was the first phase of the chitosan application method used in this research, which included the following phases: exhaustion, pad, dry and rinse. The amount of introduced chitosan onto alkaline-scoured and bleached cotton yarns after the treatment with different concentrations of chitosan solution (from 0.2 to 1%) is shown in Figure 1. Chitosan has an affinity to absorb onto cellulose due to its similar nature [23]. It was observed that the amount of introduced chitosan onto pre-treated cotton yarns increased by increasing the concentration of chitosan solution from 0.2 to 1%. Pre-treated cotton yarns showed after the chitosan treatment (Figure 1) an introduced amount of chitosan of 2.5% at 0.2% concentration of chitosan solution. The amount of introduced chitosan onto pre-treated cotton yarns increased up to 7.51% with the increase in the concentration of chitosan solution in the exhaustion bath at 1%.

The amount of accessible amino group of chitosan-treated cotton yarns was determined with dyeing with Acid Orange 7 (an acidic dye that reacts with protonated amino groups). The amount of accessible amino groups determined by the colour strength after the dyeing of chitosan-treated cotton yarns (K/S) and the amount of accessible amino groups determined with the exhaustion method of the same dye (NH_2, mmol/kg) are shown in Table 1.

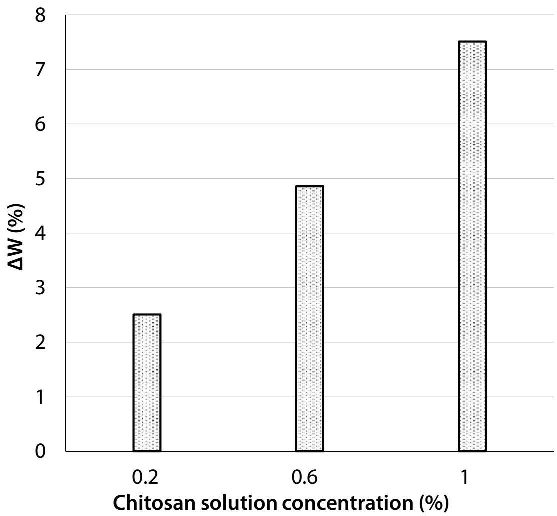

Figure 1: Amount of introduced chitosan onto alkaline-scoured and bleached cotton yarns after treatment with different concentrations of chitosan solution

The results indicate that increasing the concentration of chitosan solution increased the amount of accessible amino groups onto chitosan-treated cotton yarns. A larger amount of accessible amino groups gives a higher K/S value [24]. Chitosan-treated samples having lower K/S values indicated less accessible amino groups that can react with the negatively charged groups of the anionic dye.

Table 1: Amount of accessible amino groups onto alkaline-scoured and bleached cotton yarns treated with different concentrations of chitosan solution

Concentration of chitosan solution (%)	K/S	NH_2 (mmol/kg)
0.2	1.03	19.78
0.6	3.70	20.27
1.0	5.93	20.75

The samples were analysed by SEM concerning their surface morphology. Comparing the SEM images of alkaline-scoured and bleached cotton yarn and chitosan-treated yarn, as reported in Figure 2, the presence of chitosan was clear. The alkaline-scoured and bleached cotton yarn (Figure 2, AB) had clearly expressed fibrils on the surface of the fibre or completely removed the cuticle, while after the treatment with chitosan, the surface became smooth (Figure 2, AB-ChL). On chitosan-treated samples, no agglomerated chitosan was present on the surface, denoting the good

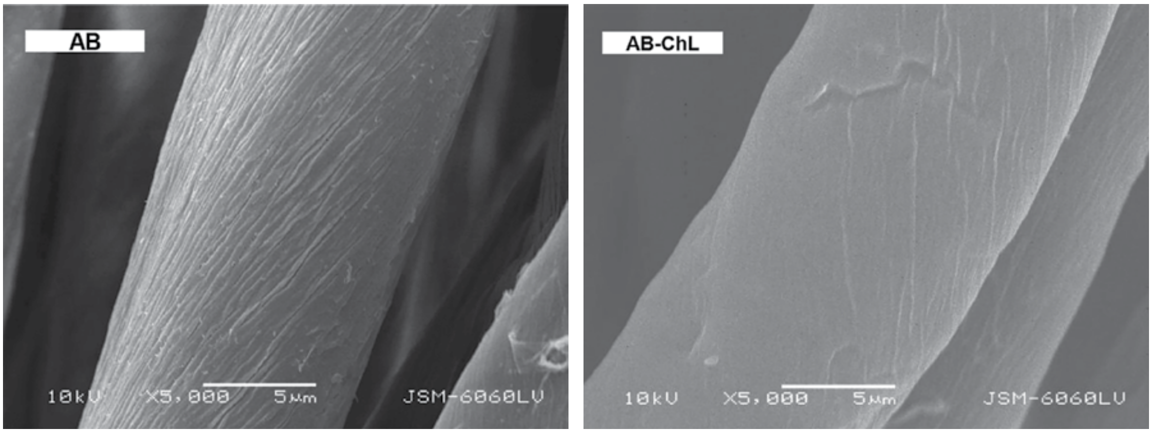

Figure 2: SEM images of surface of alkaline-scoured and bleached cotton yarns (AB) treated with 0.6% concentration of chitosan solution (AB-ChL)

quality of the chitosan solution and the effectiveness of the treatment.

The surface changes of pre-treated cotton yarns after the chitosan treatment were also observed from the FTIR-ATR spectra, which are given in Figure 3. Chitosan and cotton have similar FTIR-ATR spectra [23]. Alkaline-scoured and bleached cotton yarns (AB) showed characteristic FTIR-ATR spectra of cellulose. The presence of chitosan was confirmed by the increase of the 3295 cm^{-1} peak characteristic of ν(NH), ν(OH), and $ν(NH_2)$ and the increase of 2922 cm^{-1} and 2854 cm^{-1} peaks characteristic of ν(C-H). In addition, the increase in the peaks at 1655 cm^{-1} (C = O, amide I) and 1550 cm^{-1} (N-H, amide II) (Figure 3), characteristic of the chitosan presence [25, 26], was observed. Depending on the degree of deacetylation, the peak at 1550 cm^{-1} can also appear at 1604 cm^{-1}, 1598 cm^{-1} or 1592 cm^{-1} [27]. The addition of chitosan to the pre-treated sample showed the appearance of the peak at 1720 cm^{-1} attributable to the $-COO^-$ anion of the carboxyl group suggesting the existence of a polyelectrolyte complex formed by the interaction between the chitosan amino groups and the carboxylic group of alkaline-scoured and bleached cotton samples. The scouring and bleaching processes remove non-cellulosic components, making acidic groups more available to increase the negative values of ζ-potential [20]. The peak at 1720 cm^{-1} originates from a combination of asymmetric COO^- and NH_3^+ stretching vibrations of the formed carboxylate complex [27].

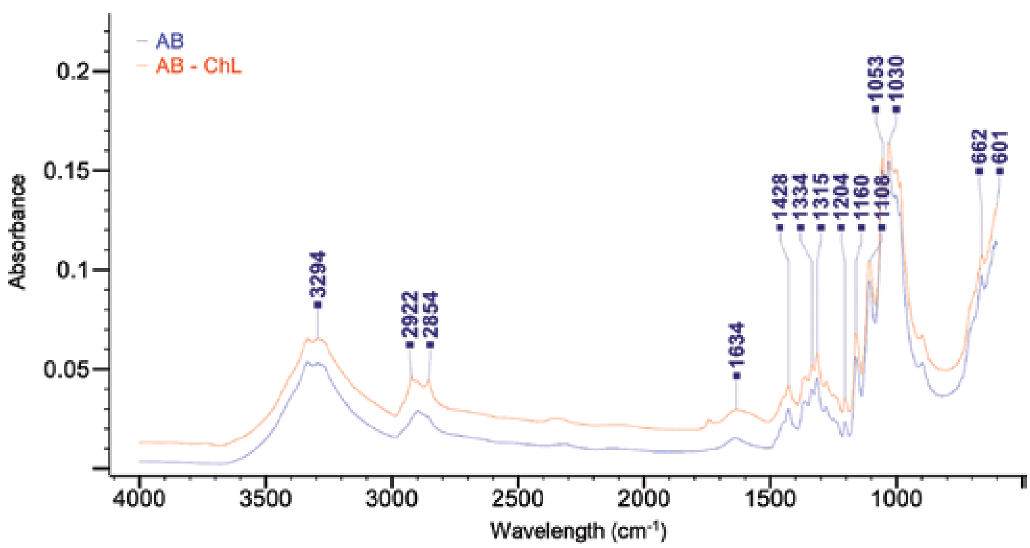

Figure 3: FTIR-ATR spectra of surface of alkaline-scoured and bleached cotton yarns (AB) treated with 0.6% concentration of chitosan solution (AB-ChL)

Chitosan contains amino groups responsible for its reactivity and antimicrobial activity [9]. The antimicrobial activity of chitosan-treated cotton yarns on the percentage reduction in CFU against *Escherichia coli* (Gram-negative bacteria) and *Staphylococcus aureus* (Gram-positive bacteria) is shown in Figure 4. Textile materials with an effective antimicrobial activity reduce the Gram-negative and Gram-positive bacteria by more than 70% [16, 28]. It was observed that regardless of the chitosan solution concentration, the chitosan-treated cotton yarns showed over 75% reduction in the number of CFU against both *Escherichia coli* and *Staphylococcus aureus*, indicating excellent antimicrobial activity of chitosan solution even at a low concentration of 0.2% (Figure 4). At 0.6% concentration of chitosan solution, the reduction rate increased to 91.74% for *Staphylococcus aureus*. The reduction increased up to 99.64% against *Escherichia coli* with the increase in the concentration of chitosan solution to 1%. The accessible amino groups of chitosan react with hydrogen ions and give NH_3^+ cations, which react with the negative charge from the surface of the bacterial cell, leading to the emission of intracellular components and disruption of cell functions [11]. The antimicrobial activity was greater against *Escherichia coli* than against *Staphylococcus aureus* (Figure 4). The mode of the antibacterial activity is a complex process that differs in Gram-positive and Gram-negative bacteria due to the differences in the bacterial cell surface [9]. According to some studies, cotton treated with chitosan has a higher antimicrobial activity against Gram-positive (*Staphylococcus aureus*) bacteria compared to Gram-negative (*Escherichia coli*) bacteria [28]. According to other research, the general trend is that chitosan-based antimicrobial textiles inhibit the growth of Gram-negative bacteria more than of Gram-positive bacteria [11].

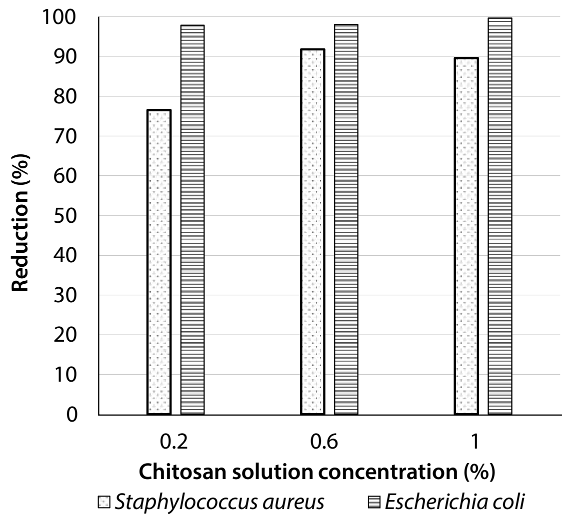

Figure 4: Reduction percentage in number of CFU against Staphylococcus aureus and Escherichia coli of cotton yarns treated with different concentrations of chitosan solution

The effect of chitosan treatment with different concentrations of chitosan solution on the mechanical properties of alkaline-scoured and bleached cotton yarns is shown in Table 2. Increasing the amount of chitosan introduced onto pre-treated cotton yarns was accompanied by decreased tensile strength, elongation at break and work of rupture after the chitosan treatment. Compared with alkaline-scoured and bleached cotton yarns, the tensile strength and work of rupture of chitosan-treated cotton yarns obtained with 0.2% concentration of chitosan solution decreased by 20%, while elongation at break decreased by 1%. The loss in tensile strength of pre-treated cotton yarns after the chitosan treatment was related to the acidity of the solution of chitosan treatment (chitosan dissolved in 1% acetic acid solution), which causes the depolymerisation of cellulose macromolecules [18].

Table 2: Tensile strength, elongation at break, and work of rupture of alkaline-scoured and bleached cotton yarns treated with different concentrations of chitosan solution

Concentration of chitosan solution (%)	Mechanical properties					
	F_a (N)		ε (%)		A (mJ)	
	M	SD	M	SD	M	SD
0.0	9.67	0.72	16.22	2.31	159.40	0.02
0.2	7.77	0.64	16.09	1.02	127.93	0.02
0.6	8.49	0.54	14.97	2.09	133.62	0.01
1.0	7.98	0.38	14.91	2.31	122.29	0.02

Table 3: Whiteness index and b colour coordinate of alkaline-scoured and bleached cotton yarns treated with different concentrations of chitosan solution*

Concentration of chitosan solution (%)	WICIE		b^*	
	M	SD	M	SD
0.0	76.24	1.02	0.95	0.06
0.2	73.15	1.84	1.73	0.07
0.6	60.43	0.88	3.27	0.07
1.0	40.72	0.97	4.85	0.09

The changes in whiteness index and b^* colour coordinate (yellowness) of alkaline-scoured and bleached cotton yarns treated with different concentrations of chitosan solution were observed as well. The whiteness index and yellowness of tested samples are shown in Table 3. Increasing the concentration of chitosan solution reduced the whiteness index and increased the yellowness of chitosan-treated cotton yarns, which was noticed from the increased values of the b^* colour coordinate. The thermal stability of chitosan may also contribute to reducing the whiteness index in chitosan-treated cotton yarns. As the temperature increases, the colour of chitosan changes, indicating that heating causes the degradation of chitosan [29]. In our research, the temperature of the drying phase was 60 °C. This drying temperature decreased the whiteness index and increased the yellowness (b^* value) of cotton yarns treated with a higher concentration of chitosan solution.

4 Conclusion

The antimicrobial textile obtained from chitosan and cotton yarns was prepared using the exhaustion-pad-dry-rinse application method. Different concentrations of chitosan solution incorporated in the exhaustion phase were used. The chitosan-treated cotton yarns were investigated using the introduced chitosan, the amount of accessible amino groups, and the antimicrobial activity against *Escherichia coli* (Gram-negative bacteria) and *Staphylococcus aureus* (Gram-positive bacteria). SEM and FTIR-ATR techniques were used to examine the surface of tested samples. The mechanical properties, whiteness index and b^* colour coordinate were determined as well. The data confirmed a significant increase in the amount of introduced chitosan and the amount of accessible amino groups when the concentration of chitosan solution from 0.2% to 1% was applied on alkaline-scoured and bleached cotton yarns, which also led to a smooth surface as illustrated by SEM and increased peaks (amide I and amide II) corresponding to the presence of chitosan shown by FTIR-ATR. All concentrations of chitosan solution showed good antimicrobial activity of chitosan-treated cotton yarns against *Escherichia coli* and *Staphylococcus aureus* (by more than 75%). The antimicrobial activity was found to be more effective against *Escherichia coli*. Chitosan caused changes in the mechanical properties, whiteness index and b^* colour coordinate (yellowness) of pre-treated cotton yarns; thus, a slight decrease in the mechanical properties and whiteness index and, consequently, an increase in the b^* value was noticed. The optimal concentration of chitosan solution for applying chitosan and obtaining antimicrobial-active chitosan-based cotton yarns with good antimicrobial activity was 0.6%. A successful treatment of chitosan onto cellulose is opening the way for several applications where the properties of biocompatibility and antimicrobial activity may be combined.

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Investigation of Bleaching of Cotton Fabrics with UV-TiO_2
Raziskava beljenja bombažnih tkanin z UV-TiO_2

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Abstract
Titanium dioxide exhibits photocatalytic properties under ultraviolet (UV) irradiation. In this study, an environmentally friendly, fast and efficient technique for bleaching cotton fabrics is presented, utilising the photocatalytic property of TiO_2. Raw cotton fabric samples were treated with TiO_2-containing and TiO_2-free treatment solutions (hydrogen peroxide and sodium hydroxide) under UV irradiation in order to bleach the samples. The results showed that cotton fabrics treated with TiO_2 were bleached satisfactorily without severe strength loss.
Keywords: ultraviolet, photocatalytic, TiO_2, cotton

Izvleček
Titanov dioksid kaže fotokatalitične lastnosti pri ultravijoličnem (UV) obsevanju. V tej študiji je predstavljena okolju prijazna, hitra in učinkovita metoda beljenja bombažnih tkanin z uporabo fotokatalitskih lastnosti TiO_2 Vzorci surove bombažne tkanine so bili obdelani z raztopinami vodikovega peroksida in natrijevega hidroksida, ki so vsebovale TiO_2 oziroma bile brez TiO_2, ter nato UV osvetljevani, da bi jih pobelili. Rezultati so pokazali, da so bile bombažne tkanine, obdelane s TiO_2, zadovoljivo pobeljene brez večje izgube trdnosti.
Ključne besede: ultravijolično, fotokatalitično, TiO_2, bombaž

1 Introduction

Cotton is the most widely used natural fibre, which is prised for its satisfactory comfort, soft touch, water absorbency, strength and easy maintenance properties [1]. Cotton fibres generally consist of 82–96% cellulose, 0.5–1% lignin, 2–6% hemicellulose and 5–7% pectin [2]. Raw cotton exhibits its hydrophobic character due to the waxy layer and pectin on it, which affects cotton finishing and dyeing processes [3].
The bleaching process is used to remove the impurities from cotton fibres. High temperatures (98 °C) and high concentrations of hydrogen peroxide (H_2O_2) are typically used in the bleaching process [4]. H_2O_2 likely breaks down the double bonds in the colour forming components of cotton into colourless fragments [5, 6]. High temperatures required in H_2O_2 bleaching increase the energy costs. In addition, peroxide bleaching effluent raises the pH value of the factory downstream and adds trace amounts of H_2O_2 and stabilizers to it [7, 8]. Energy conservation, waste control and chemical recovery became emerging issues, resulting in an increase of research for more environmentally friendly technologies.
Photocatalysis is a photochemical method, in which UV irradiation energy is converted to chemical energy, forming radicals and similar unstable chemical structures. In photocatalytic oxidation processes, hydroxyl radicals (•OH) and superoxide radical anions (O_2^-) are believed to be the primary oxidising

species [9]. Eren [10] reported that the H_2O_2 treatment under UV irradiation was successful for cotton bleaching as an Advanced Oxidation Process (AOP) [10]. The main oxidant in H_2O_2/UV AOP is the hydroxyl radical (•OH) formed under the UV irradiation of the H_2O_2 solution.

Titanium dioxide (TiO_2) is reported to exhibit self-cleaning and photocatalytic effects, and have the ability to modify surfaces when exposed to ultraviolet irradiation. TiO_2 is a non-toxic chemical and it has reasonable stability with a well-positioned valence, which makes this material important for catalytic reactions [11]. Furthermore, the redox potential of TiO_2 (2.9 eV), which is higher than that of the widely used oxidant H_2O_2 (1.77 eV), contributes to its use as a photocatalyst [12, 13]. When TiO_2 particles are subjected to UV irradiation (100–400 nm), electrons are transferred from the valence band to the conduction band to create electron-hole pairs that react with nearby oxygen or water molecules to form radicals that can oxidise various substances [14]. There are many studies in the literature reporting the photocatalytic property of TiO_2 under UV irradiation [11, 15–17]. The reactions associated with the photocatalytic effect of titanium dioxide are as follows [18, 19]:

$$TiO_2 + h \rightarrow TiO_2\,(e^- + h^+) \quad (1)$$
$$TiO_2\,(e^-) + O_2 \rightarrow TiO_2 + \bullet O_2^- \quad (2)$$
$$TiO_2\,(e^-) + \bullet O_2^- + 2H^+ \rightarrow TiO_2 + H_2O_2 \quad (3)$$
$$TiO_2\,(e^-) + H_2O_2 \rightarrow TiO_2 + \bullet OH + OH^- \quad (4)$$
$$TiO_2\,(h^+) + H_2O_{ads} \rightarrow TiO_2 + \bullet OH_{ads} + H^+ \quad (5)$$

In this study, raw cotton fabric samples were bleached by applying H_2O_2 + NaOH, TiO_2 alone, TiO_2 + H_2O_2 and TiO_2 + H_2O_2 + NaOH under UV irradiation. The aim of the study was to bleach a cotton fabric at room temperature using UV light. Whiteness, air permeability, strength values, scanning electron microscope (SEM) analysis and Fourier transmission infrared spectroscopy (FTIR) analysis of the treated samples were compared to the untreated samples.

2 Materials and methods

2.1 Materials

A plain woven 100% cotton fabric weighing 104 g/m^2 was used in the experiments. The warp and weft densities of the fabric were 20 warp/cm and 20 weft/cm, respectively. Warp yarns contained the carboxymethyl cellulose (CMC) sizing agent. Hydrogen peroxide (H_2O_2) (Merck, Germany), sodium hydroxide (NaOH) (Merck, Germany) and titanium (IV) oxide extra pure (Tekkim Kimya, Turkey) were used during the experiments.

The experiments were conducted in a specially designed UV cabinet (Figure 1). The size of the cabinet was 100 cm × 70 cm × 138 cm. The UV cabinet was equipped with 18 UV lamps on both sides and the top of the cabinet with a total power of 470 W. The wavelength of the UV lamps was 254 nm.

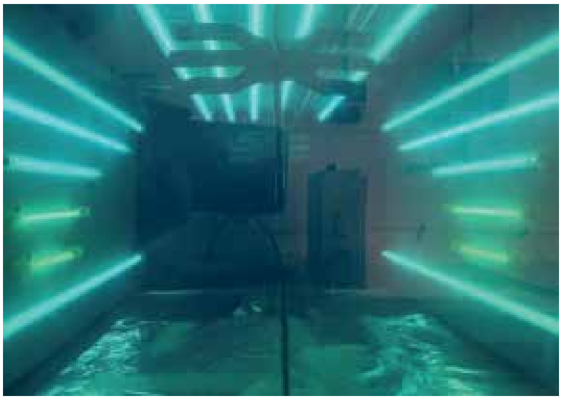


Figure 1: UV cabinet setup

2.2 Methods

A suspension solution (T) was prepared by adding 30 g of TiO_2 to 1000 mL of distilled water. The photocatalytic treatment solutions were prepared by adding 50 g/L of H_2O_2 (T+H) or 50 g/L of H_2O_2 and 30 g/L of NaOH (T+H+N) to the suspension solution (Table 1) [17]. In addition, a control treatment solution (H+N) was also prepared with a mixture of 50 g/L of H_2O_2 and 30 g/L of NaOH without TiO_2. All solutions were prepared at room temperature (20 °C). Hence, five types of cotton fabric samples were obtained: raw (R), H_2O_2 + NaOH treated (H+N), TiO_2 treated (T), TiO_2 + H_2O_2 treated (T+H), and TiO_2 + H_2O_2 + NaOH treated (T+H+N) samples.

Table 1: Types and contents of treatment solutions

Treatment solution	Solution content
H+N	50 g/L H_2O_2 + 30 g/L NaOH
T	30 g/L TiO_2
T+H	30 g/L TiO_2 + 50 g/L H_2O_2
T+H+N	30 g/L TiO_2 + 50 g/L H_2O_2 + 30 g/L NaOH

The samples were immersed in the treatment solution and passed through the foulard to adjust a wet pick-up of 100%. After impregnations, the samples were placed in the UV cabinet, hanging in the centre of the cabinet. The impregnated samples were processed in the UV cabinet for different treatment times (15 min, 30 min, 45 min and 60 min). A subsequent rinsing was applied to the samples with distilled water to remove any residual chemicals. All experiments were repeated 3 times.

2.3 Analysis of samples

Determination of whiteness

The whiteness values (Stensby) of samples were measured according to ASTM D1925, using a Konica Minolta CM 3600d spectrophotometer (Tokyo, Japan).

Air permeability

The air permeability tests of fabric samples were performed under standard laboratory conditions (20 °C ± 2 °C temperature; 65% ± 2% relative humidity). The tests were performed in an SDL Atlas Digital Air Permeability Tester (Model M 021A) according to the ISO 9237 standard (ISO 9237). The selected test pressure was 100 Pa and the test area was 5 cm^2.

Tensile strength measurements of fabrics

Tensile testing was performed according to ISO 13934:1999 on a Shimadzu Model AG-X-Plus Tensile Tester (Kyoto, Japan) under standard laboratory conditions (20 °C ± 2 °C temperature; 65% ± 2% relative humidity).

SEM analysis

Scanning electron microscope (SEM) images were taken to observe the surface morphology of the TiO_2 treated and raw fabric samples. The images were taken using the in-house method at 1000× magnification.

Fourier transmission infrared spectroscopy (FTIR) analysis

The FTIR-ATR spectra of the raw fabric and the fabric coated with TiO_2 alone were measured with a Shimadzu instrument in the range of 500–4000 cm^{-1}.

3 Results and discussion

3.1 Determination of whiteness

The whiteness values of samples were measured in order to see the effects of respective treatments and evaluate the photocatalytic effect of TiO_2 under UV irradiation. The results are presented in Figure 2. The whiteness values of all samples treated with TiO_2 containing solutions under UV irradiation were higher than the whiteness values of samples treated with the same solutions without UV irradiation. These results show the successful photocatalytic effect of TiO_2. Supporting this, it was observed that the whiteness of the H+N samples under UV irradiation and the whiteness of the H+N samples without UV irradiation did not significantly differ.

Figure 2 shows that the raw fabric has a whiteness degree of 47.22 Stensby, while the T+H and UV treated samples (60 min treatment time) have the best whiteness degree of 69.18 Stensby. The highest whiteness degrees were achieved with the T+H treatment under UV irradiation. Considering the processing times, the T+H samples yielded Stensby whiteness degrees of 62.29, 65.65, 68.60 and 69.18 for 15, 30, 45 and 60 min treatment times, respectively. These results show that the degree of whiteness increases as the process time increases. It was observed that the whiteness degrees of samples coated only with TiO_2 under UV irradiation also increased but could not reach the whiteness achieved by the T+H treatment. It was seen that after 60 minutes of processing, the whiteness degree of the samples coated only with TiO_2 reached 61.00 Stensby. In addition, the whiteness degree of the samples treated with the T+H+N recipe was close to the whiteness degree of the samples treated only with samples coated only with TiO_2.

As a result of reactions occurring during the exposure to UV irradiation, TiO_2 is known to react with superoxide and hydroxyl radicals. Oxidative radicals can attack and depolymerise the polysaccharide pectin and hemicellulose [20]. It was noted that the whiteness degree of all TiO_2 coated samples was higher than that of the raw sample. It was observed that the N+H treatment did not have a positive effect on the whiteness of samples under UV light. The addition of H_2O_2 to the TiO_2 solution supported the bleaching and the whiteness levels were slightly higher than the samples treated with TiO_2 alone. However, when NaOH was added to the TiO_2 and H_2O_2 recipe, the degree of whiteness was reduced.

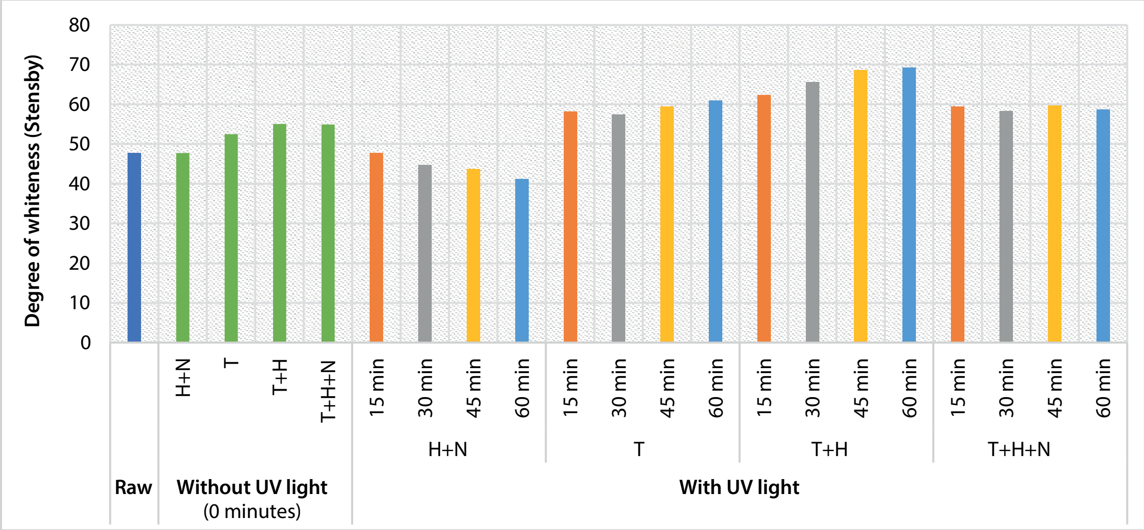


Figure 2: Degrees of whiteness of cotton fabrics

This result agreed with the literature that reports that the addition of NaOH reduces photooxidation [21]. According to the findings, adding TiO_2 to H_2O_2 significantly improves the photocatalytic activity to bleach cotton fabric samples, while the addition of NaOH to the solution has the opposite effect and reduces the photooxidation due to the alkaline medium.

3.2 Air permeability

Air permeability is an important aspect that describes the ability of air to pass through the fabric. It was found that the air permeability of the samples was lower in UV-treated fabrics compared to the raw fabric. The reason for this can be explained by a slight increase in fabric density compared to the raw fabric as a result of the treatment of the fabric. However, as it can be seen in Figure 3, it was observed that the air permeability values of samples were lower than of other samples in the UV treatment with the solutions containing TiO_2. From the SEM images in Figure 5, it was observed that TiO_2 particles penetrate the voids of the fabric, which is believed to reduce the air permeability by showing a coating effect on the fabric surface.

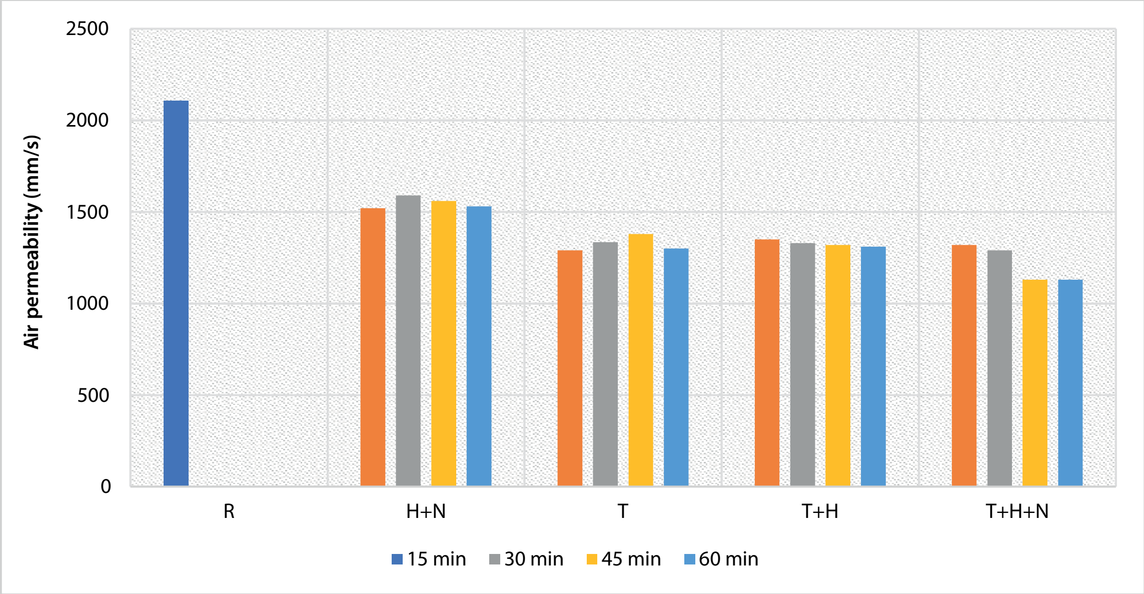


Figure 3: Air permeability of samples

3.3 Tensile strength measurements of fabrics

The results of tensile strength tests are presented in Figure 4. The results show that the strength values of treated fabrics did not significantly differ from those of the raw fabric. Although the UV treatment time did not seem to affect the strength values in general, it was observed that the strength values of the samples impregnated with the T+H solution decreased with increasing time. This is due to the reduction in strength values as a result of the attack of cellulose by oxidative radicals from H_2O_2 under UV light [22]. Since NaOH slows down the oxidation process, no significant loss of strength was observed in the processes containing NaOH [21]. The strength values of TiO_2 treated fabrics are generally higher than those of fabrics not treated with TiO_2. Tensile strength depends not only on the mechanical strength of fibres, but also on the frictional properties of fibres. The accumulation of TiO_2 particles in the fabric affects frictional properties [9]. According to this situation, the highest strength values were observed in the samples impregnated with the T+H+N solution. Except for the samples treated with the T+H solution, the UV process had no negative effect on strength.

3.4 Surface morphology of cotton fabrics

The surface morphology of the cotton fabric was observed using the scanning electron microscope (SEM) images. The impurities on the untreated cotton fabric are seen in Figure 5a. The surface of the untreated fibre appears to be a clean surface without particles (Figure 5a). The presence of TiO_2 particles was evident in the SEM images of the TiO_2 treated samples.

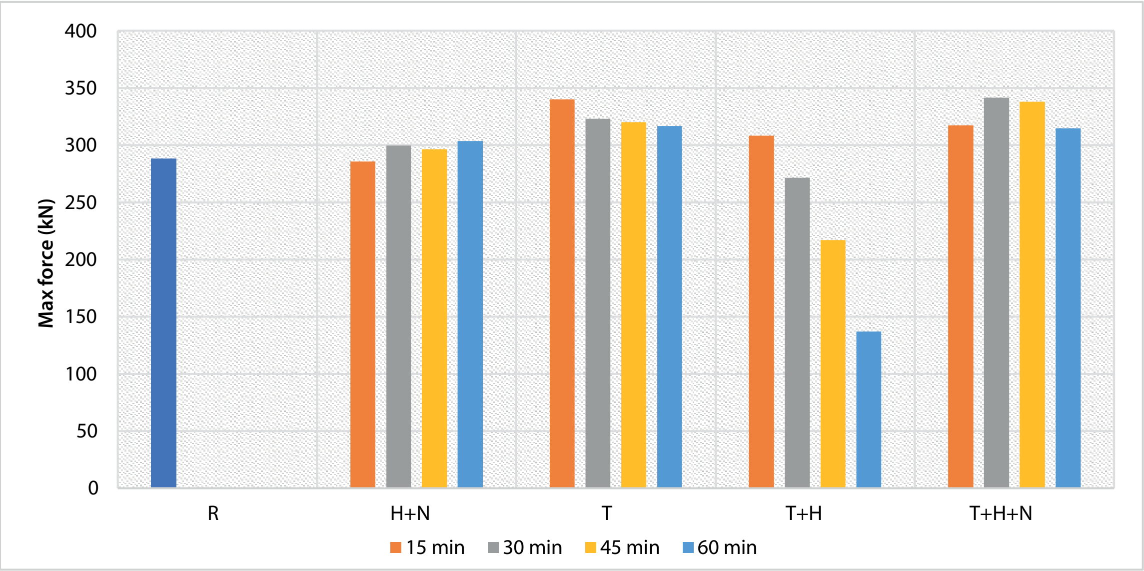
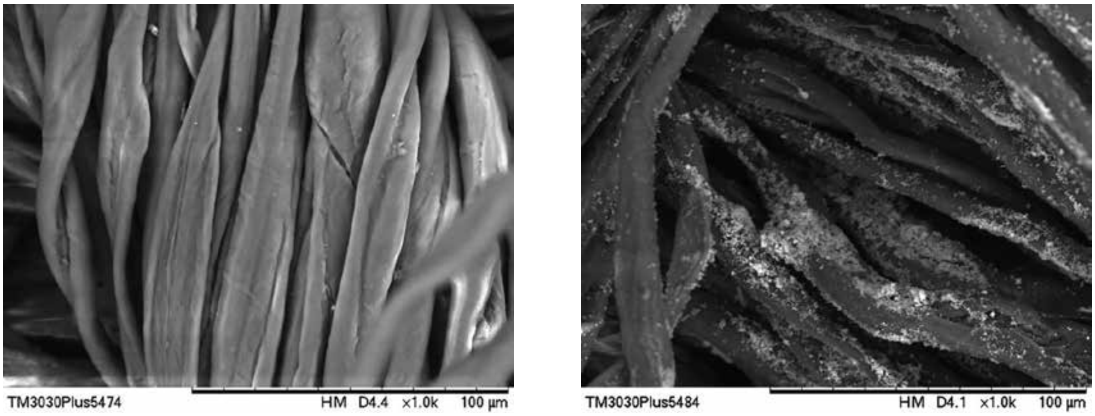
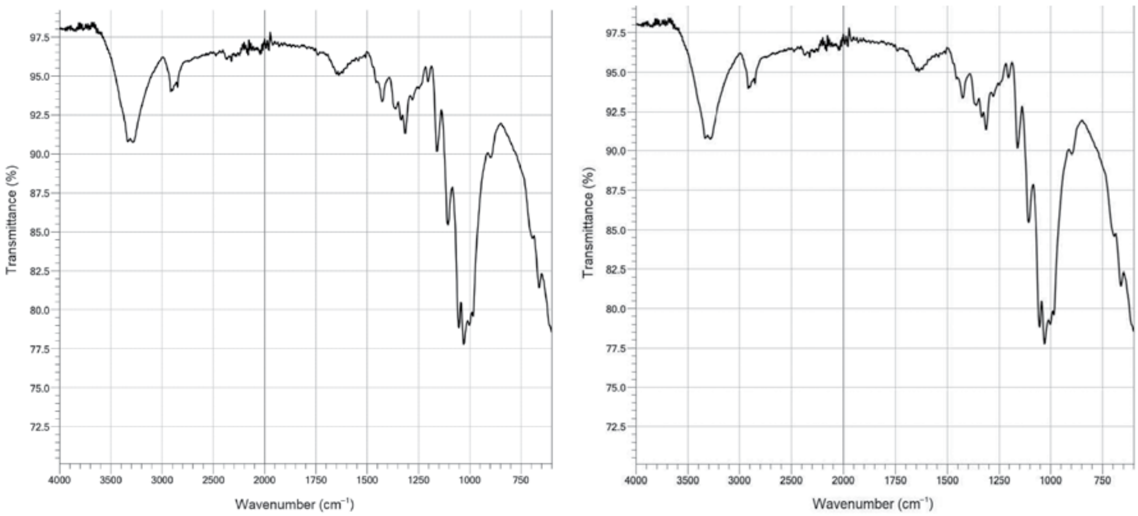


Figure 4: Tensile strength values of samples



a) *b)*

Figure 5: SEM images of cotton fibre (1000× magnification): (a) untreated with TiO_2; (b) treated with TiO_2



a) *b)*

Figure 6: FTIR analysis of samples: (a) untreated with TiO2; (b) treated with TiO2

3.5 FTIR analysis results of cotton fabrics

The FTIR analysis results of samples are presented in Figure 6. No significant peak differences were observed between the FTIR results of the raw cotton fabric and the TiO_2 coated fabric alone. The peaks of TiO_2 and cotton are similar [23, 24]. In Figure 6a, the OH functional groups in cellulose are shown by bands at around 3300 cm^{-1}. The FTIR spectroscopy, a surface sensitive technique, can detect the presence of wax and pectin. The peaks at 2916 cm^{-1} represent wax in cellulose and hemicellulose, and the C-H stretching vibration in lignin, indicating the presence of wax in the fibre. The peaks at 1750 cm^{-1} and 1200 cm^{-1} represent the free form of carboxylate in hemicellulose in the structure of cotton [25]. The bending vibrations of C–H and C–O groups in cellulose polysaccharide rings are observed in absorption bands at around 1300 cm^{-1}. The (C–O) and (O–H) stretching vibrations of polysaccharide in cellulose are responsible for the intense peaks observed at 1029 cm^{-1}. The peak at 897 cm^{-1} indicates that beta-glycosidic linkages exist between monosaccharides [26]. The peak at 690 cm^{-1} is specific to the Rutile TiO_2 vibration (Figure 6b) [27, 28].

4 Conclusion

In this study, the photooxidation effect of TiO_2 on the bleaching of a cotton fabric was investigated. Cotton fabrics were impregnated with different types of H_2O_2, TiO_2 and NaOH, and exposed to UV irradiation for different durations. The presence of TiO_2 on the surface of treated cotton samples was confirmed by the SEM images of samples. While TiO_2 alone yielded increases in whiteness values, its use in combination with H_2O_2 yielded higher whiteness values under UV irradiation. It was observed that the whiteness levels of all TiO_2-added samples were higher than of the raw fabric, which is consistent with the literature [11]. As a result, the whiteness of cotton fabric can be increased by using TiO_2 alone under UV irradiation, resulting in lower chemical consumption. The air permeability of treated samples decreased after the TiO_2 treatments, which was associated with the accumulation of TiO_2 by entering into the pores on the fabric.

Since photooxidation take place at room temperature compared to conventional process performed at the boil, it has the advantage of energy savings. Furthermore, using less water and chemicals makes this method attractive. The bleaching process was conducted under UV light only at room temperature, and a more environmentally friendly, faster and more efficient method of bleaching cotton fabric was presented. It is believed that this method may provide benefits in reducing the carbon footprint of cotton bleaching in the textile industry and may contribute to sustainability.

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Tailoring of Multifunctional Cotton Fabric by Embedding a TiO_2+ZnO Composite into a Chitosan Matrix

Oblikovanje večfunkcionalne bombažne tkanine z vgraditvijo kompozita TiO_2+ZnO v matrico hitozana

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Abstract
The use of nanomaterials to functionalise textiles offers new opportunities for chemical modification of textile fibres' surfaces to achieve multifunctional protective properties. In this study, novel coatings were tailored on cotton fabric by embedding a mixture of TiO_2 and ZnO nanoparticles (NPs) of different molar ratios into a chitosan polymer matrix. The excitation energies of the TiO_2+ZnO composites generated in the coatings ranged from 3.20 eV to 3.25 eV, indicating that the photocatalytic performance of the functionalised cotton was driven by UV light. The presence of TiO_2+ZnO composites increased the UV protection factor (UPF) of the cotton fabric from 4.2 for the untreated sample to 15–21 for the functionalised samples. The UPF values of the coatings slightly decreased after repeated washing. The ZnO in the TiO_2+ZnO composites conferred biocidal activity to the coatings, which were resistant to washing at higher ZnO concentrations. In addition, the TiO_2 in the TiO_2+ZnO composites was responsible for the enhanced photocatalytic self-cleaning of the functionalised cotton, which was observed during the initial period of illumination at lower ZnO concentrations in the composite. The main advantage of these TiO_2+ZnO composite coatings is their multifunctionality, which cannot be provided by single-component TiO_2 or ZnO coatings. Moreover, these coatings have wide-ranging practical applications, as they were composed of commercially available nanomaterials and were applied using conventional pad–dry–cure equipment.
Keywords: titanium dioxide, zinc oxide, chitosan, coating, cotton, UV protection, antimicrobial activity, photocatalytic self-cleaning

Izvleček
Uporaba nanomaterialov za funkcionalizacijo tekstilij ponuja nove možnosti kemijske modifikacije površine tekstilnih vlaken za dosego multifunkcionalnih zaščitnih lastnosti. V raziskavi je bila na bombažni tkanini oblikovana nova prevleka z vgraditvijo mešanice nanodelcev (ND) TiO_2 in ZnO različnih molarnih razmerij v matrico hitozana. Energije za vzbujanje oblikovanih kompozitov TiO_2+ZnO v prevleki so bile med 3,20 eV in 3,25 eV, kar pomeni, da je za fotokatalitsko delovanje funkcionaliziranega bombaža potrebna UV-svetloba. Prisotnost kompozita TiO_2+ZnO je povečala UV zaščitni faktor (UZF) s 4,2 za neapretiran bombaž na 15–21 za funkcionalizirane vzorce. Vrednosti UZF-prevlek so se po večkratnem pranju nekoliko zmanjšale. ZnO je kompozitu TiO_2+ZnO zagotovil biocidno aktivnost, ki je bila pri višjih koncentracijah ZnO pri pranju obstojna. TiO_2 je kompozitu TiO_2+ZnO zagotovil izboljšano fotokatalitsko samočistilnost funkcionaliziranega bombaža, ki je bila opazna pri začetnih časih osvetljevanja in pri nižjih koncentracijah ZnO v

kompozitu. Glavna prednost kompozitnih prevlek TiO_2+ZnO je njihova večfunkcionalnost, ki je z enokomponentnimi prevlekami TiO_2 ali ZnO ni bilo mogoče doseči. Prevleke imajo široko praktično uporabo, saj vključujejo komercialno dosegljive nanomateriale in so nanesene s konvencionalno opremo za impregniranje, sušenje in kondenziranje.
Ključne besede: titanov dioksid, cinkov oksid, hitozan, prevleka, bombaž, UV-zaščita, protimikrobna aktivnost, fotokatalitska samočistilnost

1 Introduction

In the last decade, the use of nanomaterials for the functionalisation of textiles has greatly increased, as they have advantages over classical finishing agents, including a high surface-to-volume ratio, which significantly increases their chemical reactivity and functionality, even at low concentrations. As inorganic nanomaterials, TiO_2 and ZnO nanoparticles (NPs) are of great importance due to their exceptional physicochemical and optical properties; they confer multifunctionality to textile fibres, including the functions of photocatalytic self-cleaning, antibacterial activity, UV protection, and thermal stability [1–9]. Both NPs are characterised by thermal, chemical, and photochemical stability, non-toxicity, biocompatibility, and a low price.

As metal oxides, TiO_2 and ZnO are semiconductor materials with photocatalytic activity under UV irradiation [10–12]. The absorption of UV radiation is related to the UV protection properties of TiO_2 and ZnO. At the same time, the excitation of semiconductors enables the formation of reactive oxygen species (ROS) on the surface of semiconductors; these are very important for the degradation of various organic compounds and the antimicrobial activity of TiO_2 and ZnO. All of these functional properties are directly affected by the particle size, morphology, and concentration. In addition, the photocatalytic efficiency of semiconductors could be significantly enhanced and moved into the visible range through various surface and interface engineering strategies, including coupling with other semiconductors to create semiconductor–semiconductor heterojunctions [13, 14]. This offers the possibility for the chemical modification of textile fibres with a composite TiO_2 and ZnO heterojunction, which would improve the photocatalytic performance of the coating.

The major drawback in tailoring textiles' functionalities by using inorganic NPs is their low affinity to textile fibres. Therefore, in order to increase the adsorption capacity of NPs and enhance their adhesive force, various approaches have been pursued, such as anchoring NPs to textile fibres with crosslinking agents or incorporating NPs into the polymer matrix formed on the fibre surface [15–19]. As a nanocomposite matrix, chitosan has already attracted attention due to its exceptional properties, such as its natural origin, non-toxicity, biocompatibility, biodegradability, and low cost [20]. Several amino and hydroxyl groups in the chitosan polymer structure are capable of creating electrostatic attractive and hydrogen bonds that enable the embedding of various NPs into the polymer matrix [21–32]. The ability of chitosan to embed semiconductor metal oxides can make it an effective platform for photocatalytic performance [21, 28, 32, 33]. Moreover, since chitosan is known as an absorbent that can absorb different organic substances by attracting –OH and $–NH_2$ functional groups, this could greatly improve the adsorption–photocatalysis process [32, 34–36].

Considering all of these aspects, the aim of this research was to develop a novel multifunctional coating on cellulose fibres by embedding a TiO_2+ZnO composite into a chitosan matrix and applying it to a cotton substrate with the facile pad–dry–cure process. Recently, the quaternary ammonium chitosan Schiff base was already synthesised and used for the in-situ synthesis of TiO_2 and ZnO NPs from the corresponding precursors with the ultrasonic irradiation process [37], which limited this research to the laboratory level. Our idea was to extend this research by using commercial products and conventional application equipment, thus providing the possibility for the functionalisation of textiles at the industrial level, which is of great practical significance. To investigate the influence of the ratio of concentrations between TiO_2 and ZnO in the composite on the functional properties, the concentration of TiO_2 was kept constant while the concentration of ZnO was varied. To determine the possibility of the formation of a TiO_2+ZnO heterojunction in the coating, the optical properties of the composites were investigated. In addition, special attention was paid to the UV protection, antibacterial activity, and photocatalytic self-cleaning of the coatings.

2 Experimental

2.1 Materials

Woven fabric made of 100% cotton in plain weave with a mass per unit area of 119 g/m^2 was kindly provided by Tekstina d.o.o. (Ajdovščina, Slovenia). The fabric was pre-scoured, bleached, and mercerized. Commercially available TiO_2 anatase nanopowder with a particle size of less than 25 nm and ZnO nanopowder with 30 nm particles were purchased from Sigma Aldrich. Chitosan solution with a viscosity of 159 mPa and a deacetylation degree of 95% was purchased from Chitoclear (Primex, Iceland).

2.2 Functionalisation of the cotton fabric

The chitosan solution was prepared at a concentration of 0.2% in deionized water in the presence of 1.0% acetic acid. The solution was left for 24 hours with constant stirring. Then, the TiO_2 and ZnO NPs were dispersed in the chitosan solution in the appropriate ratios by sonicating them for 30 minutes with a UP 200St ultrasonicator (Hielscher, Germany). For this purpose, the concentration of the TiO_2 NPs remained constant at 1.0%, while the concentration of the ZnO NPs varied between 0.5% and 2.0%. For comparison, a single component of TiO_2 at 1.0% and 3% and a single component of ZnO at 3% were dispersed in the chitosan solution, and a mixture of 1.0% TiO_2 and 2.0% ZnO was dispersed in deionized water without chitosan.

The prepared dispersions were applied to cotton fabric by using the pad–dry–cure method. The coating procedure involved the complete immersion of the cotton samples in the appropriate dispersions at room temperature, followed by squeezing on a two-roll padder (Mathis, Switzerland) for a wet pickup of 85% ± 5%, drying at 100 °C for 3 minutes, and curing at 150 °C for 2 minutes. The samples were then rinsed with distilled water to remove the unbound coatings. After rinsing, the functionalised cotton samples were air-dried. The sample codes corresponding to the applied coatings are listed in Table 1.

2.3 Washing procedure

The functionalised cotton samples were washed five times in a Gyrowash (James Heal, UK). The washing bath consisted of 2 g/L of nonionic detergent at a goods-to-liquor ratio of 1 : 20. Each washing cycle was performed at 40 °C for 30 minutes. After each washing cycle, the samples were rinsed twice with the same amount of distilled water as for the washing process and left to dry.

2.4 Analyses and measurements

2.4.1 Scanning electron microscopy (SEM) and energy-dispersive X-ray spectroscopy (EDS)

The morphological characteristics of the studied cotton samples were examined with a JSM 6060 LV scanning electron microscope (JEOL, Japan). Prior to the examination, the samples were coated with a thin layer of gold to ensure conductivity. The samples were scanned at a magnification of 2000x.

EDS analysis was performed by using a field-emission scanning electron microscope (FEG-SEM Thermo Scientific Quattro S ThermoFischer Scientific, USA). Sample analysis was performed by using an Oxford Instruments Ultim Max 65 energy-dispersive detector (EDS) and the AZtec software. The samples were coated with a thin carbon layer prior to the analysis to provide conductivity and, thus, improve the quality of the images.

2.4.2 Fourier transform infrared (FT-IR) spectroscopy

Chemical changes in the cotton samples after functionalisation were observed by using an FT-IR

Table 1: Sample codes according to the coatings

Sample code	Functionalisation procedure
CO_UN	Untreated cotton sample
CO/Ch+Ti1	Cotton sample functionalised with a mixture of 0.2% chitosan and 1% TiO_2
CO/Ch+Ti1+Zn0.5	Cotton sample functionalised with a mixture of 0.2% chitosan, 1% TiO_2, and 0.5% ZnO
CO/Ch+Ti1+Zn1	Cotton sample functionalised with a mixture of 0.2% chitosan, 1% TiO_2, and 1.0% ZnO
CO/Ch+Ti1+Zn1.5	Cotton sample functionalised with a mixture of 0.2% chitosan, 1% TiO_2, and 1.5% ZnO
CO/Ch+Ti1+Zn2	Cotton sample functionalised with a mixture of 0.2% chitosan, 1% TiO_2, and 2.0% ZnO
CO/Ch+Ti3	Cotton sample functionalised with a mixture of 0.2% chitosan and 3% TiO_2
CO/Ch+Zn3	Cotton sample functionalised with a mixture of 0.2% chitosan and 3% ZnO

Spectrum 3 spectrometer (Perkin Elmer, UK). Spectra were recorded between 4000 cm^{-1} and 600 cm^{-1} with a resolution of 4 cm^{-1} and an average of 120 spectra per sample.

2.4.3 UV–Vis spectroscopy and determination of the optical band-gap energy (E_g)

The transmission spectra of the untreated and functionalised cotton samples were recorded by using a Lamda 850+ UV/Vis spectrophotometer (Perkin Elmer, United Kingdom) that was equipped with a reflection module—a 150 mm integration sphere—and fully controlled by a computer running the WinLab 6 UV software. Transmittance (T) was measured in the wavelength range of 200–800 nm. Three measurements were made for each sample at different angles of warp alignment, and the average value of T at each wavelength was calculated. The transmission spectra were converted into absorption spectra by using the following equation:

$$A = -\log T \tag{1}$$

where A is the absorbance.

From the absorption spectra, the E_g values of the TiO_2, ZnO, and TiO_2+ZnO coatings on the cotton samples were determined by using the Tauc relation, in which the energy-dependent absorption coefficient, α, is related to the incident photon energy, $h \cdot \nu$ (Reddy 2002, Karkare 2015). This relationship is expressed by the following equation [38]:

$$(\alpha h \nu)^n = K\left(h\nu - E_g\right) \tag{2}$$

where K is the absorption constant, h is the Planck constant, ν is the frequency of light, and n is an index characterizing the optical absorption process. The latter is equal to two for the direct band-gap transitions proposed for TiO_2 and ZnO [38]. According to the Tauc method, the value of E_g was graphically determined from the Tauc plot as the value of the photon energy obtained when the linear part of the plot was extrapolated to $\alpha = 0$.

2.4.4 UV protection properties

The UV protection properties of the untreated and functionalised cotton samples were determined according the EN 13758-1: 2001 standard by measuring the UV transmission spectra (Section 2.4.3). The main values of T were calculated at wavelengths of 315–400 nm (UVA), 290–315 nm (UVB), and 290–400 nm (UVR). The ultraviolet protection factor (UPF) was calculated as follows:

$$\mathrm{UPF} = \frac{\sum_{290}^{400} E(\lambda)\cdot\varepsilon(\lambda)\cdot\Delta\lambda}{\sum_{290}^{400} E(\lambda)\cdot\varepsilon(\lambda)\cdot T(\lambda)\cdot\Delta\lambda} \tag{3}$$

where $E(\lambda)$ is the solar spectral irradiance, $\varepsilon(\lambda)$ is the relative erythemal effectiveness, $\Delta(\lambda)$ is the wavelength interval, and $T(\lambda)$ is the spectral transmittance at the wavelength λ. The UPF rating and protection categories were determined from the UPF values, which were calculated according to the Australian/New Zealand Standard for Sun-Protective Clothing—Evaluation and Classification (AS/NZS 4399, 2020), where UPF values of 15– correspond to the "minimum protection" category, UPF values of 30– correspond to the "good protection" category, and UPF values of 50– correspond to the "excellent protection" category.

In addition, the reflection (R) of the samples in the wavelength range of 250–450 nm was also recorded.

2.4.5 Antibacterial activity

The antibacterial activity of the untreated and functionalised cotton samples against the Gram-positive bacteria *Staphylococcus aureus* (*S. Aureus*; ATCC 6538) and the Gram-negative bacteria *Escherichia coli* (*E. Coli*; ATCC 25922) was evaluated by using the AATCC 100-2012 method. First, the samples were cut into a circular shape of 4.8 ± 0.1 cm in diameter. Then, a sufficient number of samples were used for the complete uptake of 1 mL of inoculum. After 24 hours of incubation at 37 °C, the samples were washed with neutralizing solution and vigorously shaken for one minute. Serial dilutions of the liquid were then prepared and spread on nutrient agar. After incubation, the number of bacterial colonies per sample was determined. The bacterial reduction (R) was calculated by using the following equation:

$$R = \frac{(B\text{-}C)}{B} \times 100 \tag{4}$$

where B is the number of bacterial colony-forming units (CFU) recovered from the inoculated untreated control samples in the jar at an incubation time of 24 hours, and C is the number of bacteria recovered from the inoculated functionalised test samples in the jar at an incubation time of 24 hours.

2.4.6 Photocatalytic self-cleaning activity

The photocatalytic self-cleaning activity of the untreated and the functionalised samples was determined based on the photodegradation of a Rhodamine B (RhB) dye under simulated sunlight. For this purpose, the samples were immersed in the RhB solution for 30 seconds and then air-dried and illuminated for five hours at 35 °C and 70% humidity in a Xenon Alpha device (Atlas, USA) equipped with a visible xenon arc lamp (radiation attitude: 0.8–2.5 kVA; extended radiation range: 300–400 nm). Before and after each hour of illumination, the colour coordinates L^*, a^*, b^*, and Y in the CIELAB colour space were determined for the studied samples by using a Datacolor Spectro 1050 spectrophotometer (Datacolor, USA). Measurements were performed with a 9 mm aperture under D65 illumination and an observation angle of 10°. Ten measurements were performed for each sample, and the colour difference (ΔE^*_{ab}) was calculated by using the following equation [39]:

$$\Delta E^*_{\mathrm{ab}} = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2} \quad (5)$$

where ΔL^*, Δa^*, and Δb^* are the differences in the lightness, green–red, and blue–yellow colour coordinates, respectively, calculated between the illuminated and non-illuminated samples. Colour fading in the samples due to the photodegradation of the RhB dye was also estimated from the Y coordinate, which was the luminance and represented the perceived brightness. The efficiency of colour fading was calculated as the ratio of Y_t/Y_0, where Y_0 and Y_t represent the Y coordinates before and after a certain irradiation time, respectively.

3 Results and discussion

3.1 Morphological and chemical properties

The morphological properties of the untreated and functionalised cotton samples are shown in Figure 1. In the SEM images, it is evident that compared to the untreated cotton sample, the application of TiO_2 and ZnO NPs increased the roughness of the fibres, as there were visible agglomerates of both TiO_2 and ZnO NPs on the fibre surface. It is also evident that the number of NPs on the fibre surface increased when the concentration of ZnO NPs in the dispersion was increased from 0.5% to 2%. The comparison of the CO/Ch+Ti3 and CO/Ch+Zn3 samples showed that at the same concentration of 3.0% in the dispersion, the loading of ZnO NPs was higher than that of TiO_2 NPs, with agglomerates of a smaller size being uniformly distributed in the chitosan matrix on the surface of the cotton fibres. The presence of TiO_2 and ZnO NPs on the surface of the cotton fibres was confirmed by the EDS analysis (Figure 2), as characteristic peaks were observed at 0.5, 4.5, and 4.9 keV for TiO_2 and at 1.0, 8.6, and 9.4 keV for ZnO in the CO/Ch+Ti1+Zn2 sample.

The chemical characteristics of the untreated and functionalised cotton samples were investigated by using FT-IR analysis, and the results are shown in Figure 3. The ATR spectra of all samples, regardless of the chemical modification, exhibited the bands characteristic of the fingerprint of cellulose fibres and adsorbed water [40, 41]. Thus, the band at 2890 cm^{-1} was attributed to the valence vibration of the CH_2 and CH_3 groups, the band at 1640 cm^{-1} corresponded to the deformation vibration of the

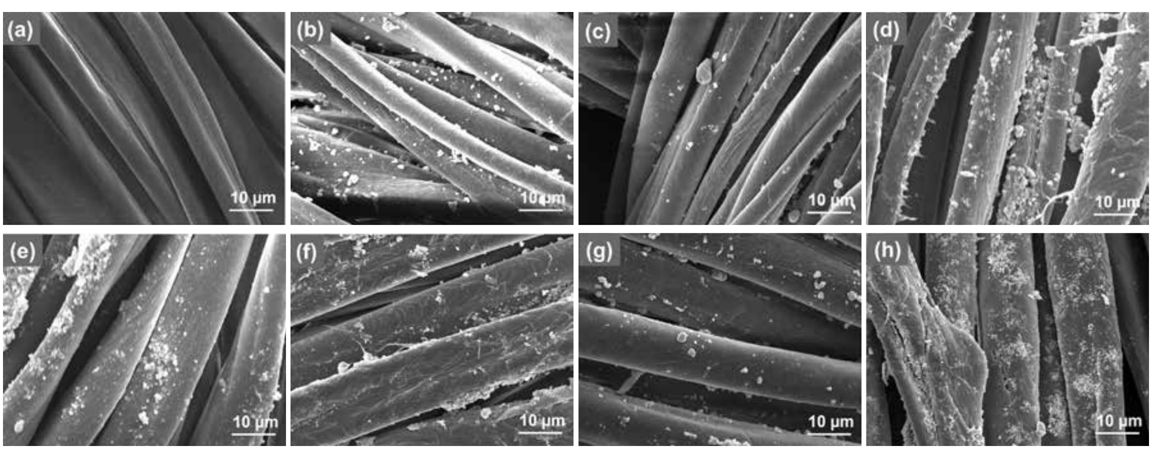
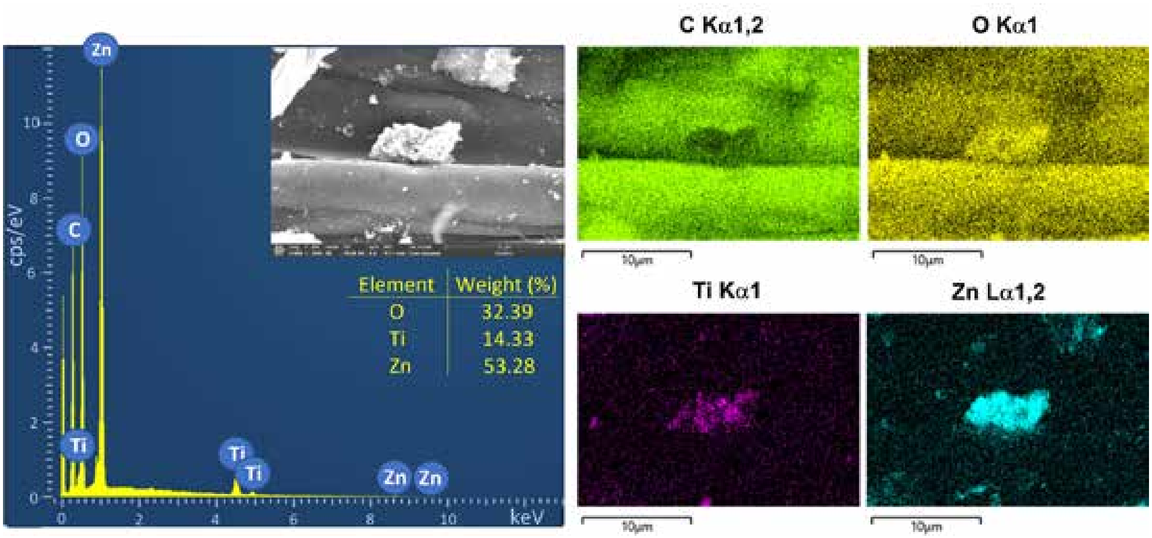


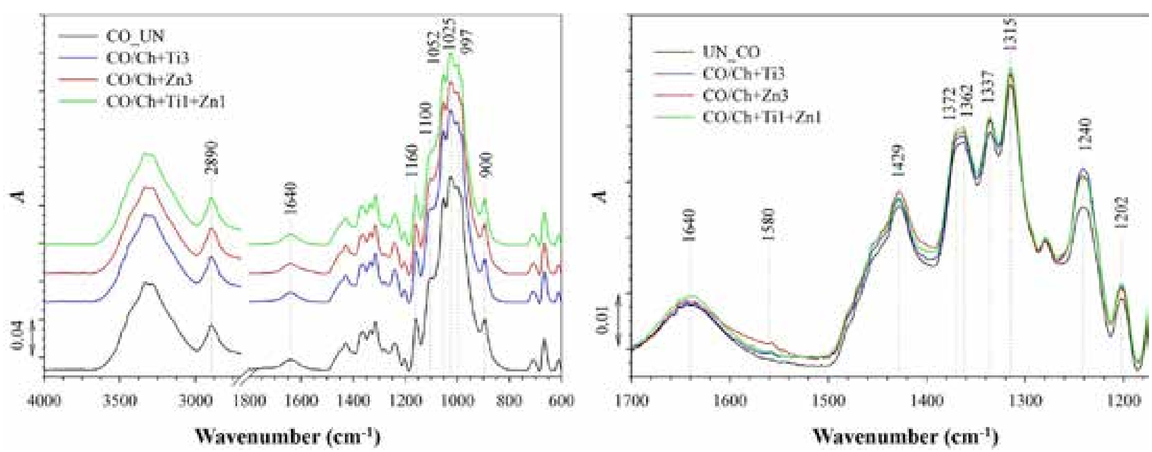
Figure 1: SEM images of the untreated (a) and functionalised cotton samples: CO/Ch+Ti1 (b), CO/Ch+Ti1+Zn0.5 (c), CO/Ch/Ti1+Zn1 (d), CO/Ch+Ti1+Zn1.5 (e), CO/Ch/Ti1+Zn2 (f), CO/Ch+Ti3 (g), and CO/Ch/Zn3 (h)



a) b)

Figure 2: EDS spectrum (a) and element mapping images of C, O, Zn, and Ti (b) in the CO/Ch/Ti1+Zn2 sample

OHO groups, the band at 1160 cm^{-1} corresponded to the asymmetric valence vibration of the C-C groups, the band at 1100 cm^{-1} was attributed to the asymmetric valence vibration of the C-O-C groups, the band at 1052 cm^{-1} was attributed to the asymmetric stretching of the glycosidic ring, the bands at 1025 cm^{-1} and 997 cm^{-1} were attributed to the valence vibration of the C-OH groups of the secondary and primary alcohols, respectively, and the band at 900 cm^{-1} corresponded to the asymmetric valence vibration of the C_1-O-C_4 groups. For the functionalised CO/Ch+Ti3, CO/Ch+Zn3, and CO/Ch+Ti1+Zn1 samples, no characteristic bands of TiO_2 and ZnO were detected, indicating the absence of chemical interactions of these NPs with the functional groups of cotton cellulose [41]. For these samples, the typical band of N-H bending of the amino groups of chitosan at 1580 cm^{-1} could not be detected, as the concentration of chitosan was too low (0.2%). Moreover, the band at 1601 cm^{-1}, which was characteristic of the C=O group of the amide group, was blurred by the vibrations of the cellulose macromolecules [40].



a) b)

Figure 3: IR ATR spectra of the untreated cotton sample (CO_UN) and the chemically modified CO/Ch+Ti1+Zn1, CO/Ch+Ti3, and CO/Ch+Zn3 samples in the spectral region of 4000–600 cm^{-1} (a) and in the spectral region of 1700–1180 cm^{-1} (b)

3.2 Optical properties

The influence of the presence of the coatings on the optical properties of the functionalised cotton samples is shown in Figure 4. From the absorption spectra (Figure 4a and 4b), it can be seen that the absorption of UV radiation was significantly increased for all of the functionalised samples compared to the untreated cotton sample, which was attributed to the presence of TiO_2 and ZnO NPs, which are known to be effective UV absorbers. A comparison of the CO/Ch+Ti1 and CO/Ch+Ti3 samples (Figure 4a) shows that increasing the TiO_2 concentration from 1% to 3% in the dispersion did not significantly change the absorbance of the functionalised cotton samples. Moreover, a comparison of the CO/Ch+Ti3 and CO/Ch+Zn3 samples with the same 3% NPs in the dispersions reveals that the absorption efficiency of TiO_2 in the UVA region from 320 to 400 nm was significantly lower than that of ZnO. For the cotton samples with TiO_2+ZnO composites (Figure 4b), the absorption in the entire UV region was lower than that of the samples with single-component TiO_2 or ZnO coatings. It is also evident that increasing the concentration of ZnO NPs in the TiO_2+ZnO composite beneficially affected the absorption efficiency of the samples in the UVA region.

The Tauc plots (Figure 4c) and the calculated values of E_g (Figure 4d) show that the excitation energies of TiO_2 and ZnO were 3.25 eV and 3.20 eV, respectively, and that the energies required for the excitation of the TiO_2+ZnO composites were between 3.20 eV and 3.25 eV. All of these estimated excitation energies were those of UV rays, and there was not a bathochromic shift in the absorption of the TiO_2+ZnO composites to visible light. This clearly indicated that the simple mixing of TiO_2 and ZnO NPs in the dispersion was not sufficient to form a heterojunction with visible-light-driven photocatalytic performance.

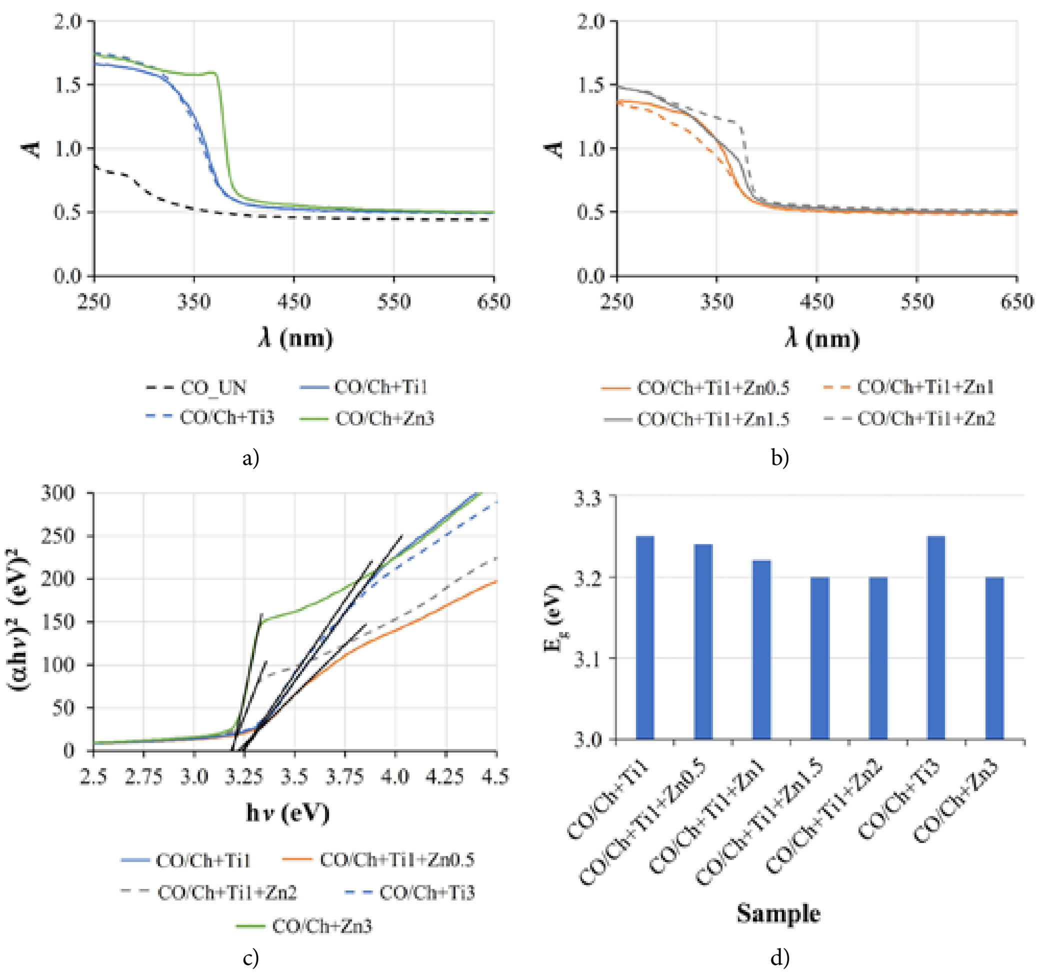


Figure 4: Absorption spectra of the untreated and functionalised cotton samples (a, b); Tauc plots of the representative samples (c) and E_g values of the functionalised cotton sample

3.3 UV protection properties

Since the UV protection properties were directly related to the transmission of UV rays through the cotton fabric, the transmission and reflection spectra of the untreated and the functionalised cotton samples were recorded, and the results are presented in Figure 5 and Table 2. The results clearly show that the presence of all coatings significantly reduced the transmittance and the reflectance of the cotton fabric. Since the transmittance of the CO/Ch+Ti3 and CO/Ch+Zn3 samples was very similar in the UVB region (280–320 nm), the transmittance in the UVA region of the CO/Ch+Zn3 sample was much lower than that of the CO/Ch+Ti3 sample, which was beneficial for UV protection. In addition, the CO/Ch+Ti3 sample also exhibited lower transmission of UV rays than that of all cotton samples with the TiO_2+ZnO composites. Since the lower transmission of UV rays through the functionalised cotton sample was accompanied by lower UV light reflection, this indicated that the UV-blocking mechanism of TiO_2 and ZnO was based on the absorption of UV rays. These results are in good agreement with the absorption spectra (Figures 4a and 4b).

The lower the transmittance of the cotton fabric for UV rays, the higher the UPF value. The results in Table 2 show that the UPF value of the untreated cotton sample was very low, indicating insufficient protection against UV radiation. The CO/Ch+Ti1, CO/Ch+Ti3, and CO/Ch+Zn3 samples provided good protection against UV radiation, with UPF values of 32.3, 32.4, and 39.2, respectively. Since the transmission of UV rays through the samples with the coatings of the two-component TiO_2 and ZnO NPs was generally high compared to that of the cotton samples with the single-component TiO_2 or ZnO coatings, their UPF values were lower—as expected—and were in the range of 15–25, which is described as providing minimum protection. After five repetitions of washing, the UPF values of all functionalised samples decreased, indicating that the functionalisation of the cotton fibres was not permanent, that the chitosan matrix did not chemically bind the TiO_2 and ZnO NPs to the cotton fibres, and that they gradually released from the samples during the washings. These results are consistent with the results of the FT-IR analysis.

3.4 Antibacterial activity

The reduction in bacterial growth in the functionalised cotton samples compared to the untreated cotton sample is shown in Figure 6. It was found that even at the highest concentration of 3% in the dispersion, TiO_2 could not provide a sufficient reduction in both the Gram-positive bacteria *S. aureus* and the Gram-negative bacteria *E. coli*. Accordingly, the CO/Ch+Ti1 and CO/Ch+Ti3 samples did not exhibit antibacterial properties. In contrast, the addition of ZnO to the TiO_2 and ZnO mixture dramatically increased the antibacterial activity of the functionalised cotton samples and reduced the growth of both bacteria by 100%, even at the lowest concentration of 0.5% ZnO. Increasing the ZnO concentration from 1.0% to 2.0% had a beneficial effect on the durability of the antibacterial properties of the samples, resulting in a 100% bacterial reduction after five repeated washings for the CO/Ch+Ti1+Zn1, CO/Ch+Ti1+Zn1.5, and CO/Ch+Ti1+Zn2 samples. Similar results were also obtained for the CO/Ch+Zn3 sample. Although these

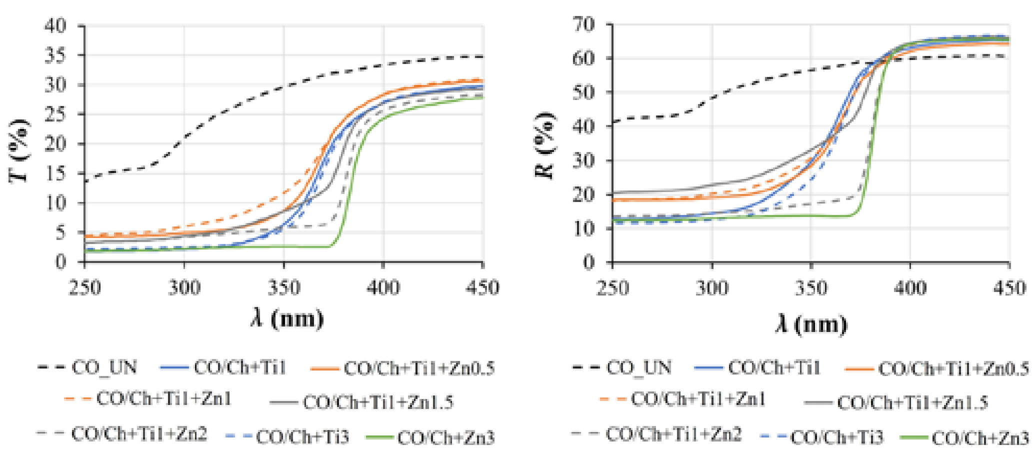


Figure 5: Transmittance (a) and reflectance (b) versus wavelength for the untreated and chemically modified samples

Table 2: The arithmetic mean of T in the UVA, UVB, *and* UVR *ranges and the* UVR *protection categories for the untreated and functionalised cotton samples according to the Australian/New Zealand Standard Sun-Protective Clothing—Evaluation and Classification—before and after five repetitions of washing*

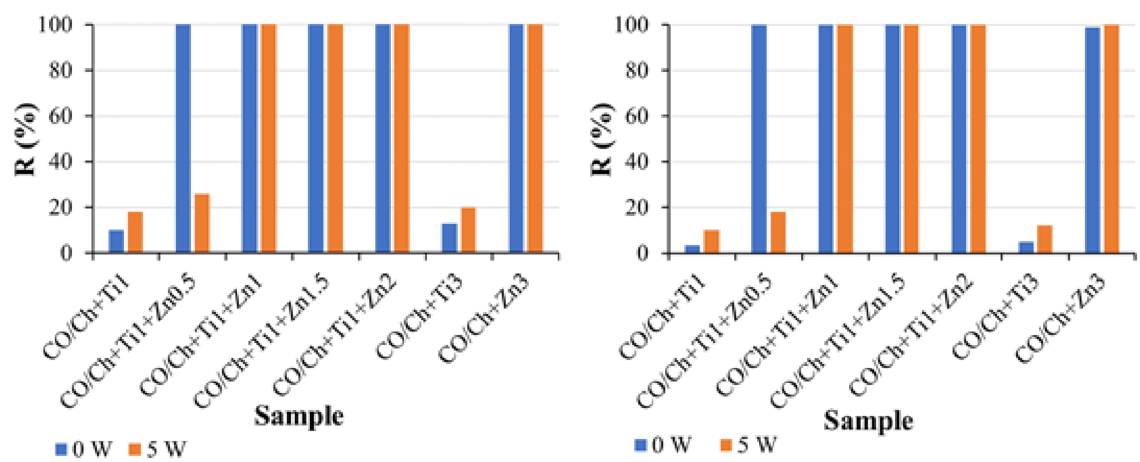
Sample	Number of washings	*T* (UVA) (%)	*T* (UVB) (%)	*T* (UVR) (%)	UPF	UVR protection category [a)]
CO_UN	0	30.0	21.3	28.0	4.2	NR
	5	28.2	18.6	24.8	5.8	NR
CO/Ch+Ti1	0	12.5	2.21	10.1	32.3	G
	5	19.9	4.9	16.1	15.4	M
CO/Ch+Ti1+Zn0.5	0	14.6	5.0	12.4	17.1	M
	5	17.8	4.7	14.7	11.7	NR
CO/Ch+Ti1+Zn1	0	16.11	6.14	13.8	15.6	M
	5	21.8	10.3	19.1	8.4	NR
CO/Ch+Ti1+Zn1.5	0	12.7	4.5	10.8	18.7	M
	5	22.1	10.5	19.5	8.2	NR
CO/Ch+Ti1+Zn2	0	9.8	4.3	8.5	20.8	M
	5	18.5	8.2	16.1	10.5	NR
CO/Ch+Ti3	0	12.0	2.5	9.8	32.4	G
	5	16.8	3.8	13.8	19.9	M
CO/Ch+Zn3	0	6.7	2.3	5.7	39.2	G
	5	11.9	5.8	10.5	15.5	M

[a)] NR – non rateable, M – minimum protection, G – good protection, E – excellent protection

results could not be directly compared with those obtained by Rafaee et al. [37], who synthesised two TiO_2/ZnO nanocomposites with different molar ratios of TiO_2:ZnO, a similar trend could be found, as the ZnO-rich TiO_2/ZnO nanocomposite provided better antibacterial activity than that of the TiO_2-rich one. However, in that study, no single-component nanocomposites were used as references.

3.5 Photocatalytic self-cleaning

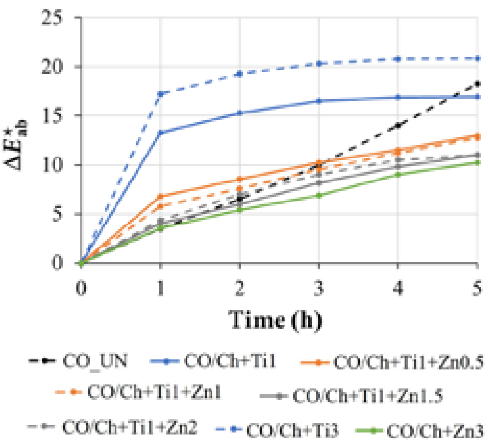
The photocatalytic self-cleaning properties of the functionalised samples were determined based on the photodegradation of RhB dye in the functionalised samples in comparison with the untreated cotton sample after different illumination times (Figure 7). The results show that increasing the illumination time caused the photodegradation of



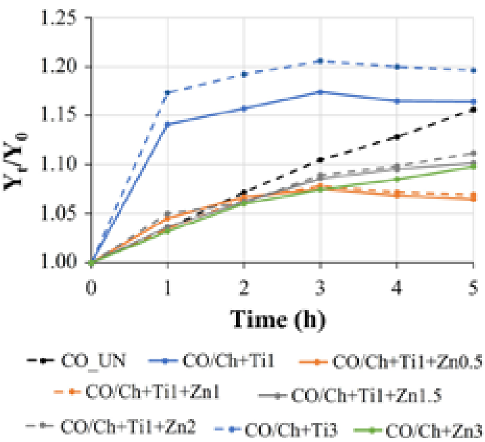
a) b)

Figure 6: Bacterial reduction, R, *of the functionalised cotton samples against S. aureus (a) and E. coli (b) before (0 W) and after five (5 W) washings*

the RhB dye in all samples, including the untreated one, resulting in an increase in the ΔE^*_{ab} value (Figure 7a), as well as a fading of the colour (Figure 7b). It can also be seen that the CO/Ch+Ti1 and CO/Ch+Ti3 samples exhibited the highest photocatalytic self-cleaning efficiency, resulting in a drastic colour change in the RhB dye after the first hour of illumination. The higher the TiO_2 concentration, the greater the colour change. The results also showed that the degradation of the RhB dye in the CO/Ch+Ti1 and CO/Ch+Ti3 samples was completed after 3 hours of illumination, which meant that the colour could not fade further with a longer illumination time. Figure 7a also reveals that ZnO alone in the CO/Ch+Zn3 sample did not show any photocatalytic performance. This was likely the reason for why the presence of ZnO in the mixture with TiO_2 hindered the photocatalytic self-cleaning of the coatings in comparison with the single-component TiO_2 coatings. While photocatalytic self-cleaning properties were observed for the CO/Ch+Ti1+Zn0.5 and CO/Ch+Ti1+Zn1 samples in the initial phase of illumination, this phenomenon was less pronounced for the coatings containing ZnO in higher concentrations (the CO/Ch+Ti1+Zn1.5 and CO/Ch+Ti1+Zn2 samples).



a)



b)

Figure 7: The colour difference (Δ), (a), and Y coordinate ratio (b) between the samples stained with the RhB dye and illuminated for different periods of time and the stained unilluminated samples

In contrast to all functionalised samples, the colour change in the untreated cotton sample gradually increased during the illumination period, resulting in an increase in the ΔE^*_{ab} value, which even exceeded the ΔE^*_{ab} value determined for the CO/Ch+Ti1 sample. However, a look at the digital images of the samples in Figure 8 reveals that after five hours of illumination, the untreated cotton sample (CO_UN) stained with the RhB dye was more intensely coloured than the CO/Ch+Ti1 and CO/Ch+Ti3 samples, as well as the CO/Ch+Ti1+Zn1 and CO/Ch+Ti1+Zn2 samples. To find the reason for these ΔE^*_{ab} and Y values in Figures 7a and 7b, the colour coordinates CIE a^* and CIE b^* of the dyed samples were examined (Figure 9). The results show that both colour coordinates (CIE a* and CIE b*) of the functionalised samples were significantly different from those of the untreated sample even before illumination and that after illumination, the differences in the CIE a^* and CIE b^* values were significantly smaller than those of the untreated sample. This phenomenon was particularly evident for the CIE b^* coordinate, which represents the yellow–blue axis. While the CIE b^* value of the untreated sample changed from more to less blue during the illumination, the CIE b^* coordinates of the CO/Ch+Ti1 and CO/Ch+Ti3 samples were negative and very close to zero, and they hardly changed with the illumination time. This indicated that the colour was more greyish, which was also consistent with the Y coordinate, which actually decreased after three hours of illumination. This clearly affected the value of ΔE^*_{ab}. Figure 8 also shows that the affinity of the RhB dye for the CO/Ch+Ti1 and CO/Ch+Ti3 samples was significantly higher than for the untreated cotton sample and the samples with coatings that included ZnO, resulting in a higher colour yield. However, the colour of these samples faded almost completely after only one hour of illumination.

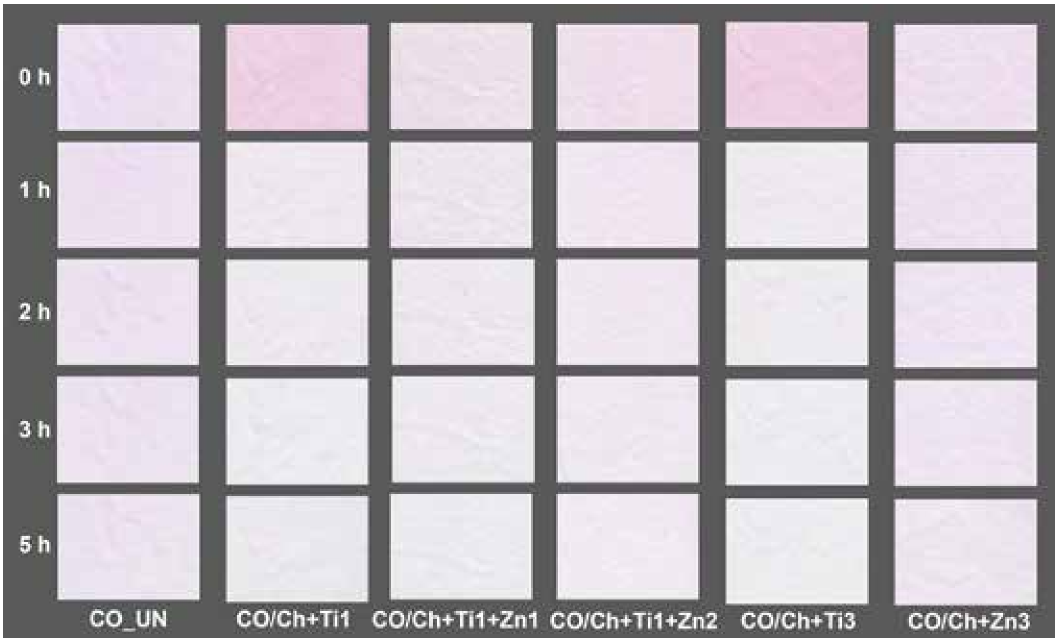


Figure 8: Digital images of the samples stained with RhB dye before and after different illumination times

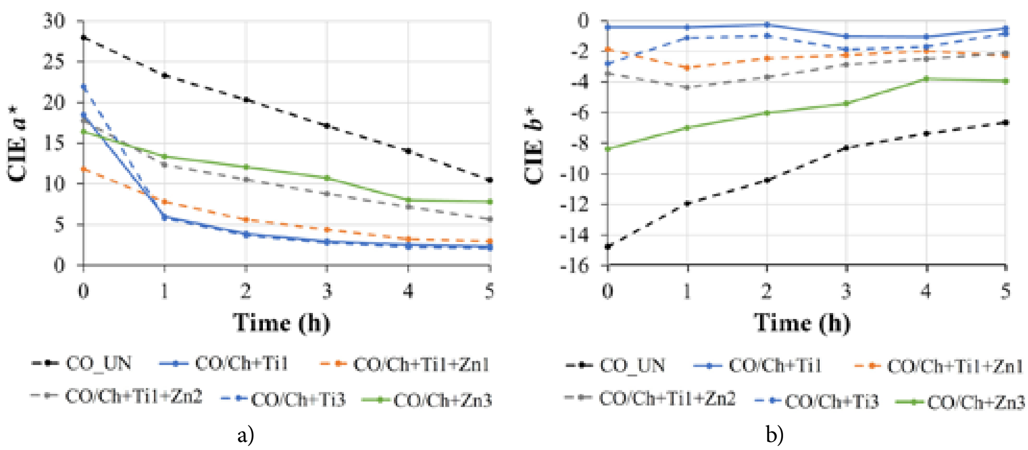


Figure 9: CIE a (a) and CIE b* (b) of the samples stained with RhB dye before and after different illumination times*

4 Conclusion

In summary, a novel and facile method was developed for the preparation of a multifunctional coating on a cotton fabric consisting of a TiO_2+ZnO composite embedded in a chitosan matrix. Although the simple mixing of commercial TiO_2 and ZnO NPs in a dispersion was not sufficient to form a heterojunction with enhanced photocatalytic performance, the presence of both TiO_2 and ZnO in the coating conferred multifunctional properties to the cotton fibres that could not be achieved with single-component TiO_2/chitosan and ZnO/chitosan coatings. Namely, the coatings simultaneously exhibited the following functionalities:

- Minimum UV protection properties that were less effective than those of the single-component TiO_2/chitosan and ZnO/chitosan coatings.
- Bactericidal activity due to the presence of ZnO, which could not be achieved even at the highest TiO_2 concentration in the single-component TiO_2/chitosan coatings.
- The improved photocatalytic self-cleaning, which was not as effective as that in the single-component TiO2/chitosan coating but was much more effective than that in the single-component ZnO/chitosan coating.

The use of commercially available TiO_2 and ZnO NPs, chitosan, and the pad–dry–cure application process with conventional equipment enables the functionalisation of textiles on an industrial scale, which is of great practical significance.

Acknowledgment

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Study on Effect of Consumer Age, Family Income and Family Size on Fast Fashion Consumption Pattern

Študija o vplivu starosti potrošnika, prihodkov in velikosti družine na vzorec potrošnje hitre mode

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Abstract

The aim of the study was to analyse the impact of various consumer attributes on the fast fashion consumption pattern. The effect of consumer age, family income and family size on the percentage of monthly income spent on clothing and percentage of monthly clothing consumption spent on fast fashion by consumers in NCR (National Capital Region) of India was studied in this research. Causal research was employed in this study. Correlations among the variables were established using the response surface methodology (Box-Behnken experimental design) to understand whether the impact is significant or not. Control factors, studied at 3 levels of variation, were age, monthly family income and family size. The responses for the experiment were the percentage of monthly income (per person) spent on clothing and the percentage of monthly clothing consumption spent on fast fashion. The study revealed that age and monthly family income have a strong influence on the percentage of monthly income spent on clothing, while family size has a negligible or no effect on the percentage of monthly income spent on clothing. It was also found that age, monthly family income and family size have a strong influence on the percentage of monthly clothing consumption spent on fast fashion. The demand for fast fashion and clothing is rising at a very high rate, which has made it hard for retail brands and apparel manufacturers to meet the consumer expectations. The analysis of consumer behaviour provides the advantage to fashion brands in anticipating and meeting consumer demands in a more efficient manner to create brand loyalty.
Keywords: fast fashion, fashion buying motives, consumer buying behaviour

Izvleček

Glavni namen študije je bil analizirati vpliv različnih atributov potrošnikov na vzorec potrošnje hitre mode. Proučevani so bili vplivi starosti potrošnika, prihodkov in velikosti družine na odstotek porabe mesečnega prihodka za oblačila in odstotek mesečne porabe oblačil hitre mode. V raziskavo so bili zajeti potrošniki iz regije glavnega mesta v Indiji. Uporabljena je bila vzročna raziskava. Korelacije med spremenljivkami so bile proučevane z metodo odzivnih površin (Box-Behnkenov eksperimentalni načrt), da bi razumeli, ali je vpliv posamezne spremenljivke statistično značilen. Kontrolni dejavniki, ki so bili proučevani na treh različnih ravneh, so bili starost, mesečni družinski prihodek in velikost družine. Odziva v eksperimentu so predstavljali odstotek mesečnega prihodka na osebo, porabljenega za oblačila, in odstotek mesečne porabe oblačil za hitro modo. Študija je razkrila, da starost in mesečni družinski prihodek močno

vplivata na odstotek mesečnega dohodka, namenjenega za oblačila, medtem ko ima velikost družine zanemarljiv ali nikakršen vpliv na odstotek mesečnega prihodka, namenjenega za oblačila. Ugotovljeno je bilo tudi, da starost, mesečni družinski prihodek in velikost družine močno vplivajo na odstotek mesečne porabe oblačil za hitro modo. Povpraševanje po hitri modi in oblačilih zelo hitro narašča, zato blagovne znamke in proizvajalci oblačil težko izpolnjujejo pričakovanja potrošnikov. Analiza vedenja potrošnikov omogoča učinkovitejše predvidevanje in zadovoljevanje potreb potrošnikov z namenom ustvarjanja zvestobe blagovni znamki.
Ključne besede: hitra moda, motivi za nakupovanje modnih oblačil, nakupno vedenje potrošnikov

1 Introduction

The success of fast fashion is embodied in offering trendy and fashionable merchandise at affordable price in a short span of time. Consumers discard garments very frequently due to boredom and communicative failure [1].The growth of fast fashion has forced the textile and apparel industry to make products with shorter lifespan and quicker production to satisfy impulse buying. Fast fashion retailers capture the market by following the latest fashion trends, displaying them in ever changing product offering [2].The fast fashion phenomenon has been studied from two different perspectives. One is from the supplier's perspective and another from the consumer's perspective. There have been many studies explaining the growth of fast fashion as a competitive advantage over other fashion suppliers; however, less research has been conducted in the field of fast fashion consumption from the consumer's perspective [3]. There is no empirical proof to depict the effect of change in consumer buying behaviour on the fast fashion growth. It has only been studied as a business model developed to address new challenges of the fashion industry [4].

Consumers start developing preferences for some products or brands over others in their early childhood as they confront different stimuli defining their decisions [5]. The development of the right product that satisfies consumers' needs is possible only by means of analysing and understanding the factors which affect the consumer buying behaviour [6], which encompasses all activities required to purchase a product or service. Consumers can be persuaded to purchase a particular product or service by influencing some factors that motivate them to buy [7]. Bringing cheaper replicas of high end fashion, fast fashion has seen enormous growth in the garment sector recently, capturing a huge share in the market [8, 9].

As depicted by the statistics from the clothing industry, consumers have been increasingly spending more on clothing in the past decade. The fashion and apparel industry has witnessed a massive rise in the sales from major fast fashion brands. The target market for fast fashion brands are females aged below 35. The age of consumers significantly influences the consumer buying behaviour. People tend to spend less on trendy clothes as they grow older. Consumers change their buying behaviour according to the change in their economic conditions [10]. In a major part of India, individual's economic condition depends on the family income and family size. In today's time, it has become a norm to stay updated with the latest trends and fashion. People want to look relevant with the emerging trends. As numerous styles and trends keep emerging, fast fashion brands have changed their marketing and advertising media. This can be partially attributed to the advent of social media. The number of social media users has increased from 970 million in 2010 to 4.48 billion in 2021, making social media indispensable in the lives of the majority of consumers, especially teenagers. Along with the massive growth of social media, numerous social media influencers have become popular over the last decade. Consequently, many brands have started hiring these influencers for advertising. This trend has evolved as a new channel of marketing. The fashion and apparel industry has been using celebrities to promote their products. Nevertheless, the factor responsible for the growth of influencer marketing is the consumers themselves, as it has been found that consumers relate more easily to an "ordinary" person. Social media has also changed the consumer behaviour by altering the spending options and patterns. It is driving fast fashion and people want products the very next day. This requires fashion retailers to develop and deliver products more quickly than ever before. Fast fashion has affected the way the clothing industry used to function along with consumer behaviour [11]. The competition on the market has become extremely harsh, luxury products and fast fashion merchandise have shorter lifespan, many options being available for the same category. Therefore, knowing the consumers and their preferences is of the essence [12]. Nevertheless, it will become very hard to check the impact of fast fashion clothing if it keeps progressing at the current pace. Apart from fast fashion, there is another evolving concept in the fashion industry, which is being referred to as ultra-fast fashion. This new category of fast fashion prefers less inventory, local manufacturing and short lead times with on demand manufacturing [13]. Short lead time, low prices and inexpensive manufacturing are the key characteristics of fast fashion. Consumer preferences are the most important factor to fast fashion brands. These retailers make all the efforts to reduce the time taken by garments to reach the retail stores [14]. The merchandise price has a significant impact on the consumer response to fashion. This has contributed for the popularity of fast fashion [15]. It is also found that consumers buy fast fashion products due to their desire for novelty. They make the buying decision after comparing all the available options on the basis of various parameters, e.g. price of the product/service, brand reputation and quality. Hence, consumers can be persuaded to purchase a particular product or service by influencing some of the factors that motivate them to buy [7].

The present study is an attempt to explain the impact of various consumer attributes on fast fashion consumption. The effect of consumer age, family income and family size on the fast fashion consumption pattern was studied in this research, employing comparative or causal, respectively, research. Causal research is employed to find causal relationships, i.e. cause and effect relationships, among individual variables. Although correlational research seeks and explains the relationships between two variables, it does not prove that either of the variables causes the other to behave in a particular way. In contrast, causal research has the ability to check whether one variable affects another variable. A quantitative survey was used to collect various data from consumers by means of questionnaires. The collected data was analysed to understand the buying pattern of fast fashion buyers. The correlation among the variables was studied using the response surface methodology (Box-Behnken design of experiment) to understand whether the impact is significant or not.

1.1 Theoretical background

Fast fashion is a collection of low cost fashion merchandise. It has captured a huge share in the market as cheaper replicas of high end fashion. Fast fashion has seen enormous growth in the garment sector recently, as consumers look at it as an affordable alternative to high end fashion. The emergence of fast fashion over the traditional 6-month-cycle fashion can be attributed to the consumers' changing lifestyle and preferences. Moreover, consumers are more knowledgeable and informed about the fashion trends now. Fast fashion offers them the opportunity to be in tune with the latest fashion at affordable cost [16]. Fast fashion retailers offer a new product range in every two to six weeks at a very affordable price [17].

1.1.1 Factors influencing consumer buying behaviour

The influence of some factors can be temporary while for others, it could be long lasting. Some of the influencing factors are listed below.

Marketing factors

The marketing mix, i.e. product, price, promotion and place, can significantly influence the buying decision. Product uniqueness, physical shape/structure and product packaging may influence consumer buying decision. The price of a product is a very important factor, as consumers will make the purchase only if the price is within the scope of their budget. Promotion also has the potential to affect the purchase decision. Publicity, advertising, sales promotion etc. should be planned as per target consumers. Furthermore, place has a significant impact on consumer buying behaviour. The channel and place of distribution need to be appropriate for target consumers [18].

Psychological factors

Factors related to psychology are major drivers for consumer buying behaviour. There are four aspects of psychological factors. These include motivation, perception, learning and attitude. The motivation is the inner factor responsible for consumers' particular behaviour. Hence, consumers can be persuaded to purchase a particular product or service by influencing the factors that motivate them to buy. The perception is the impression created in the minds of consumers about a product, service or brand. The motivation makes the consumers to act; however, the direction of the action is decided by the consumers' perception. Information can be gathered by experience or feedback from others [18].

Social factors

Aristotle said that humans are social animals [18]. Therefore, it is very natural for all humans to have the desire to be socially accepted. This is reflected in their buying preferences as well. Social factors include family, friends, reference groups and status/role in the society. Family is the main social factor influencing consumer buying behaviour. However, today, consumers are well connected with other sources that can have a significant influence on their purchase decisions. Consumers tend to buy clothes according to the roles or status in the reference group. The reference group may influence consumers' purchase decision by affecting their values, attitudes and exposing them to new lifestyles [18].

Cultural factors

Culture is considered to be the most comprehensive influencing factor for consumer buying behaviour. People from the same culture share the same ideologies and values. The culture has a very powerful effect on the purchase intentions of consumers. The cultural factors include culture, subculture and social class. Cultural ideologies, values and beliefs are transferred down the generations via family, society, educational organisations etc., e.g. clothing choices of consumers are affected by their religious beliefs. As there are many sub-cultures in any culture, it is hard to develop a marketing plan catering to one culture. Therefore, retailers should develop a multi-cultural approach for marketing by designing, developing and distributing merchandise to satisfy the needs of consumers from various cultures and sub-cultures [18].

Personal factors

Personal factors are the factors which are very personal and hence different for everyone. This leads to varying expectations, perceptions and consumer buying behaviour. Personal factors include age, gender, personality, occupation and lifestyle. The age of consumers significantly influences consumer buying behaviour. People tend to spend less on trendy clothes as they grow older. Female consumers may spend more on fast fashion if compared to male consumers. Working employees and professionals may prefer formal clothing over casual wears. Thus, it is very important for brands to consider the personal factors of their target consumers as well [18].

Economic factors

Economic conditions and factors have a major effect on consumer buying behaviour. Various aspects of economic factors are national economic situation, personal income, family income and liquid assets. Consumers change their buying behaviour in line with the change in their economic conditions. The buying behaviour is also affected by the economic conditions of countries and the global market [18].

1.1.2 Motives for fast fashion buying

The fashion sense for consumers within the age group 18–23 years is influenced by their self-image, whereas the fashion sense for consumers within the age group 24–29 years and 30–35 years is influenced by media exposure [19]. Hence, age has a dominant effect on consumer buying decisions. Consumers start developing preferences for some products or brands over others in the early childhood as they confront different stimuli defining their decisions [5]. Brand and product promotion has come out to be a great method to alter the preferences of consumers and influence their buying choices. Advertisements have the strength to persuade the consumer's buying decision. This effect is vastly positive [20]. It is very much evident that there are also psychological factors that influence the buying decisions as there are many people who cannot understand their own decision after buying a product [21]. Marketing strategies are based on consumer psychology as it is very important to comprehend the mental stimuli of the buying decision process [6]. Consumers are influenced by advertisements, as are their buying decisions [12]. The purchase decisions have been explored from many different approaches, e.g. rational, emotional, cognitive aspects etc., to arrive at certain conclusions [22]. Fashion buying is related more to emotional buying behaviour which follows the irrational decision making process. This is identified with a sudden rise of desire to buy and satisfy the need by immediately making the purchase [23]. A remarkable proportion of sales is generated through the unplanned purchases that were not intended prior visiting the store [24]. Fashion buying is more related to impulse buying, which happens with a generated sudden strong emotional need. It is characterised by low cognitive and rational control. The buyers seek immediate gratification in such a type of buying decisions [25,26]. In addition to being emotional, fashion buying is affected by several other factors as well [27]. Brand loyalty is a result of the interaction between a consumer and a shopping environment. All characteristics of the environment, consumer's psychological and emotional state, available knowledge and brand personality will affect the end decision [28]. In impulse buying, there is a lack of emotional control originating from the conflict of negative consequences and immediate satisfaction [29].

The fast fashion buying decision is found to be influenced by the consumer's desire to blend in with the social group and create a unique self-identity [30]. Consumers make the buying decision influenced by certain factors which are responsible for that particular buying behaviour. Consumers buy products to satiate their needs, wants and purchasing capacity at a given time [31]. They have become a huge dynamic force to drive the economy after the increase in their income. As the income increases, so does the freedom to save or spend. The concept of discretionary income is driven from the concept of surplus income or comparative increase in income. Discretionary income refers to the amount of income of an individual left after paying the taxes and necessities such as rent, utilities, credit card debts and student loans. The central idea behind the discretionary income is the complete control of consumers over the allocation of that income regarding the amount to be saved and spent. In case of discretionary income, consumers have options other than compelled buying decisions or the purchasing absolutely necessary products. Consumers are found to be spending the major portion of their discretionary income on luxury goods and for recreational purpose. There are three major characteristics of discretionary expenses. The first one is not having any compelling need for making that expense. The second is not being a habitual expense and the third is not being the decision taken in the heat of the moment. Hence, discretionary expenditure is related to the buying of all the non-necessary items [32].

The clothing industry is a consumer-centric industry. It is nearly $2 trillion in size globally, despite having seen a slight downfall due to the impact of Covid-19. Fashion and clothing are the top preferences of consumers when they decide to buy non-essential goods. The fashion and apparel industry is also known as the employment generating industry [33]. The demand for fast fashion and clothing is rising at a very high rate. This has made it hard for retail brands and apparel manufacturers to meet consumer expectations. The analysis of consumer behaviour provides the advantage to fashion brands in anticipating consumer demands. The fashion buying behaviour has reflections of socioeconomics as it is affected by the purchasing power of consumers. The buying behaviour of a fashion consumer is a complex phenomenon. The fashion buying is affected by various factors other than socioeconomics, e.g. cultural, social and psychological factors. Fashion brands have to be aware of the factors affecting their target market. The product suitable for a target market can be offered only by ensuring the factors driving the target consumers are identified and utilised in product development. The major challenge faced by retail brands is expanding their consumer base while maintaining the existing one. All consumer factors such as age, income, educations and social background have a significant impact on consumer buying behaviour. For instance, the demand for fast fashion is increasing among consumers, especially teenagers, despite its negative environmental and social implications. It is very important to forecast the consumer demand to develop the right product for the market [34]. Fashion retailers will be unable to affect the buying decision of consumers unless they have a thorough comprehension of the factors which influence consumer buying behaviour [35].

2 Methodology

The consumers of NCR (National Capital Region) of India were studied in this study. Exponential non-discriminative snowball sampling was employed to collect data. This sampling method is majorly used in research for an unknown and rare population. It is used for the situations when it is difficult to select respondents for the sample. It is a very fast, cost-effective and convenient method of sampling for such studies. A quantitative survey was used to collect input data from consumers through a structured questionnaire.

Questionnaire for fast fashion consumption pattern

Fast fashion describes low-priced yet stylish clothing that moves quickly from design to retail stores to meet trends, with new collections being introduced continuously. Brands like Zara, H&M, UNIQLO, GAP and Topshop are examples from the fast fashion field.

Below follow the categories from the questionnaire for collecting data:

** Required*

1. Name *
2. E-mail
3. Mobile number
4. Age *
   - 25 Years
   - 30 Years
   - (C) 35 Years
5. Gender *
   - Male
   - Female
6. Occupation *
7. Monthly income (INR) *
8. Number of members in family (Family size) *
9. Monthly family income (INR) *
10. Amount spent on clothing in a month (INR) *
11. Amount spent on fast fashion in a month (INR) *

The questionnaire was shared online with the respondents. Causal research was employed in this study, which is used to find causal relationships, i.e. cause and effect relationships among variables. Although correlational research seeks and explains the relationships between two variables, it does not prove that either of the variables causes the other to behave in a particular way. In contrast, causal research has the ability to check whether one variable affects another variable.

The collected data was analysed to understand the buying pattern of fast fashion buyers.

The correlations among the variables were studied using the response surface methodology (Box-Behnken experimental design) to understand whether the impact of control variables on the observed responses is significant or not.

Scrutinised control factors for the experimental design were age, monthly family income and family size. The selected age group was not a part of "Gen Z". The responses for the aforementioned research design were the percentage of monthly income spent on clothing and the percentage of monthly clothing consumption spent on fast fashion. The levels of variations can be seen in Table 1. A three-factor and three-level Box-Behnken experimental design considering three-centre nodes as depicted in Table 2 was used for sample planning for the number of runs to be optimised. Such an experimental design is very useful to create the response surface of higher order with fewer required runs in comparison to a conventional factorial design. The sample size per run was 150–250, depending on the coefficient of variation of the respective run (Table 2). The total number of responses received was 2750. Suitable replication, randomisation and blocking were incorporated in the Box-Behnken experimental design.

3 Results and discussion

Various levels of factors and their corresponding responses are depicted in Table 2. The influence of control variables on the responses was studied using ANOVA analysis at 95% level of confidence with the help of design expert software. The significance of influence was studied on the basis of p-value. The p-value lower than 0.05 suggests that there is a strong effect, whereas the p-value higher than 0.05 suggests that there is a weak effect of control factors over the responses. The independent control factors, i.e. age, monthly family income and family size, were studied to assess the statistical significance. The ANOVA summary is as depicted in Tables 3 and 4.

3.1 Effect of control variables on percentage of monthly income spent on clothing

The results show that age has a strong influence on the percentage of monthly income spent on clothing. It was observed that with increasing age, the percentage of monthly income spent on clothing reduced. The major cause for this behaviour is the availability of discretionary income. At higher age,

Table 1: Control variables and corresponding levels of variation

Control variables	Levels of variation		
	–1	0	+1
Age (years)	25	30	35
Monthly family income (INR)	50,000	1,00,000	1,50,000
Family size	2	3	4

Table 2: Control factors and corresponding observed responses

Runs	Control variables			Observed responses	
	Age (years)	Monthly family income (INR)	Family size	Percentage of monthly income *(per person)* spent on clothing	Percentage of monthly clothing consumption spent on fast fashion
1	–1	–1	0	16.98	46.88
2	1	–1	0	13.17	33.47
3	–1	1	0	23.05	70.43
4	1	1	0	20.14	57.43
5	–1	0	–1	15.95	60.51
6	1	0	–1	17.45	56.78
7	–1	0	1	21.27	53.77
8	1	0	1	14.62	51.67
9	0	–1	–1	13.56	52.14
10	0	1	–1	21.17	62.33
11	0	–1	1	14.78	45.67
12	0	1	1	20.05	55.37
13	0	0	0	16.08	55.12
14	0	0	0	15.71	54.37
15	0	0	0	15.09	52.26

Table 3: ANOVA general quadratic model summary through p-value analysis for percentage of monthly income spent on clothing

Factors	A – Age	B – Monthly family income	C – Family size
p-value	0.0006	< 0.0001	0.1583

Table 4: ANOVA general linear model summary through p-value analysis for percentage of monthly clothing consumption spent on fast fashion

Factors	A – Age	B – Monthly family income	C – Family size
p-value	0.0003	0.0168	0.0001

the discretionary income is reduced due to the increase in liabilities. The graphical representations of the effect of control variables on the percentage of monthly income spent on clothing are shown in Figure 1.

Monthly family income also has a strong influence on the percentage of monthly income spent on clothing. It was observed that with increasing family income, the percentage of monthly income spent on clothing increased. Similarly as with age, the availability of discretionary income could be the reason for this behaviour here as well. Individuals with higher family income most likely have higher discretionary income.

Family size has a negligible or no effect on the percentage of monthly income spent on clothing. The effect of family size was not observed in this study. This could be attributed to a narrow range of variation in the factor. The effect of family size may be evident at larger family size.

3.2 Effect of control variables on percentage of monthly clothing consumption spent on fast fashion

The results showed that age has a strong influence on the percentage of monthly income spent on clothing. It was observed that with increasing age, the percentage of monthly clothing consumption spent on fast fashion reduced. The major cause for this behaviour is the availability of discretionary income. At higher age, the discretionary income is reduced due to the increase in liabilities.

Monthly family income also has a strong influence on the percentage of monthly income spent on clothing. It was observed that with increasing family income, the percentage of monthly clothing consumption spent on fast fashion increased. Individuals with higher family income most likely have higher discretionary income.

It was observed that with increasing family size, the percentage of monthly clothing consumption spent on fast fashion reduced. The effect of family size is

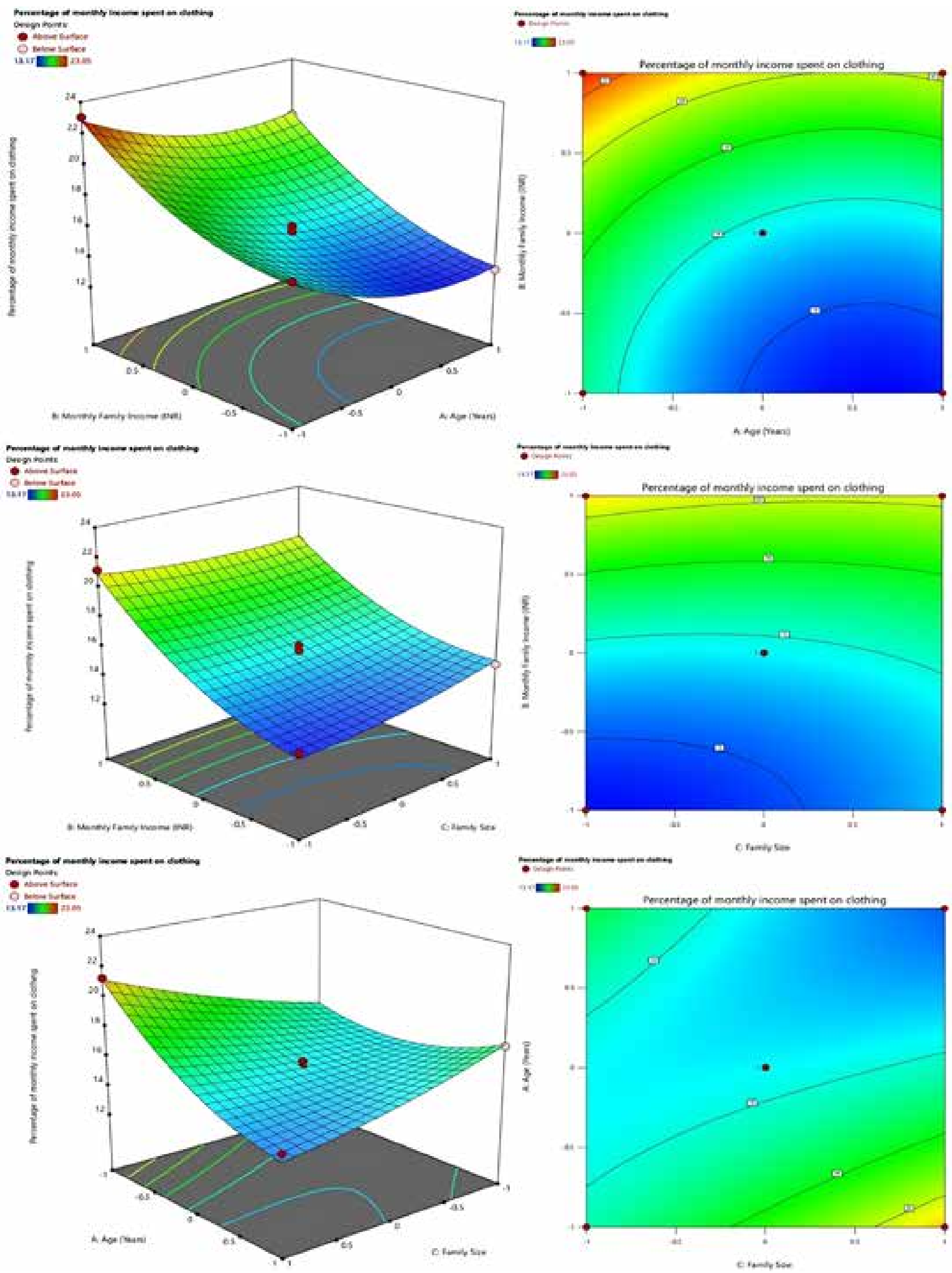

Figure 1: Effect of control variables on percentage of monthly income spent on clothing (ANOVA general quadratic model)

more dominant in this case. Individuals with larger family size most likely have lower discretionary income due to higher liabilities.

In consequence, young individuals with higher family income spend more on clothing, and young individuals with higher family income and smaller family size spend more on fast fashion. It can thus be stated that clothing and fast fashion consumption is inversely related to the age and family size factors, and directly related to the family income factor. The graphical representations of the effect of control variables on the percentage of monthly clothing consumption spent on fast fashion are shown in Figure 2.

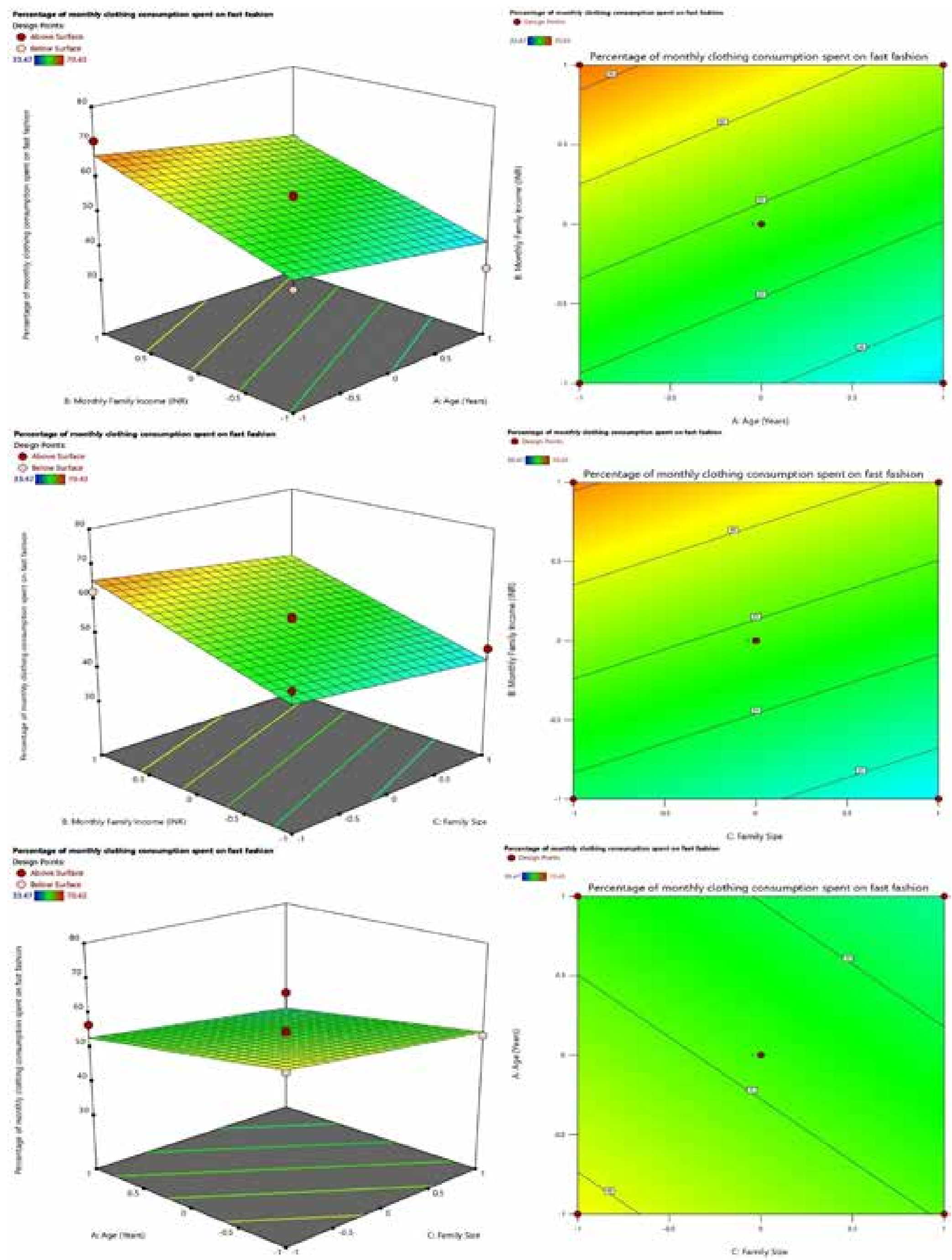

Figure 2: Effect of control variables on percentage of monthly clothing consumption spent on fast fashion (ANOVA general linear model)

4 Conclusion

This study illustrates the impact of various consumer attributes on fast fashion consumption. The effect of consumer age, family income and family size on the fast fashion consumption pattern was studied in this research. It was established that age and monthly family income have a strong influence on the percentage of monthly income spent on clothing, while family size has a negligible or no effect on the percentage of monthly income spent on clothing as contour plots depict in Figure 1. The p-values for age, monthly income and family size are 0.0006, < 0.0001 and 0.1583, respectively. It was observed that with increasing age, the percentage of monthly income spent on clothing reduced, while with increasing family income, the percentage of monthly income spent on clothing increased. This is aligned with monthly family income and family size being found to have a strong influence on the percentage of monthly clothing consumption spent on fast fashion as contour plots depict in Figure 2. The p-values for age, monthly income and family size are 0.0003, < 0.0168 and 0.0001, respectively. The effect of family size is more dominant in this case. It was observed that with increasing age and family size, the percentage of monthly clothing consumption spent on fast fashion reduced, while with increasing family income, the percentage of monthly clothing consumption spent on fast fashion increased. Young individuals with higher family income spend more on clothing and young individuals with higher family income and smaller family size spend more on fast fashion. It can hence be stated that clothing and fast fashion consumption are inversely related to the age and family size factors, and directly related to the family income factor.

The study results are aligned with the existing studies as mentioned in the theoretical background of the paper. Earlier studies were vastly focused on variables such as age, gender, price and personal income. The work on the effect of family size and family income is scarcer. These factors are required to be explored in more detail.

This research has been performed over a narrow range of variation in the factors. The effect of some factors may not be evident in this study, which could be attributed to a narrow range of variation in the factors. The effect of these may be evident at a higher variation level.

The demand for fast fashion and clothing is rising at a very high rate. This has made it hard for retail brands and apparel manufacturers to meet consumer expectations. The analysis of consumer behaviour provides the advantage to fashion brands in anticipating consumer demands.

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