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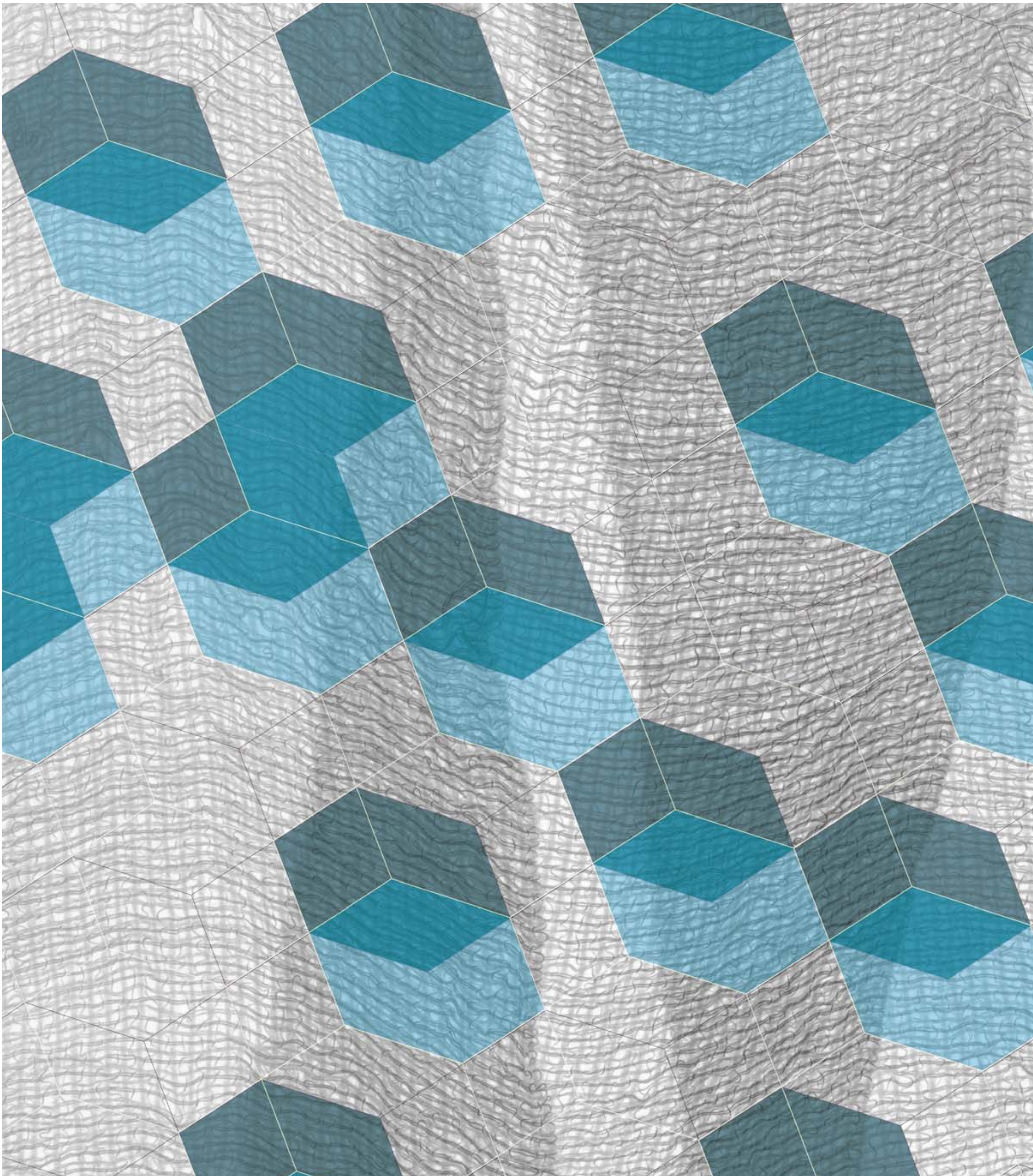

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Evaluation of Personal Factors of Workers Affecting Productivity in RMG Sector in Bangladesh

Vpliv značilnosti osebnih dejavnikov zaposlenih na produktivnost sektorja konfekcioniranih oblačil v Bangladešu

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Abstract
The readymade garment sector in Bangladesh is considered the backbone of earning foreign currency that includes a large number of workers and is mostly responsible for the economic growth of the country. Nevertheless, despite the remarkable growth of the RMG sector and its bright projection, impediments need to be overcome as well. Readymade garment industries in Bangladesh are currently facing some challenges to ensure fire safety and better work environment for garment workers. Apart from several technical factors, personal factors of workers, e.g. education, age, training, work experience and motivation, might also have a substantial impact on the increase in productivity to compete in the global export market. Thus, it was vital to observe the impacts personal factors of workers have on the productivity of readymade garment industries. This study enabled an identification of personal factors of workers which affect the productivity of readymade garment industries. The factors were examined through some critical analyses, e.g. hypothesis test, factor analysis and fishbone diagram analysis. After the investigation of empirical data, principal factors were identified and highlighted to improve the productivity in these industries.
Keywords: personal factors, productivity, readymade garment sector, fishbone diagram analysis

Izvleček
Sektor konfekcioniranih oblačil v Bangladešu, ki velja za najpomembnejšega pri pridobivanju tujih valut, vključuje veliko število delavcev in je večinoma odgovoren za gospodarsko rast v državi. Kljub temu, da sektor hitro raste in ima svetlo prihodnost, obstajajo prepreke, ki jih mora premagovati. Konfekcijska oblačilna industrija v Bangladešu se danes sooča z izzivi, kako zagotoviti požarno varnost in boljše delovno okolje. Poleg številnih tehničnih dejavnikov imajo lahko tudi osebni dejavniki delavcev, kot so izobraževanje, starost, usposabljanje, delovne izkušnje in motivacija, pomemben vpliv na povečanje produktivnosti, da bi lahko konkurirali na svetovnem izvoznem trgu. Zelo pomembno je spremljati vplive osebnih dejavnikov delavcev na produktivnost konfekcioniranih oblačil. V tej raziskavi so bili prepoznani osebni dejavniki delavcev, ki vplivajo na produktivnost konfekcijske oblačilne industrije, in ovrednoteni z uporabo kritičnih analiz, kot so preverjanje hipotez, faktorska analiza in analiza diagrama ribje kosti. Na osnovi raziskave empiričnih podatkov so bili določeni in poudarjeni glavni dejavniki za izboljšanje produktivnosti v industriji.
Ključne besede: osebni dejavniki, produktivnost, sektor konfekcioniranih oblačil, analiza diagrama ribje kosti

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1 Introduction

Productivity is one of the prime concerns in every production-oriented organisation. It typically represents the efficiency of manpower employed in an industry. Apart from the quality and price, productivity has become the fundamental factor in the readymade garment (RMG) sector as retailers have been in the past couple of years continuously asking to decrease the production time. On the other hand, the industries must not only maintain but also increase the productivity of workers. According to Halder *et al.* [1], the owners should analyse the underlying factors that contribute to variation in the production of the RMG industry. The productivity in apparel industries is largely associated not only with monetary factors but also with work environment and other nonfinancial incentives. According to Hossan *et al.* [2], the work environment and other incentives increase workers' focus on work, raising workers' income and employer's profit. In addition, Ferdous [3] stated that on time payment of wages, increments on a regular basis, allowable facilities, treatment by production officers and managers, safe work environment, availability of healthy foods, a day care and medical centre are some of the key factors that also have a substantial impact on both workers' satisfaction and productivity. Several researches have been conducted in the field of workers' productivity in different industries and Kazaz *et al.* [4] suggested that basic motivational factors can also improve the productivity of workers in the RMG industries. Burton et al. [5] tried to find out among the personal factors the effects of health risk and diseases on workers' productivity, and they reported that health risk and workers' productivity are inversely proportional, meaning that productivity decreases with increased health risk. On the other hand, Halkos and Bousinakis [6] examined the effects of stress and satisfaction on employees' productivity and they found that it was accelerated with increased satisfaction and decreased stress. Furthermore, Saha and Mozumder [7] studied the effects of work environment on the productivity of RMG industries in Bangladesh. According to them, ineffective management was considered the foremost reason for bad work environment that subsequently leads to poor productivity. Again, Vanours and Stoeldraijer [8] observed that workers aged between 30 and 45 years are the most productive and stated that wage costs increase with age while productivity goes down with age. Day care facilities offered to working parents also have an impact on productivity. According to Shellenback [9], about 29% of working parents in different organisations witnessed a loss in productivity due to being absent from work as there were no child care facilities available in the work institution. Training is another significant factor that can also influence workers' performance. It was reported by Degrip and Sauermann [10] that trainings are imperative to improve productivity and active involvement in trainings can increase workers' performance by 10%.

However, all of the above studies did not bring out the impacts of all personal factors on productivity, especially in the RMG sector in Bangladesh. Therefore, this paper focuses on the evaluation of effects of major personal factors of workers that lead to poorer productivity in the RMG sector in Bangladesh.

2 Methodology

The study was performed in four RMG industries in Bangladesh, i.e. Style Garden Ltd, Fakir Apparels Ltd, AJI Apparels Industry Ltd and MIM Dresses Ltd, which vary in their workforce, production capacity and product category (woven or knit fabrics). The aim of this study was to identify and examine the impact of personal factors of workers on the productivity in the RMG sector in Bangladesh. We wanted to establish to what extent personal factors have adverse effects on productivity, how important some specific personal factors are to enhance workers' productivity. Furthermore, we wanted to obtain various aspects related to personal factors of workers and productivity in the garments sector that improve the understanding of concepts.

The survey was divided into two sections. In the first section, demographic data was collected and in the second section, several questions were posed to respondents to state their agreement with each of the statement on a five-point rating scale (1-strongly disagree, 2-disagree, 3-neutral, 4-agree, 5-strongly agree). In this survey, the following questions were incorporated into the questionnaire:

1. To what extent does the age of workers influence the productivity of RMG industries?
2. To what extent does the institutional knowledge of workers impact on the productivity of RMG factories?

3. To what extent does the work experience impact on the productivity of RMG factories?
4. To what extent do trainings, workshops and technical experience impact on the productivity of RMG industries?
5. To what extent does the safety- and security-related knowledge impact on the productivity of RMG industries?
6. To what extent does the payment of wages or salaries impact on the productivity of RMG industries?
7. To what extent do the ventilation and lighting facilities impact on the productivity of RMG industries?
8. To what extent do baby day care facilities impact on the productivity of RMG industries?
9. To what extent does supervision impact on the productivity of RMG industries?
10. To what extent do rewards and incentives impact on the productivity of RMG industries?
11. To what extent do wage or salary increments impact on the productivity of RMG industries?
12. To what extent does promotion impact on the productivity of RMG industries?
13. To what extent does political turmoil impact on the productivity of RMG industries?
14. To what extent does the efficiency of co-workers impact on the productivity of RMG industries?
15. To what extent do biasness and discrimination in the workplace impact on the productivity of RMG industries?

The questionnaire was completed using face-to-face interviews within 30 days in 4 different garment factories in Dhaka and nearby places. There were a total of 8,356 workers in four garment factories; however, we completed around 112 questionnaires and after eliminating those with unusual errors, we retained 100 questionnaires. 65% of them were answered by skilled workers, the second most dominant group of respondents being semiskilled workers (24%). The sample was unbalanced in terms of gender ratio, as 32% was male and 68% female. Most respondents were aged between 20 and 25 (78%) and 18% were older than 25. To have enough time to go through the whole questionnaire and answer all questions, including those that require more time, we conducted the interviews at respondents' convenience.

Several researchers have used the factor analysis in their investigations for data exclusion, e.g. BASHIR *et al.* [11] used the factor analysis in their study to identify the key obstacles that were responsible for preventing productivity enhancement programmes in the manufacturing industries in Oman. Following this work, Rocha and Gonçalves [12] also used the critical analysis to identify the essential indicators of productivity in the red ceramic industry in Brazil. These researchers used the factor analysis in their study to reduce data to form different clusters from highly correlated factors which were then labelled accordingly. Additionally, the principal component analysis (PCA) is another dimension-reduction tool and a statistical technique to emphasise variation and bring out robust patterns in a dataset. It is frequently used to investigate and visualise data more easily. Nevertheless, this study was restricted to the factor analysis only.

Table 1: Discrete statistics

Factory name	Total work-force	Female workers [number/%]	Male workers [number/%]	Workers age [years/%]				
				15–25 years	26–35 years	36–45 years	46–55 years	56 years and above
Style Garden	107	73/68.2	34/31.8	85/79.4	17/15.9	3/2.8	2/1.9	0/0
Fakir Apparels	7624	5521/72.4	2103/27.6	5954/78.1	1330/17.	247/3.2	86/1.1	7/0.09
AJI Apparels Industry	487	323/66.3	164/33.7	375/77.0	85/17.5	18/3.7	7/1.4	2/0.4
MIM Dresses	138	97/70.3	41/29.7	113/81.9	17/12.3	5/3.6	2/1.4	1/0.7

3 Results and discussion

This study represents the statistics (cf. below) about the total work force in four different factories, and its breakdown regarding women-men and age structure.

From Table 1, it becomes obvious that more female workers are employed in the RMG factories that were included in the study. If compared to the age group 26–35 years, more workers are younger than 26 and belong to the age group 15–25 years. It is also essential to mention that all factories showed reluctance to recruit workers aged 36–45 years, 45–55 years or more than 56 years, and there are very few employees found in the analysed industries from these age groups.

In this study, 15 variables (short-listed from reviewed literature on related subject matter) were taken into consideration. An appropriate factor analysis can transform these variables into common variables only when correlations exist among them. These variables are stipulated below:

1. Age of workers
2. Institutional knowledge
3. Work experience
4. Trainings, workshops and technical experience
5. Safety- and security-related knowledge
6. Payment of wages or salary
7. Ventilation and lighting facilities
8. Baby day care facilities
9. Supervision
10. Rewards and incentives
11. Increment of wages or salary
12. Promotion
13. Political turmoil
14. Efficiency of co-workers
15. Biasness and discrimination in workplace.

Bartlett's test of sphericity was used to test the null hypotheses that the variables in the study are not correlated with each other. In other words, the null hypothesis states that the population correlation matrix is an identity matrix. In an identity matrix, all diagonal terms are 1 and all off-diagonal terms are 0. The test statistics for sphericity is based on a chi-square transformation of the determinant of the correlation matrix. A large value of test statistics will favour a rejection of the null hypotheses. If this hypothesis cannot be rejected, the appropriateness of factors is questioned. Another useful statistics is the Kaiser Meyer-Olkin (KMO) measure of sampling adequacy. This index compares the magnitudes of observed correlation coefficients to the magnitudes of partial correlation coefficients. Small values (below 0.5) of KMO statistics indicate that the correlations between pairs of variables cannot be explained by other variables and a factor analysis may not be appropriate.

It is quite evident from Table 2 that the factor analysis is appropriate. Here, the KMO value is 0.633, i.e. between 0.5 and 1.0, and the approximate chi-square statistic is 605.475 with 105 degrees of freedom, which is significant at the 0.05 level. Therefore, the null hypotheses can be rejected and alternative hypotheses that all variables are correlated with each other can be accepted. To analyse the variables ranging from V_1 to V_{15}, the factor analysis was used for data reduction. This analysis depicts the most important personal factors that can influence the level of productivity in the RMG industry of Bangladesh.

Table 3 shows that only 5 factors were extracted, as the cumulative percentage is greater than 65% at this point and eigenvalue is greater than 1.0 (it is recommended that factors with Eigen values greater than 1.0 be retained), which indicates the analysis adequacy using derived factors.

The extracted 5 factors can be interpreted in terms of variables that prioritize high coefficients. It can be seen in Table 4 that component or factor 1 has

Table 2: Kaiser-Meyer-Olkin and Bartlett's test

Kaiser-Meyer-Olkin measure of sampling adequacy		0.633
Bartlett's test of sphericity	Approx. chi-square	605.475
	Df[a)]	105
	Sig.[b)]	0.000

[a)] Degree of freedom

[b)] Level of significance

Table 3: Total variance explained

Component	Initial Eigen values			Extraction sums of squared loadings			Rotation sums of squared loadings		
	Total	Variance [%]	Cumulative [%]	Total	Variance [%]	Cumulative [%]	Total	Variance [%]	Cumulative [%]
1	3.181	21.207	21.207	3.181	21.207	21.207	2.642	17.611	17.611
2	2.339	15.594	36.801	2.339	15.594	36.801	2.103	14.022	31.633
3	2.075	13.832	50.633	2.075	13.832	50.633	1.883	12.554	44.187
4	1.556	10.372	61.005	1.556	10.372	61.005	1.842	12.281	56.468
5	1.107	7.379	68.384	1.107	7.379	68.384	1.787	11.916	68.384
6	0.917	6.111	74.495						
7	0.761	5.070	79.565						

Extraction method: Principal component analysis.
NB: For convenience, other components were discarded by the researchers.

high coefficients for rewards and incentives (0.742), increment of wages or salary (0.679), and promotion (0.727). As rewards, incentives, increments and promotions give recognition to workers for their work in all organisations, and encourage them to concentrate on work even more, this factor was labelled *"Motivation"*. On the other hand, factor 2 has high coefficients for the payment of wages or salary (0.798), ventilation and lighting facilities (0.823), baby day care facilities (0.847) and supervision

Table 4: Rotated component matrix

Personal factors of workers	Component 1	2	3	4	5
Age of workers	0.298	–0.175	0.324	0.229	**0.683**
Institutional knowledge	0.231	0.017	–0.171	**0.782**	0.240
Work experience	–0.085	0.072	0.066	0.058	**0.860**
Trainings, workshops and technical experience	–0.124	–0.071	0.031	**0.725**	–0.556
Safety and security related knowledge	–0.254	0.459	0.049	**0.624**	0.047
Payment of wages or salary	–0.173	**0.798**	0.136	–0.067	0.211
Ventilation and lighting facilities	–0.109	**0.823**	0.144	–0.241	0.122
Baby day care facilities	0.044	**0.847**	–0.039	–0.117	–0.083
Supervision	0.087	**0.719**	–0.216	0.179	0.032
Rewards and incentives	**0.742**	–0.051	–0.288	–0.161	0.042
Increment of wages or salary	**0.679**	0.197	0.046	0.627	–0.411
Promotion	**0.727**	0.352	–0.287	–0.203	0.335
Political turmoil	0.396	0.320	**–0.726**	0.462	0.210
Efficiency of co-workers	–0.191	0.453	**–0.531**	0.324	–0.469
Biasness and discrimination in workplace	0.390	0.446	**–0.646**	–0.375	0.445

Extraction method: Principal component analysis.
Rotation method: Varimax with Kaiser normalisation.

(0.719). The assurance of getting on time wages or salary, good ventilation and lighting facilities in the organisation, baby day care facilities offered within the company and appropriate attitude of supervisors satisfy workers to a great extent; therefore, this factor was reflected as *"Overall satisfaction"*. Moreover, factor 3 has negative coefficients for political turmoil (–0.726), efficiency of co-workers (–0.531), and biasness and discrimination in the workplace (–0.646). Since political instability, poor cooperation of workers in the vicinity and unfairness of the management hinder pleasant work life, this factor in this study was identified as *"External hurdles"*. Apart from this, factor 4 has very high coefficients for institutional knowledge (0.782), trainings, workshops and technical experience (0.725), and safety- and security-related knowledge (0.624). The essential knowledge from academies, trainings and workshops make workers skilled, as they get technical experience along with safety and security knowledge; thus, this factor was called *"Skills"*. Lastly, factor 5 has a very high coefficient for the age of workers (0.683) and work experience (0.860). The age and job experience of workers are essential to resolve critical problems that impede the productivity of manufacturing industries. This factor was labelled *"Age and work experience"*.

Previous statistical analyses revealed that some specific personal factors of workers enhance the level of productivity in the RMG industry. A further discussion on these extracted factors follows below:

i) **Motivation**: From the analysis, it was clear that there are also other parameters apart from monetary benefits that catalyse workers to perform at their best level. It became evident during the survey that the workers of MIM dresses are relatively satisfied, since they are given various rewards and incentives, and regular promotion; moreover, they are pleased as they meet their production target. Regular increments also make workers think in a positive way. The arrangement of such nonmonetary motivation helps workers consider the company as their own and they see their whole future in the betterment of that company. As a result, the productivity of motivated workers increases substantially.

ii) **Overall satisfaction**: It has been found that most workers are semiskilled and their institutional knowledge is also not extremely high. Furthermore, workers' expectation in the RMG sector is greatly associated with due payment of their salary and wages. Again, the majority of workers are female in these factories and married workers prefer having baby day care facilities in their workplace for them to be able to concentrate fully on work. The suffocated environment and improper supervision are two major factors according to respondents that inhibit workers' performance level more significantly. In Style Garden Ltd, workers were found to be considerably satisfied and engaged in the production process, as the factory has a good ventilation arrangement and proper supervision from the management. Thus, due time paid salary and wages, presence of baby day care facilities, work environment and proper supervision play a substantial role in the improvement of productivity of RMG industries.

iii) **External hurdles**: It was also found that except for the above stated personal factors, there are some other factors that can influence productivity. The political environment imposes a major threat for the garment industry in Bangladesh. Sometimes, consequences are so severe that people are compelled to go out to earn their livelihood by risking their life during political turmoil. This way, they always remain in an insecure position that can harm their productivity; nevertheless, it was established that the political situation does not have that much of an influence on the job as does not the absence of assistance from inefficient co-workers. Discrimination and biasness in the workplace hurt the moral philosophy of workers and hence lower their productivity in the workplace.

iv) **Skills**: Skills always give an extra advantage to the workers in the RMG industry. The level of productivity particularly depends on how skilled the workers are. Skills mainly come from some intermediate factors, e.g. institutional knowledge, trainings or workshops, and technical experiences, which are imperative for performing any specific work. Additionally, it is also important for a worker to have knowledge about the safety and security issues which are highly associated with that particular job. Productivity means how efficiently the lowest input can be transformed into the highest output, so it can be considered as one of the most influential personal factors.

v) **Age and work experience**: It was common while surveying workers that persons from the eldest age group, with more experience in that particular factory and in other garments, were applauded by others as they do their work more effectively and efficiently. Usually, they give first hand guidelines to other workers who have just joined the company and motivate them to work productively. It was found out that the productivity of workers depends on how experienced they are, where age is also a point of consideration.

After the factor analysis, five personal factors were extracted and labelled accordingly. The fishbone diagram (cf. Figure 1) also helped exhibit root causes that resulted in poorer productivity in four RMG industries in Bangladesh.
Figure 1 shows a fishbone diagram that identifies principal causes of poorer productivity in the RMG industries, such as motivation, overall satisfaction, external hurdles, skills, and age and work experience.

4 Conclusion

The RMG sector in Bangladesh has been facing its unprecedented growth in comparison to previous decades and now is the right time for the RMG sector to introduce Bangladesh as an industrialised country to the world. Nevertheless, the problem is that Bangladesh can hardly capitalise its human and other resources which would give it a much needed competitive advantage towards other rival countries. Therefore, it is essential to boost up the productivity of the RMG industries to the highest level through the reconciliation of all adverse issues that can have even a slim negative impact on this giant sector. This study mainly emphasised major personal factors of workers that affect industrial productivity. However, other technical matters are also accountable and have a substantial influence on the productivity in the RMG factories. Henceforth, this research article becomes very much noteworthy for the people of the RMG sector to identify the key

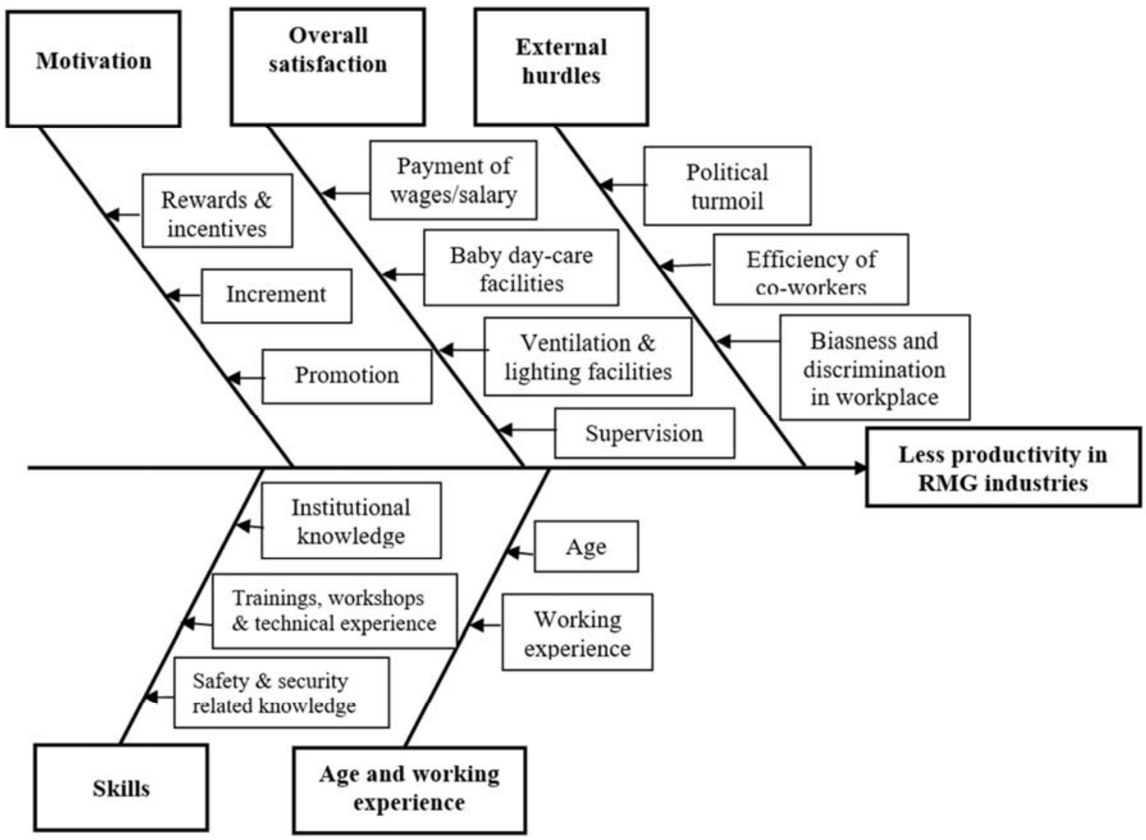

Figure 1: Fishbone diagram representing effects of workers' personal factors on productivity in RMG industries in Bangladesh

personal factors of workers that have evident impacts on this giant sector.

Acknowledgements
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Prognosis of Dimensional Stability and Mass per Unit Area of Single Jersey Cotton Knitted Fabric with Fuzzy Inference System

Napoved dimenzijske stabilnosti in ploščinske mase bombažnega levo-desnega pletiva s sistemom mehkega sklepanja

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Abstract
Endeavour has been made in this research work using experimental data for constructing a fuzzy inference model based on the Mamdani approach to prognosticate the shrinkage and mass per unit area of a single jersey cotton knitted fabric. To control the dimensional stability of the cotton knitted fabric in advance, an artificial intelligent system is required in the knitting industry which simulates all product and process variables and is able to give human-like decisions in advance. The most important controlling parameters of knitted fabric properties such as stitch length, yarn count and overfeed percentage in stenter were considered as input variables, and mass per unit area, lengthwise shrinkage and widthwise shrinkage as output variables. Overall, 35 experiments were conducted to construct the model, varying different parameters. The applicability of the model was validated by comparing the results from 15 newly conducted experiments. The coefficient of determination of predicted and actual data for mass per unit area, lengthwise shrinkage and widthwise shrinkage were 0.97, 0.99 and 0.99, respectively which validates the model relatively effectively for an industrial application. The proposed model can assist a fabric manufacturer by taking a decision in selecting knitting and finishing parameters prior to producing the fabric. Moreover, it can reduce the time and energy required, and waste produced in the process by skipping the sample development step before bulk production.
Keywords: stenter machine, overfeed, fuzzy prediction, membership function

Izvleček
Za napovedovanje krčenja in ploščinske mase bombažnega levo-desnega pletiva so si z uporabo eksperimentalnih podatkov v tej raziskavi prizadevali izdelati model mehkega sklepanja, ki temelji na pristopu Mamdanija. Za nadzor dimenzijske stabilnosti bombažnega pletiva je v pletilnicah potreben umetni inteligentni sistem, ki simulira vse spremenljivke izdelka in procesa ter je sposoben oblikovati človeku podobne odločitve. Najpomembnejše lastnosti pletiva, ki jih je potrebno nadzirati, so dolžina zanke, dolžinska masa preje in odstotek prehitevanja pletiva na razpenjalnem sušilniku. Te so bile upoštevane kot vhodne spremenljivke, medtem ko so bile ploščinska masa, krčenje po dolžini in širini izhodne spremenljivke. Za izdelavo modela je bilo izvedenih skupno 35 eksperimentov z

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variiranjem parametrov. Uporabnost modela je bila potrjena s primerjavo z rezultati iz 15-ih na novo izvedenih eksperimentov. Koeficienti določenih predvidenih in dejanskih vrednosti ploščinske mase, krčenja po dolžini in širini so znašali 0,97, 0,99 in 0,99, kar potrjuje relativno učinkovitost modela za industrijsko uporabo. Predlagani model lahko pomaga proizvajalcu pletiv z odločitvijo o izbiri parametrov pletenja in dodelave pletiva. Poleg tega lahko zmanjša čas, energijo in odpadek, ki nastane v proizvodnji, s tem ko ni potrebno izdelati vzorca pred začetkom masovne proizvodnje.
Ključne besede: razpenjalni sušilnik, prehitevanje, mehko predvidevanje, funkcija članstva

1 Introduction

Knitted fabrics are generally a combination of a series of knitted loops which are readily perverted during its manufacturing process. Cotton knitted fabrics are very popular among customers, due to the excellence attributes of comfort; however, nowadays, the demand of customers has changed as they pay more attention to quality along with reasonable cost. A common complain from the customer's and manufacturer's side is the dimensional instability of cotton knitted fabrics [1]. During the knitting action, the casting off a new loop through the old loop by a needle develops some tension in yarn that initiates distortion in the loop shape. It has been reported that the stitch density of a single jersey fabric is controlled by loop length rather than yarn and knitting variables [2]. According to Munden, yarn properties would not dominante the knitted loop and after the removal of mechanical strains, the knitted loop would take a natural shape [3]. Again, the takedown mechanism and fabric spreader in the knitting machine produce both length- and widthwise tension in the fabric that also perverts the knitted loop shape. The latter will remain distorted after the removal from the machine. This type of loop distortion has a slight influence on the shrinkage properties of the finished fabric. This means that the loop distortion could be lessened by applying an appropriate finishing process in the knitted fabric [4].

The research of dimensional behaviour of weft knit ramie, cotton and viscose fabrics conducted by Li et al. [5] reveals that the loosely knitted fabrics of hydrophilic fibres, including cotton and viscose, undergo progressive shrinkage in the vertical (wale) dimension and progressive stretch in the horizontal (course) dimension. Moreover, it has been reported in a few studies that though the types of yarn like ring or compact yarn do not have a significant effect on shrinkage, the presence of elastomeric yarn and/or tightness factor, yarn count and stitch length can have a great influence on dimensional properties [6–8]. Moreover, a few other factors such as the finishing process, washing, drying and relaxation state are also found crucial for the dimensional stability of knitted fabrics [9–11].

However, every change in the manufacturing process has more than one consequence; therefore, it is relatively difficult to improve the shrinkage property by changing a single parameter. For example, the changes in yarn count, stitch length and machine diameter during the fabric production to control shrinkage also affect the tightness factor, mass per unit area and width along with the shrinkage property, and also develop spirality as these all are correlated with each other. Most common methods that are used by factories for developing a new sample or upgrade existing quality are previous experience, guess work, or trial and error method that are not only expensive but also time-consuming and a waste of production resources. It is also very risky as there may not be enough time or resources to be successful. The necessity of establishing a prognostic model for forecasting the performance of a proposed fabric quality before its production has become obligate.

There are three different models for predicting knitted fabric characteristics, i.e. mathematical model, statistical regression model and intelligent model.

The mathematical models implemented by many researchers for predicting different properties of a textile material are very appealing since they are established on the fundamental theories of basic science, which provide a clear conception about the work process [2, 3, 12–18]. The well-developed prediction model for forecasting knitted fabric shrinkage called STARFISH has some limitations as it uses an enormous amount of data accumulated from all over the world, consequently adversely affecting the prediction performance. Moreover, while the program predicts the properties, the reference production condition and latest finishing procedure explained in STARFISH is strictly maintained for good prediction performance that is relatively difficult for most factories to maintain. The computational database model which has been developed in an Excel spread sheet for predicting knitted fabric shrinkage used a huge amount of data for establishing a model which is very challenging to collect as well as time-consuming.

Several researchers developed models using statistical regression that are used in the relevant field [14–21]. Hence, large amounts of sample data, as well as a prior assessment of the relationship between inputs and outputs, are required for constructing a statistical model. Moreover, the non-linear relationship between inputs and outputs cannot be caught by both mathematical and statistical models [22–23].

Essentially, the advent of artificial intelligent techniques such as artificial neural network (ANN) and adaptive neuro-fuzzy inference system (ANFIS) has given a new incentive in the research world for developing a prediction model. Now, based on different parameters, a lot of work has been done by many researchers to forecast knitted fabric attributes, e.g. bursting strength, pilling tendency, air permeability, thermal resistance, spirality, hand evaluation, defect classification etc, and also in the woven and apparel industry [24–30]. An enormous amount of noise free data is required in establishing the ANN and ANFIS model, which becomes very difficult and time consuming to accumulate from the textile industry [22, 23, 31]. Moreover, the ANN model works like a black box as it is not able to give precise intensification of non-linearity between input-outputs and core logic on which a decision could be made [22, 23, 32].

Conversely, the fuzzy inference system is a very proficient modelling tool which overcomes the lacunas of ANN, ANFIS and statistical regression, as it is based on fuzzy logic that can easily interpret the knowledge of experts into a set of rules in an inference system and is focused on modes of reasoning that are fairly accurate rather than exact. The fuzzy expert system implementation is easier than other models, since it can execute the modelling operation with a small amount of experimental data in the non-linear, imprecise, vague, trial-error and complex textile domain [22–25, 31–33]. Therefore, in this current research, the predictions of mass per unit area and shrinkage properties of a plain cotton knitted fabric were performed by constructing a fuzzy knowledge-based model as it is more user-friendly, of low design cost and simply applicable.

2 Methodology

2.1 Knitting process

100% cotton plain single jersey fabrics were knitted in 30 inches (76.2 cm) diameter, 20 gauge single jersey circular knitting machine. For constructing the fuzzy model, yarn count was considered in the English count (Ne) system as this unit is commonly used in knitting industries. In total, seven different types of samples were made. The amount of each sample was 5 kg. The knitting parameters that were used during the making of samples are shown in Table 1.

Table 1: Knitting parameters of experimental samples

Sample	Yarn count		Stitch length [mm]
	[tex]	Corresponding English count [Ne]	
1	21.09	28	2.65
2	24.61	24	2.75
3	21.09	28	2.75
4	19.69	30	2.75
5	22.72	26	2.85
6	21.09	28	2.85
7	19.69	30	2.85

2.2 Pre-treatment and finishing procedure

Scouring and bleaching of cotton knitted fabrics were done in a common bath. The process was carried on a sample dyeing machine (Sclavos, Greece) using detergent 0.5 g/l (Ecowett JTLF, Vijol, India), anti-creasing agent 0.5g/l (Lenetol PAC, Croda, India), sequestering agent 0.3 g/l (Eco SQ-114FE, Jintex, Taiwan), stabilizing agent 0.2g/l (Eco ST-201, Jintex, Taiwan), sodium carbonate (Na_2CO_3) 5 g/l, sodium hydroxide (NaOH) 0.5 g/l, hydrogen peroxide 50% 4 g/l. Afterwards, the fabric samples were washed. Finally, 1 g/l acetic acid (CH_3COOH) and 0.2 g/l peroxide killing agent (peroxidase enzyme) were applied onto fabrics for neutralization. After the scouring and bleaching, the samples were slit in a Bianco sliting machine. Then, they were passed in a Brukner stenter machine at 13 m/min speed at 150 °C with the constant width of 1.6 m (63 inches). To observe the effect of overfeed percentage on mass per unit area and dimensional stability of a knitted fabric, each sample was processed with five different overfeed percentages, e.g. 10%, 20%, 30%, 40%, 50% of the stenter machine. Therefore, 7 × 5 = 35 samples were obtained. Before the testing, all samples were kept on a flat surface for conditioning for at least 24 hours. Standard atmospheric conditions, i.e. relative humidity (65 ± 2)% and temperature (20 ± 2) °C, were properly maintained during

Table 2: Experimental results of fabric mass per unit area (GSM) and shrinkage properties

Sample no.	Knitting parameters		Finishing parameter	GSM [g/m²]	Shrinkage [%]	
	Yarn count [Ne]	Stitch length [mm]	Overfeed in stenter machine [%]		Lengthwise shrinkage (LS)	Widthwise shrinkage (WS)
S1	26	2.85	10	133	–18	–1
S2	28	2.85	10	119	–20	–7
S3	30	2.85	10	111	–20	–6
S4	26	2.85	20	141	–14	–2
S5	28	2.85	20	136	–11	–5
S6	30	2.85	20	132	–15	–5
S7	26	2.85	30	150	–12	–1
S8	28	2.85	30	138	–11	–3
S9	30	2.85	30	135	–11	–5
S10	26	2.85	40	150	–10	–4
S11	28	2.85	40	144	–10	–3
S12	30	2.85	40	134	–10	–4
S13	26	2.85	50	154	–11	–2
S14	28	2.85	50	148	–8	–4
S15	30	2.85	50	135	–9	–4
S16	24	2.75	10	180	–14	–2
S17	28	2.75	10	125	–17	–8
S18	30	2.75	10	116	–18	–7
S19	24	2.75	20	185	–9	–1
S20	28	2.75	20	140	–10	–6
S21	30	2.75	20	135	–10	–6
S22	24	2.75	30	191	–7	0
S23	28	2.75	30	144	–9	–2
S24	30	2.75	30	138	–10	–4
S25	24	2.75	40	195	–4	0
S26	28	2.75	40	150	–6	–3
S27	30	2.75	40	140	–6	–2
S28	24	2.75	50	205	–2	1
S29	28	2.75	50	152	–4	–4
S30	30	2.75	50	148	–5	–2
S31	28	2.65	10	135	–12	–5
S32	28	2.65	20	148	–6	–5
S33	28	2.65	30	154	–5	–4
S34	28	2.65	40	160	–3	–1
S35	28	2.65	50	165	0	0

the conditioning of samples. After the washing, the length- and widthwise shrinkage properties of each sample were investigated according to AATCC-TM 135 [34]. The GSM of 35 samples was measured in line with ISO 3801 [35] and weighed on an electronic weighing machine. The experimental results of all 35 samples are listed in Table 2.

2.3 Establishment of fuzzy prediction model

The fuzzy prediction model was constructed by using three different variables, namely stitch length (SL), yarn count (YC) and overfeed (OF) percentage in a stenter machine as input variables, and mass per unit area (GSM), length- and widthwise shrinkage (LS, WS) of knitted fabrics as output variables. The selected variables have a great influence on the shrinkage of knitted fabrics. The proposed fuzzy prediction model of fabric shrinkage and GSM was developed by using a fuzzy logic toolbox from MATLAB (version 8.2.0.701). The construction of the fuzzy prediction model for LS, WS and GSM of knitted fabrics is illustrated in Figure 1.

For fuzzification, input and output variables were classed into some probable linguistic subsets for the fuzzy expert system being able to trace small changes in output variables with any variation of input variables. The linguistic fuzzy sets for input-output parameters are given in Table 3.

Among all the membership functions, the triangular-shaped membership functions are very popular due to their simplicity and precision. In this research, triangular functions were applied for both input and output variables as variables can easily be described by them [36].

Mamdani max-min fuzzy inference mechanism assures a linear interpolation of outputs between the rules [24, 25]. Therefore, the model is constructed by using this mechanism. Theoretically, there could be 4 × 3 × 5 = 60 fuzzy rules as the input variable SL has 3 linguistic levels, Count

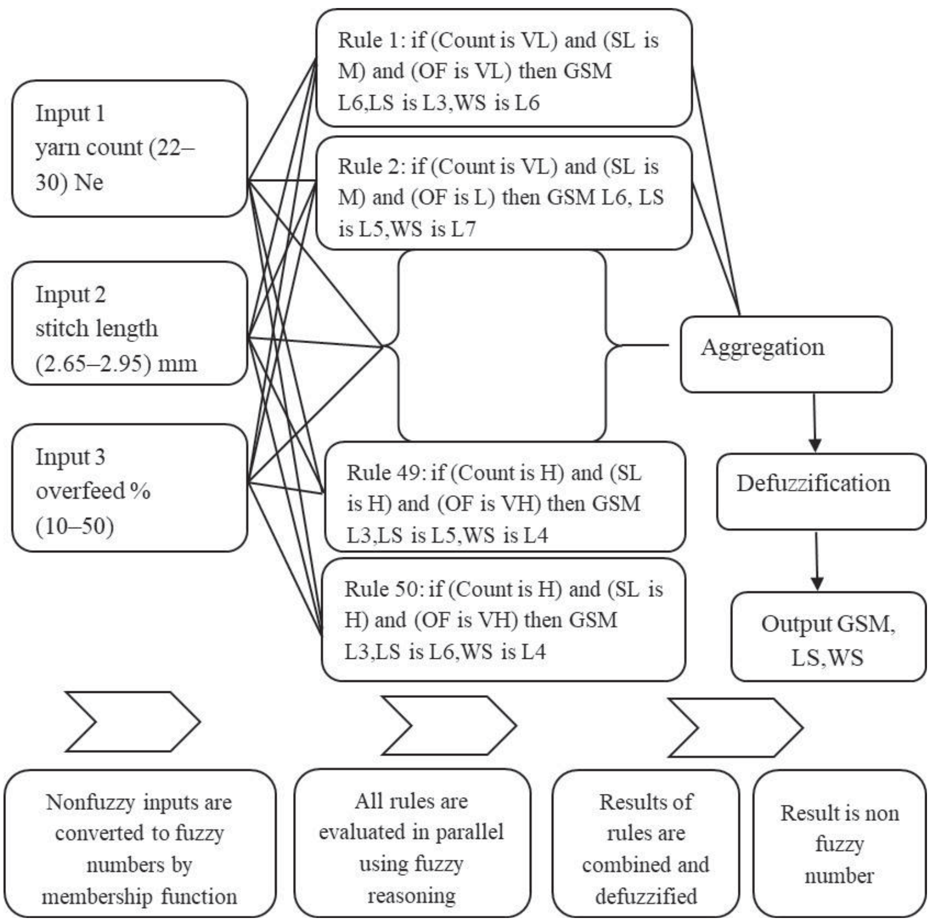

Figure 1: Construction of fuzzy intelligent modelling for fabric shrinkage and GSM

Table 3: Linguistic fuzzy sets for input-output variables

Input variables	Unit	Range	Linguistic fuzzy set
Stitch length (SL)	mm	2.65–2.95	Low, Medium, High
Yarn count (YC)	Ne	22–30	Very low, Low, Medium, High
Overfeed in stenter machine (OF)	%	10–50	Very low, Low, Medium, High, Very high
Output variables	**Unit**	**Range**	**Linguistic fuzzy set**
Lengthwise shrinkage (LS)	%	–20 to –2	Level 1, Level 2, Level 3, Level 4, Level 5, Level 6, Level 7, Level 8, Level 9
Widthwise shrinkage (WS)	%	–8 to +1	Level 1, Level 2, Level 3, Level 4, Level 5, Level 6, Level 7, Level 8
Mass per unit area (GSM)	g/m^2	110 to 210	Level 1, Level 2, Level 3, Level 4, Level 5, Level 6, Level 7, Level 8

has 4 linguistic levels and Overfeed percentage in the stenter machine has 5 linguistic levels [23]. However, on the basis of expert knowledge and prior experience, only 50 rules have been used which make the fuzzy expert system simple and more easy to use [22, 23]. Some examples of established fuzzy rules are revealed in Table 4.

For instance, Rule 1 and Rule 18 are described as follows:

Rule 1: If Count = VL and SL = M, and OF = VL, then GSM = L6, LS = L3 and WS = L4, i.e. if Count is Very low, Stitch length is Medium and Overfeed percentage is Very low, then GSM is Level 6, Lengthwise shrinkage percentage is Level 3 and Widthwise shrinkage is Level 6.

Rule 18: If Count = L, SL = H, and OF = M, then GSM = L4, LS = L4 and WS = L7, i.e. if Count is Low, Stitch length is High and Overfeed percentage is Medium, then GSM is Level 4, Lengthwise shrinkage percentage is Level 4 and Widthwise shrinkage is Level 7.

Each linguistic value that is used in each input variable has a level of a membership. Equations 1–6 were applied for fuzzification of input variables and the membership functions are also demonstrated in Figures 2–7:

$$SL\ (i_1) = \begin{cases} i_1;\ 2.65 \le i_1 \le 2.95 \\ 0;\ Otherwise \end{cases} \quad (1),$$

$$YC\ (i_2) = \begin{cases} i_2;\ 22 \le i_2 \le 30 \\ 0;\ Otherwise \end{cases} \quad (2),$$

$$OF\ (i_3) = \begin{cases} i_3;\ 10 \le i_3 \le 50 \\ 0;\ Otherwise \end{cases} \quad (3),$$

$$LS\ (O_1) = \begin{cases} O_1;\ -20 \le O_1 \le -2 \\ 0;\ Otherwise \end{cases} \quad (4),$$

$$WS\ (O_2) = \begin{cases} O_2;\ -8 \le O_2 \le 1 \\ 0;\ Otherwise \end{cases} \quad (5),$$

$$GSM\ (O_3) = \begin{cases} O_3;\ 110 \le O_3 \le 210 \\ 0;\ Otherwise \end{cases} \quad (6).$$

Table 4: Developed fuzzy rules for modelling

Rules	Input variables			Output variables		
	YC	SL	OF	GSM	LS	WS
Rule 1	VL	M	VL	L6	L3	L6
. . .	. . .	. . .	. . .	. . .	. . .	. . .
Rule 18	L	H	M	L4	L4	L7
. . .	. . .	. . .	. . .	. . .	. . .	. . .
Rule 50	H	H	VH	L3	L6	L4

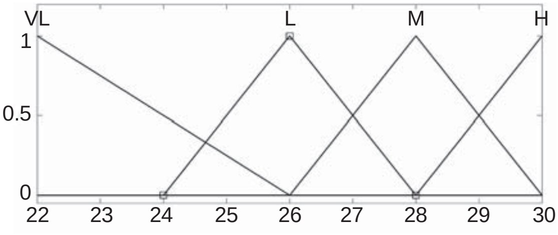

Figure 2: Membership function of input variable count (Ne)

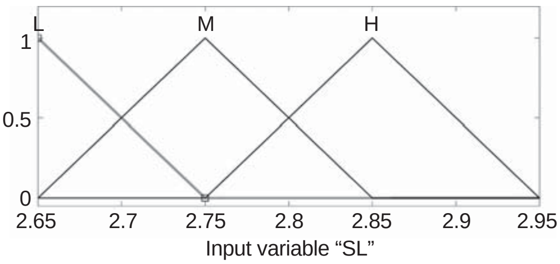

Figure 3: Membership function of input variable stitch length (SL)

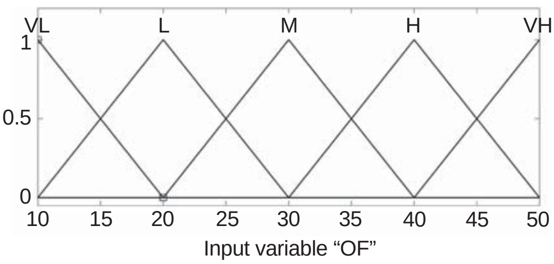

Figure 4: Membership function of input variable overfeed percentage (OF)

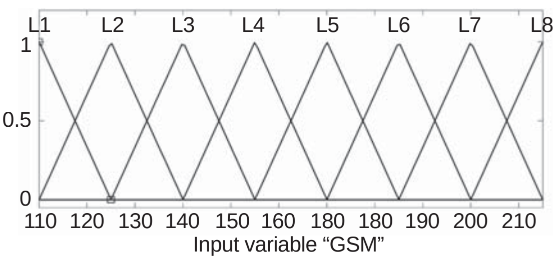

Figure 5: Membership function of output variable GSM

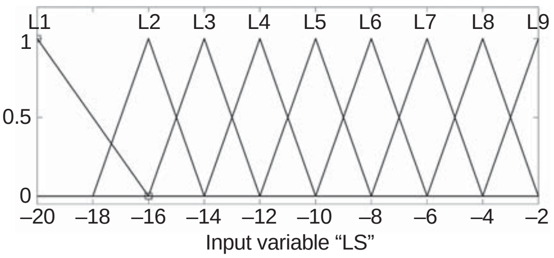

Figure 6: Membership function of output variable lengthwise shrinkage (LS)

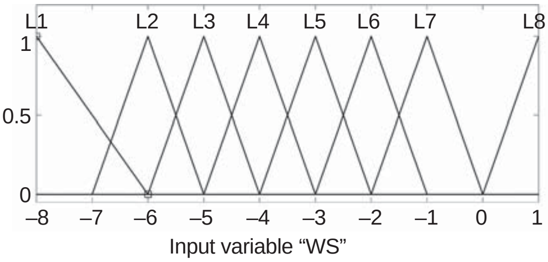

Figure 7: Membership function of output variable widthwise shrinkage (WS)

To elucidate the fuzzification process, linguistic terms for triangular membership functions can be interpreted through equation 7 [37]:

$$\mu_{triangle}(x, c_1, c_2, c_3) = \begin{cases} \frac{x - c_1}{c_2 - c_1}; \; c_1 \le x \le c_2 \\ \frac{c_2 - x}{c_3 - c_2}; \; c_2 \le x \le c_3 \\ 0; \; x \ge c_3 \end{cases} \quad (7).$$

The linguistic expression and membership function of stitch length, yarn count and overfeed percentage found from the established rules and the formula above is presented in equations below (equations 8–15) [31, 32, 37]:

$$\mu_M(SL) = \begin{cases} \frac{i_1 - 2.65}{2.75 - 2.65}; \; 2.65 \le i_1 \le 2.75 \\ \frac{2.85 - i_1}{2.85 - 2.75}; \; 2.75 \le i_1 \le 2.85 \\ 0; \; i_1 \ge 2.85 \end{cases} \quad (8),$$

$$\mu_M(SL) = \left\{ \frac{0}{2.65} + \frac{0.5}{2.70} + \frac{1}{2.75} \dots + \frac{0.5}{2.80} + \frac{0}{2.85} \right\} \quad (9),$$

$$\mu_H(SL) = \begin{cases} \frac{i_1 - 2.75}{2.85 - 2.75}; \; 2.75 \le i_1 \le 2.85 \\ \frac{2.95 - i_1}{2.95 - 2.85}; \; 2.85 \le i_1 \le 2.95 \\ 0; \; i_1 \ge 2.95 \end{cases} \quad (10),$$

$$\mu_H(SL) = \left\{ \frac{0}{2.75} + \frac{0.5}{2.80} + \frac{1}{2.85} \dots + \frac{0.5}{2.90} + \frac{0}{2.95} \right\} \quad (11),$$

$$\mu_L(Count) = \begin{cases} \frac{i_2 - 24}{26 - 24}; \; 24 \le i_2 \le 26 \\ \frac{28 - i_2}{28 - 26}; \; 26 \le i_2 \le 28 \\ 0; \; i_2 \ge 28 \end{cases} \quad (12),$$

$$\mu_L\,(Count) = \left\{\frac{0}{24} + \frac{0.5}{25} + \frac{1}{26} \ldots + \frac{0.5}{27} + \frac{0}{28}\right\} \quad (13),$$

$$\mu_L\,(Count) = \begin{cases} \frac{i_2 - 26}{28 - 26};\ 26 \le i_2 \le 28 \\ \frac{30 - i_2}{30 - 28};\ 28 \le i_2 \le 30 \\ 0;\ i_2 \ge 30 \end{cases} \quad (14),$$

$$\mu_M\,(Count) = \left\{\frac{0}{26} + \frac{0.5}{27} + \frac{1}{28} \ldots + \frac{0.5}{29} + \frac{0}{30}\right\} \quad (15).$$

In the same way, the linguistic expression and membership function of other variables was determined. Among different defuzzification methods, the centre of gravity (COG) defuzzification method was used for converting the fuzzy output into non-fuzzy crisp numeric value [22, 37]. The truth degrees (μ) of each rule are enumerated with the help of the min and by taking the max between active rules [32, 38]. It can be explained by considering the following example, for crisp input SL = 2.8, count = 26 and OF = 30%, the rules 13 and 18 will be fired. The truth values (α) of the two rules are given as:

$$\alpha_{13} = \min\,\{\mu M(\text{SL}), \mu L(\text{count}), \mu M(\text{OF})\} = \\ = \min\,(0.5, 1, 1) = 0.5,$$

$$\alpha_{18} = \min\,\{\mu H(\text{SL}), \mu L(\text{count}), \mu M(\text{OF})\} = \\ = \min\,(0.5, 1, 1) = 0.5.$$

The membership function was calculated according to the Mamdani max-min inference system such as max (α_{13}, α_{18}) = 0.5.

Then, the crisp output was enumerated. Hossain et al. [32] alluded that the crisp decision obtained from a system, the output of which is fuzzy by showing the output in a single scalar quantity. In this case, LS^{crisp} (Output) was enumerated by multiplying the output membership values with their corresponding singleton values followed by dividing the obtained value by the sum of membership values which is shown in equation 16 [32, 37, 38]:

$$LS^{crisp} = \frac{\sum_i a i \mu(i)}{\sum_i \mu(i)} \quad (16),$$

where a_i is the spot of the singleton in the i^{th} universe and $\mu_{(i)}$ is the firing strength of the truth values of rule i [22, 32, 37, 38].

The crisp output of LS was calculated by using equation (16) as −10% and widthwise shrinkage −1.5%, as shown in Figure 8. The calculation of LS is given below.

$$\text{COG} = \frac{-(13 + 11 + 9 + 7) \times 0.5}{0.5 + 0.5 + 0.5 + 0.5} = -10$$

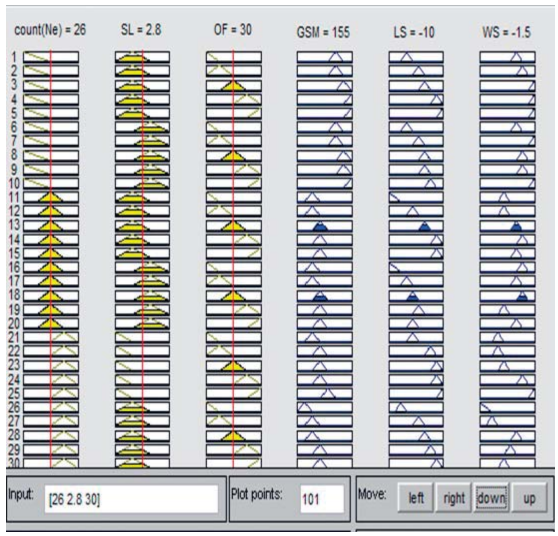

Figure 8: Rule viewer of fuzzy inference system

2.4 Validation of prediction ability

The proposed model was investigated according to the global prediction error such as mean absolute error percentage (MAEP) and coefficient of determination (R^2) for determining the prediction ability of the model. The formulas of accuracy measurements are given in equations 17–19 [31, 32, 37–39]:

$$R^2 = 1 - \left(\frac{\sum_{i=1}^{i=N} (E_a - E_p)^2}{\sum_{i=1}^{i=N} (E_a - E_M)^2}\right) \quad (17),$$

$$RMS = \sqrt{\frac{\sum_{i=1}^{i=N} (E_a - E_p)^2}{N}} \quad (18),$$

$$MAEP = \frac{1}{N} \sum_{i=1}^{i=N} \left(\frac{|E_a - E_p|}{E_a} \times 100\right) \quad (19),$$

where E_a is actual result, E_p is predicted result, E_m is mean value and N represents the number of the pattern.

3 Results and discussion

3.1 Influence of input variables on GSM

The impact of count, stitch length and overfeed percentage on fabric GSM was shown in Figures 9–11. It can be seen in Figure 9 that finer yarn count coupled with lower stitch length exhibited higher fabric GSM. An approximately 25–30% increment in fabric GSM was found for 7% drop off in stitch length. This might have occurred as lower stitch length increases stitch density in the unit area, which then resulted in heavier weight of a fabric [40]. Moreover, Figure 9 also showed that yarn getting finer by up to 30 Ne, stitch length from 2.7 to 2.9 mm caused lighter GSM in the knitted fabric. It can be seen in Figures 10 and 11 that lower OF did not substantially affect fabric weight whereas at OF above 20%, the GSM of the knitted fabric increased dramatically with the rise of OF. When the OF was increased from 20% to 35% in stenter, about 15% fabric GSM was increased, which was probably due to the accumulation of the fabric in the feeding area of the stenter machine, which raised the density of the fabric [41]. However, fabric GSM came to an optimal level in between 35 to 50% OF. Figure 11 shows that GSM increased to around 73% and around 37% with thicker yarn and higher overfeed percentage, respectively.

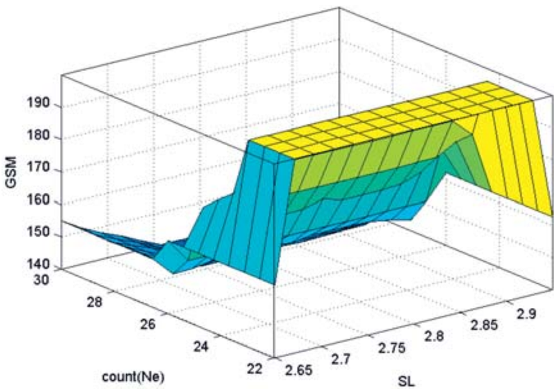

Figure 9: Surface plot exhibiting dominance of titch length and Count on GSM (Count-SL)

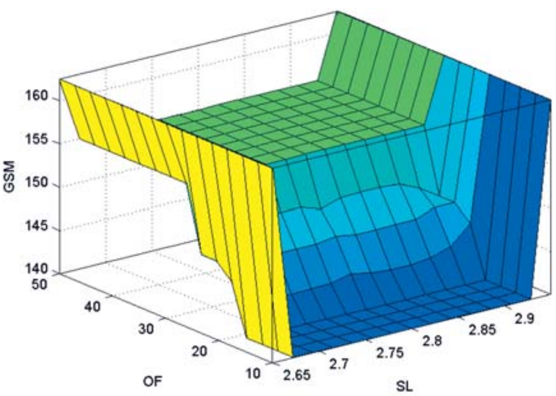

Figure 10: Surface plot viewing impact of stitch length and overfeed percentage on GSM (OF-SL)

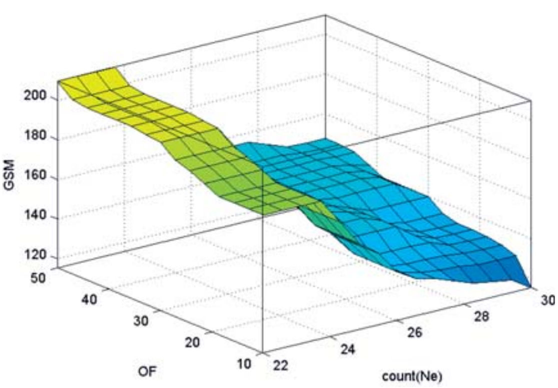

Figure 11: Surface plot showing effect of count and overfeed percentage on GSM (Count-SL)

3.2 Influence of input variables on lengthwise shrinkage

Effect of overfeed percentage, count and stitch length on lengthwise shrinkage is shown in Figures 12–14. Figure 12 depicts that LS was improved with the increase of OF and vice versa. Initially, no significant effect was observed in LS when increasing SL. However, LS was highly affected by OF valued near 20% and upwards. Only SL (2.8 mm to 2.9 mm) had an individual effect on LS which improved steadily with the increase of OF. LS was improved at around 75% for elevating the overfeed from 20% to 50% within the range 2.65 mm to 2.75 mm SL, while no significant effect was observed for 10% OF. Nevertheless, in the mid-range SL (2.7–2.8 mm), LS was improved by about 40% for increasing overfeed from 10% to 50%. It can also be seen in Figure 13 that the effect of yarn count on the length-wise shrinkage property was not linear but OF showed a linear relationship with the LS property of the fabric. LS showed relatively better performance for coarser yarn than finer as it was enhanced by around 67% when increasing overfeed from 10% to 50% in coarser count (22–24 Ne). Very high OF (40% to 50%) upgraded shrinkage property for both coarser and finer yarn count [42]. No notable improvement in lengthwise shrinkage was observed in Figure 14 for increasing stitch length in the range 2.7–2.9 mm for thicker yarn count. Conversely, thinner yarn count (28–30 Ne) showed better performance in LS from 2.65 to 2.75 mm SL, whereas with the elevation of stitch length in finer yarn, the LS property declined. Specifically, in the case of 28–30 Ne of yarn count, the increase of LS due to the increase of SL from 2.65 mm to 2.9 mm was around 60%. From the overall context, this may be justified as the compact knitted structure formed by either lower SL or higher OF or coarser count or combination of them made the fabric more stable after the washing. Due to higher OF, the forces in the processing of a cotton fabric with lower SL and coarser count contributed to the contraction of the fabric as the forces push mechanically the knitted loops towards each other to make them closer. Hence, after the washing, the non-linear hysteresis effect caused the cotton fabric to become denser (as loops do not get enough space to shrink) and the fabric consequently became more dimensionally stable [41].

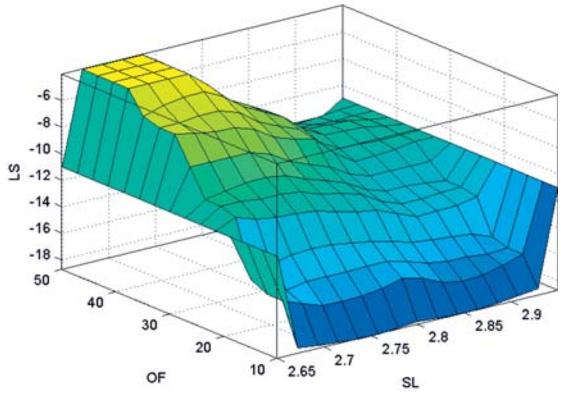

Figure 12: Surface plot exhibiting impact of SL and Overfeed percentage on LS (OF-SL)

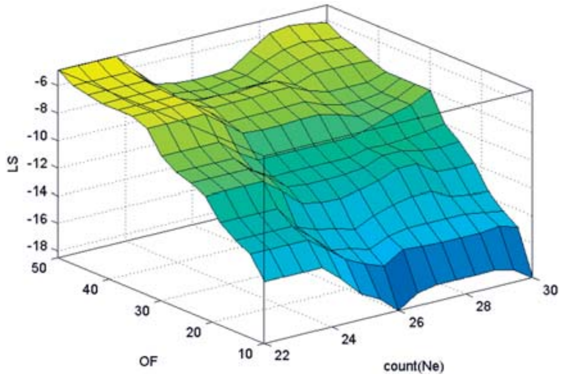

Figure 13: Surface plot exhibiting impact of Count and Overfeed percentage on LS (OF-Count)

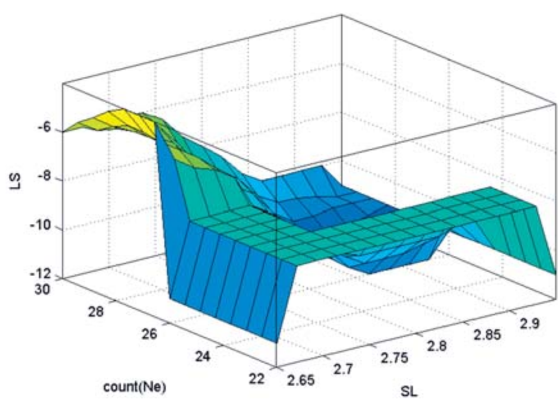

Figure 14: Surface plot exhibiting impact of Count and SL on LS (Count-SL)

3.3 Influence of input variables on widthwise shrinkage

The impact of count, stitch length, overfeed percentage on widthwise shrinkage (WS) is shown in Figures 15–17. The WS of the knitted fabric improved linearly with OF and SL, which is shown in Figure 15. WS was improved by approximately 46% when overfeed was increased from 10% to 50% at 2.65 mm SL, whereas in mid-range SL (2.7–2.8mm), it progressed by about 30%. As lengthwise shrinkage improved at high overfeed percentage, the width of the fabric changed as well. Figure 16 revealed that though in the finer count and lower SL there was no impact on WS, the latter decreased slowly with greater SL in almost 22 to 26 Ne count. An approximately reduction in the widthwise direction increased by 25% when SL increased from 2.7 to 2.8 mm for finer counts, i.e. 28 and 30 Ne. As after washing, finer yarn with high stitch length gets more space for swelling and comes close together, this lessen the width of the fabric after relaxation. Conversely, coarser yarn with high stitch length fabric showed a lower value of shrinkage in the widthwise direction, as it contained high course length and less space between loops that caused the fabric to extend in the width direction rather than shrink [42].

Lastly, Figure 17 shows that WS enhanced significantly with higher OF percentage and vice versa. The effect of 28–30 Ne count with 10–20% OF on WS was not perceptible enough. At over 20% of OF, WS improved sharply in ascending order. In low-range count (22 to 24 Ne) with 50% OF, low WS in the fabric was found. In the light of the above context, it can be summarized that the effectiveness of stitch length, count and overfeed % on WS was less significant for all the fabrics as they were made in the same diameter of the knitting machine and passed in a stenter, keeping constant width.

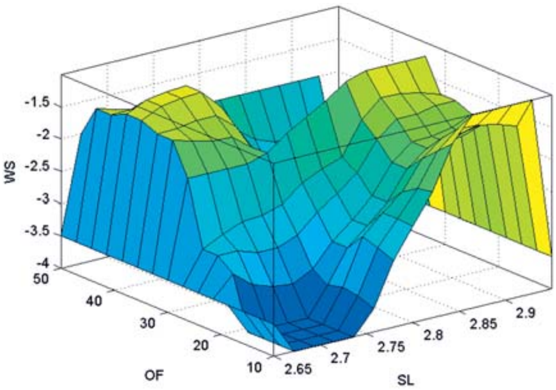

Figure 15: Surface plot showing dominance of OF and SL on WS (SL-OF)

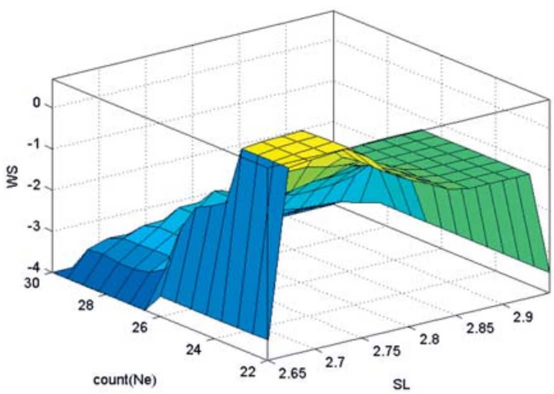

Figure 16: Control surface plot viewing impact of Count and SL on WS (SL-count)

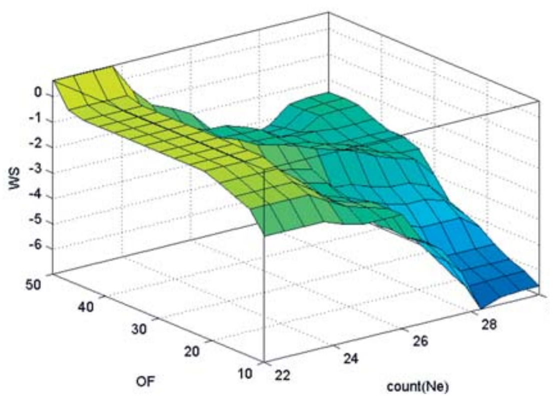

Figure 17: Surface plot viewing impact of count and OF on WS (OF-Count)

3.4 Justification of fuzzy prediction model

In this study, the proposed model was verified by conducting 15 new experiments. The prediction accuracy of the developed model was estimated by enumerating the coefficient of determination (R^2) and mean absolute error percentage (MAEP) between the real and prognosticated values of fabric GSM, LS and WS. A comparison between the predicted values obtained from the established fuzzy logic model and the empirical values is shown in Table 5.

The correlation between prognosticated and actual values of fabric GSM, LS and WS in different conditions is depicted in Figures 18–20. It was observed that the obtained coefficients of determination (R^2) from the prognosticated and actual values of GSM, LS and WS were 0.975, 0.9903 and 0.99. This means that the proposed model can describe up to 99.7% of the total variability of fabric GSM, 99.5% of the total changeability of LS and 98.5% of the total variation in WS. Again, the absolute error indicates a deviation between the actual value and predicted value, and the requirement of absolute error value is to be zero. The mean absolute errors (MAEP) between the experimental and predicted value were 1.85, 3.10 and 5.15. Therefore, the validation of predicted values with the experimental values suggests that the developed fuzzy intelligent model may possess very good applicability in industrial scale for predicting the shrinkage and GSM of knitted fabrics.

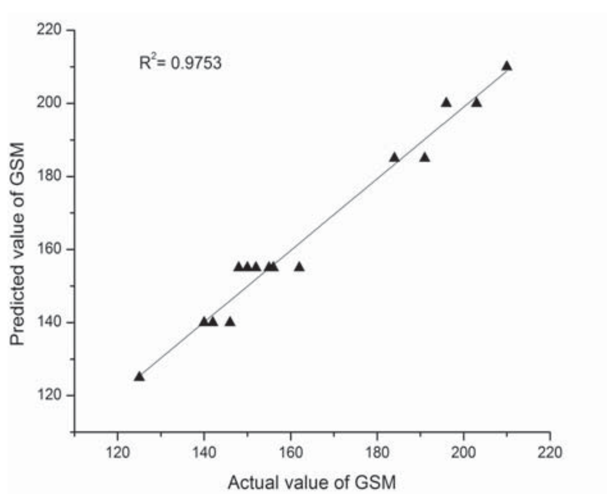

Figure 18: Correlation between actual and predicted values of GSM of single jersey cotton knitted fabric

Table 5: Comparisons of actual and predicted values of GSM, LS and WS of single jersey fabric

Trial no.	SL [mm]	YC [Ne]	OF [%]	Actual GSM	Predicted GSM	GSM AE[a)] [%]	Av[b)] of LS [%]	Pv[c)] of LS%	LS AE [%]	Actual WS [%]	Predicted WS [%]	WS AE [%]
T1	2.65	30	10	125	125	0.00	–12.5	–12	4.00	–6	–6	0.00
T2	2.65	30	20	142	140	1.41	–8	–8	0.00	–6	–6	0.00
T3	2.65	30	30	148	155	4.73	–6	–6	0.00	–4	–4	0.00
T4	2.65	30	40	152	155	1.97	–4	–4	0.00	–2	–2	0.00
T5	2.65	30	50	155	155	0.00	–2.5	–2.61	4.40	–1	–1	0.00
T6	2.75	26	10	140	140	0.00	–18	–18.7	3.89	–4	–4	0
T7	2.75	26	20	146	140	4.11	–12	–12	0.00	–4	–4	0
T8	2.75	26	30	150	155	3.33	–7	–8	14.29	–2	–2	0
T9	2.75	26	40	156	155	0.64	–5	–4	20.00	–1	–1	0
T10	2.75	26	50	162	155	4.32	–4	–4	0.00	–2	–2	0
T11	2.85	22	10	184	185	0.54	–14	–14	0.00	–2	–2	0.00
T12	2.85	22	20	191	185	3.14	–10	–10	0.00	0.5	0.69	38.00
T13	2.85	22	30	196	200	2.04	–8	–8	0.00	–1	–1	0.00
T14	2.85	22	40	203	200	1.48	–8	–8	0.00	–1	–1	0.00
T15	2.85	22	50	210	210	0.00	–6	–6	0.00	0.5	0.69	39.20
Mean absolute error (MAEP)							1.85		3.10		5.15	
Root mean square (RMS)							3.96		0.43		0.07	
Coefficient of determination (R^2)							0.975		0.990		0.99	

a) Absolute error

b) Actual value

c) Predicted value

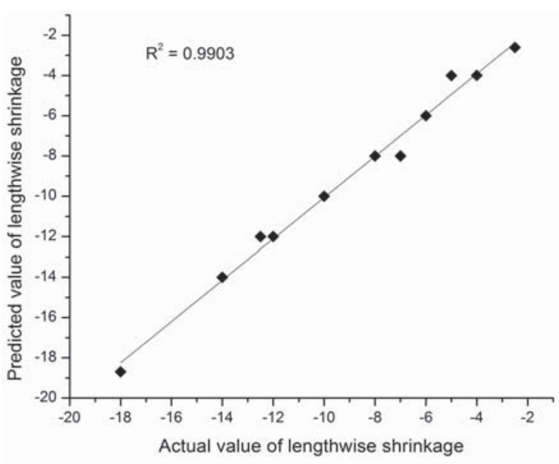

Figure 19: Correlation between actual and predicted values of lengthwise shrinkage of single jersey cotton knitted fabric

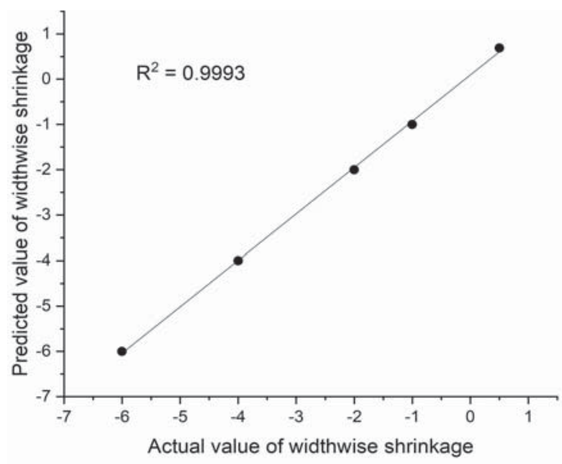

Figure 20: Correlation between actual and predicted values of widthwise shrinkage of single jersey cotton knitted fabric

4 Conclusion

Single jersey cotton knitted fabrics have the tendency to change their dimension permanently according to the variables in knitted fabric manufacturing and processing. From the prepared model, it will be possible to predict the dimension of the fabric before its production in industrial scale if the variables and their effects are known and controlled. From the empirical study, it has been elucidated that in addition to yarn count and stitch length, the overfeed percentage of a stenter machine also has a great impact on the fabric mass per unit area and shrinkage property of a single jersey knitted fabric. By increasing overfeed percentage in a stenter machine, the lengthwise shrinkage property of a single jersey fabric can also be improved for all yarn's count and stitch length considered in this work; however, this also increases the mass per unit area of the fabric. On the other hand, knitted fabric made from yarns with higher count with a lower range of stitch length exhibited better performance in both length- and widthwise shrinkage property. Again, the developed fuzzy intelligent model confers an outstanding clarification about the interaction between the variables and their effect on the mass per unit area and shrinkage property of a plain single jersey knitted fabric. This model may act as a decision-making tool and support the textile engineer to prognosticate knitted fabric mass per unit area, and length– and widthwise shrinkage in advance, which can minimize production time, costs and wastages generated in developing and improving the quality of the knitted fabric. In the future of this ongoing research, we will consider input variables from a compactor machine for the prediction of finished fabric properties, which will further extend the applicability of this model.

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Cationic Pretreatment of Cotton and Dyeing with *Fallopia Japonica* Leaves

Kationska predobdelava bombaža in barvanje z listi japonskega dresnika (Fallopia Japonica)

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Abstract

This work examines the possibility of using leaves from the invasive plant species *Fallopia japonica* (Japanese knotweed) as a source of dye for the natural dyeing of cotton. To achieve a higher uptake of extracted dye, a cationic agent instead of a classical mordant was used to treat the cotton prior to dyeing. Distilled water and 0.5 M NaOH were used as extraction mediums to produce natural dyebaths with different concentrations (10, 20 and 50 g/L) of *Fallopia japonica* leaves. The colorimetric measurements revealed that a higher concentration of extract, the extraction of leaves in NaOH and a cationic pretreatment of cotton yield a dark-brown-coloured cotton with good wash stability.
Keywords: *Fallopia japonica* leaves, cotton, dyeing, cationic pre-treatment, wash stability

Izvleček

Raziskana je možnost uporabe listov invazivne rastlinske vrste Fallopia japonica (japonski dresnik) kot vir barvila za naravno barvanje bombažne tkanine. Za povečanje adsorpcije ekstrahiranega barvila na bombaž je bila tkanina namesto s klasično čimžo predobdelana s kationskim sredstvom. Kot ekstrakcijski medij za barvilo sta bila uporabljena destilirana voda (H_2O) in 0,5 M natrijev hidroksid (NaOH). Barvalne kopeli so bile pripravljene v treh koncentracijah listov japonskega dresnika, tj. 10, 20 in 50 g/l. Rezultati refleksijske spektrometrije so pokazali, da višja koncentracija listov, ekstrakcija v NaOH in kationska predobdelava vodijo v temnejša rjava obarvanja bombaža z zelo dobro obstojnostjo pri pranju.
Ključne besede: listi, japonski dresnik, barvanje, kationska predobdelava, obstojnost pri pranju

1 Introduction

Invasive alien plant species (IAPS) cause damage to European ecosystems and economies. The "APPLAUSE" project aims to use IAPS as a resource for the development of new products (e.g., dyes for textiles). The rhizome and leaves of *Fallopia japonica* (*F. japonica*) have the potential to be used as dyes for textiles. To date, no research has been published on the subject, except for a study on the dyeing of plasma-treated cotton and bamboo rayon with *F. japonica* rhizome extract [1], where it was found that plasma-treated textile samples had a higher adsorption of dye and, consequently, better antibacterial properties. The traditional pretreatment of textiles, when dyeing with natural dyes, is mordanting. Mordants are metal salts that enable a higher adsorption of dye onto textiles, and can be used to achieve different colours with the same natural dye [2]. Alternatives to the classical mordants are plasma, chitosan, and cationic agent pretreatments [3–5]. Plasma is a partially ionised gas that enables the formation of new functional groups on the fibres' surface and/or their micro- to nano-etching [6]. It is an

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ecologically benign form of textile modification. Natural dyes extracted from curcumin and green tea were shown to have a higher adsorption onto cotton fabric if the fabric was pretreated with ammonia plasma [3]. In contrast, the adsorption of natural dyes was shown to decrease if the cotton samples were pretreated with oxygen plasma. It was found that plasma pretreatment did not influence the change in the bathochromic or hypsochromic shift of the absorption spectra of dyed cotton. The pretreatment of wool with oxygen plasma was shown to enable a better adsorption of dendrimer with amine end groups, and consequently a better adsorption of cochineal dye [7]. A great amount of dye was absorbed due to the electrostatic attraction between the negatively charged dye molecules and positively charged dendrimers as well as the positively charged amine groups of wool fibres. Chitosan is poly-cationic amino polysaccharide and has acquired great importance as a new functional material for textile applications mainly because of its biocompatibility and non-toxicity [8]. When it is used to pretreat textiles for dyeing with natural dyes, it serves as a "biological" mordant that enhances the adsorption of the dye, e.g., between wool and tea [9], wool and henna [10] and cotton and black tea [11].
The purpose of this research was to examine the potential of *F. japonica* leaves as a source of textile dye and to use a cationic agent instead of metal mordants to pretreat cotton.

2 Experimental

2.1 Material

For the research bleached 100% cotton fabric (Tekstina d. o. o., Ajdovščina) was used. The Japanese knotweed leaves were collected and delivered by SNAGA d. o. o., washed with water to remove the dirt, air dried at room temperature and grounded into powder.

2.2 Preparation of extracts

The extracts were prepared in two extraction media, i.e., deionised water (H_2O) and 0.5 M NaOH. The weighted leaves powder (at concentrations of 10, 20 and 50 g/L) was put in cold extraction medium and heated to boiling. The extraction of the dye took 60 minutes. Afterwards, the mixture was filtered. The extract was further used as a dyeing bath.

2.3 Cationic pretreatment

Prior to dyeing, cotton samples were treated with 5% Denimcol FIX-OS (CHT, Switzerland) as a cationic agent. The cationic bath included 2.5 mL/L of 32% NaOH. The cationic pretreatment was performed at a liquor-to-goods ratio of 10:1, at 50 °C, for 20 min. The cotton fabric was neutralised afterwards with 5 mL/L of 30% CH_3COOH at room temperature for 5 min.

2.4 Dyeing

Dyeing of untreated and cationic pretreated samples was performed in a GyroWash laboratory machine (James Heal, Great Britain), which simulates exhaustion dyeing. Dyeing was performed in the prepared extracts at the liquor-to-goods ratio of 20:1, at 60 °C, for 60 min. After dyeing, the samples were washed with water and air-dried at room temperature.

2.5 Wash test

A wash fastness test of dyed samples was performed in a GyroWash laboratory machine according to the ISO 105-C06:2010 standard method. The samples were washed 10 times at 40 °C for 45 min. The washing solution contained 4 g/L of Standards Development Committee (SDC) standard detergent. After washing, the samples were rinsed twice in distilled water at 40 °C and then air-dried at room temperature.

2.6 Colour measurements

The colour (CIELAB values) of dyed samples was measured on a reflectance spectrophotometer (Datacolor Spectraflash SF 600 PLUS-CT). All measurements were performed using four layers of fabric with a 9 mm aperture, wherein the specular component was under D65 illumination and a 10° standard observer. An average of 10 measurements was recorded for each sample.

3 Results and discussion

The results of the colour measurements (Table 1) show that the colour is dependent on three parameters, i.e., the initial concentration of *F. japonica* leaves for extract preparation, the extraction medium (H_2O or NaOH), and the cationic pretreatment of cotton.

Table 1: CIELAB values and photos of cotton samples dyed with dye extracted from F. japonica leaves

Extraction medium	c_{extr} [g/l]	Cotton pretreatment	*L**	*a**	*b**	Photo
H_2O	10	Without	83.92	0.96	20.68	
		Cationic	70.98	1.80	10.80	
	20	Without	79.97	2.28	11.91	
		Cationic	64.59	1.39	11.14	
	50	Without	76.23	2.20	14.04	
		Cationic	60.66	2.68	13.20	
0.5 M NaOH	10	Without	72.18	6.14	16.54	
		Cationic	46.71	6.23	18.38	
	20	Without	65.76	7.25	19.40	
		Cationic	43.49	7.41	17.55	
	50	Without	60.05	9.13	18.35	
		Cationic	40.17	9.91	19.20	

Increasing the concentration of *F. japonica* leaves for extract preparation caused the dyed sample to become darker (CIE *L** decreases), redder (CIE *a** increases) and yellower (CIE *b** increases), regardless of the medium used for extract preparation or cationic pretreatment. The samples that were dyed in extract prepared in NaOH medium were darker and redder. The value on the yellow–green axis differed according to the concentration of the used extract; i.e., at a lower concentration (10 g/L) the samples were less yellow (CIE *b** decreases) and at higher concentrations (20 and 50 g/L) the samples were more yellow. In the case where the samples were pretreated, the samples that were dyed in NaOH extract were darker, redder and yellower for all used extract concentrations. The cationic pretreatment of cotton influenced the colour of dyed samples mostly on the lightness axis (CIE *L**), as the pretreated samples were much darker than the untreated samples. The effect was even more pronounced for those samples that were dyed in extract prepared in NaOH medium. The dye that is present in *F. japonica* is emodin [1]. Figure 1 presents the reaction of emodin with NaOH.

The newly formed compound is red in colour, water soluble and more substantive to cellulose. The dye was ionized to yield a negatively charged anion dye with positively charged sodium cations [12]. The negative potential of the cellulose (cotton fibers) can repulse the anions in the dye; however, the large amount of sodium ion content ensures that the negative potential of the fibers is overcome, so it is not necessary to put any additional common salt in the dyeing bath [12]. The cationic pretreatment (which is a reactive polyammonium compound) of cotton ensures that the fibers have cationic sites onto which anionic dyes can be more easily adsorbed; therefore, the dyeability of the cotton is increased [5].

Table 2 presents the measured CIELAB values after 10 repeated washings. In the case of untreated cotton, the samples almost completely lost their color, while the color remained in the cationic pretreated samples. Therefore, the cationic pretreated cotton, which was dyed with natural dye extracted from *F. japonica* leaves, had very good wash stability. In the case where extract was prepared in NaOH medium, the samples became lighter, less red and less yellow after washing. An interesting effect after washing was observed for cationic pretreated samples dyed with extract prepared in H_2O medium. The value on the lightness axis was decreased, meaning that the samples became darker after washing. The same effect was also observed in a study on dyeing cotton with Goldenrod extract, where the fabric was precationised [5].

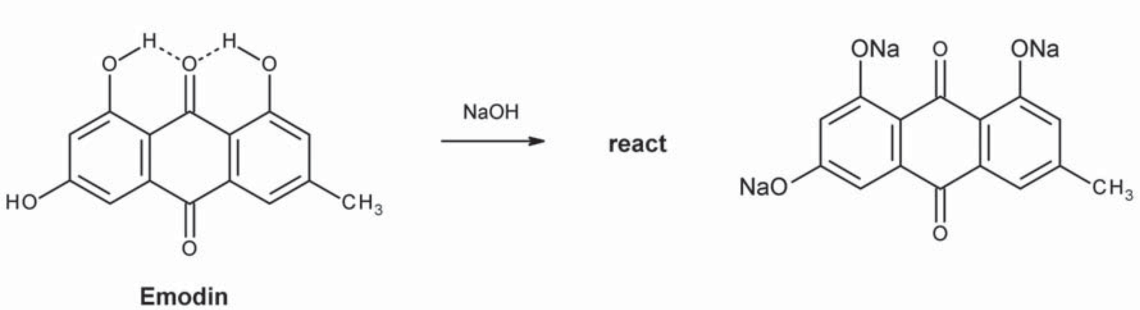

Figure 1: Reaction of emodin with NaOH

Table 2: CIELAB values and photos of cotton samples dyed with dye extracted from F. japonica leaves after ten repetitive washings

Extraction medium	c_{extr} [g/l]	Cotton pretreatment	*L**	*a**	*b**	Photo
H_2O	10	Without	87.20	1.01	5.99	
		Cationic	62.08	3.11	19.89	
	20	Without	88.81	1.19	5.65	
		Cationic	50.87	2.31	12.29	
	50	Without	84.46	1.16	5.94	
		Cationic	48.22	2.07	14.26	
0.5 M NaOH	10	Without	84.86	1.33	9.12	
		Cationic	56.59	4.83	16.14	
	20	Without	83.77	1.77	8.76	
		Cationic	50.58	6.28	18.66	
	50	Without	78.58	3.99	11.10	
		Cationic	45.28	9.21	20.25	

4 Conclusion

The results of this study show that extract from *F. japonica* leaves has great potential to be used for the dyeing of cotton in different brown shades (from light to very dark), depending on the amount of leaves used for the extraction and cationic pretreatment of cotton. The cationic pretreatment, which rendered good wash stability, can be used in the natural dyeing of cotton instead of traditional mordants. The samples that were not pretreated with the cationic agent were found to have very poor wash stability.

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Dyeing of Cotton with Indigo Using Alkaline Protease and Additives

Barvanje bombaža z indigom z uporabo alkalne proteaze in aditivov

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Abstract

Indigo is invariably applied on cotton to produce an attractive blue shade, together with the desired wash-down effects. Because it is water insoluble, indigo is reduced and solubilised with sodium dithionite and NaOH to develop affinity for cotton. Sodium dithionite dissociates into hazardous by-products viz. sulphate, sulphite and thiosulphate with a harmful effect on the environment due to their toxicity, as well as a corrosive effect on waste lines. To overcome these problems, the eco-friendliness of alkaline protease, together with iron (II) sulphate ($FeSO_4$) as a reducing agent, was studied as a replacement for sodium dithionite. Dyed samples were characterised by attenuated total reflection, using Fourier transformation infrared spectroscopy, scanning electron microscope and X-ray diffraction (XRD). It was observed that alkaline protease, together with iron (II) sulphate, is also capable of producing a comparable reduction potential in dye baths, reduction bath stability, and the surface colour strength and colour fastness properties of dyed cotton compared to those obtained using sodium dithionite.
Keywords: indigo, protease, colour strength, sodium dithionite, ferrous sulphate

Izvleček

Indigo se na bombažu uporablja vedno z namenom, da dobimo privlačen modri odtenek, skupaj z želenimi učinki izpranosti. Indigo je v vodi netopen. Da razvije afiniteto do bombaža, ga je treba reducirati in solubilizirati z natrijevim ditionitom in NaOH. Pri disociiaciji natrijevega ditionita nastanejo nevarni stranski produkti, in sicer sulfatni, sulfitni in tiosulfatni ioni, ki zaradi strupenosti in korozivnega učinka škodljivo vplivajo na cevni sistem odpadne vode. Da bi odpravili te težave, je bila namesto natrijevega ditionita preučevana okolju prijazna alkalna proteaza skupaj z železovim (II) sulfatom ($FeSO_4$) kot reducentom. Obarvani vzorci so bili analizirani s pomočjo spektroskopije FTIR ATR, rastrske elektronske mikroskopije, in rentgenske difrakcije (XRD). Pokazalo se je, da v primerjavi z natrijevim ditionitom dosežemo z alkalno proteazo in železovim (II) sulfatom primerljiv redukcijski potencial v barvalnih kopelih, stabilne redukcijske kopeli, površinsko močno obarvanje in barvno obstojnosti na bombažu.
Ključne besede: indigo, proteaza, intenzivnost obarvanja, natrijev ditionit, železov sulfat

1 Introduction

Indigo is one of the oldest and the most frequently used dyes to produce the attractive blue shade, together with the desired wash-down effect on denim [1]. Indigo is water insoluble, and is used to develop an affinity for cotton in the presence of a reducing agent and alkali. Solubilised indigo is generally applied using the '6 dip 6 nip' technique with dithionite ($Na_2S_2O_4$) as a reducing agent and sodium hydroxide as an alkali [2]. Sodium dithionite is thermally, hydrolytically and oxidatively unstable, and easily oxidised by atmospheric oxygen, while stability is reduced with an increase in temperature, even in absence of oxygen. Some of the

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by-products formed due to the decomposition of sodium dithionite are sulphur compounds (e.g. Na_2S, NaHS, etc.), which pollute the atmosphere through the formation of hydrogen sulphide. At the same time, sulphur salts in the form of sulphates and sulphites (Na_2SO_3, $NaHSO_4$, Na_2SO_4 and $Na_2S_2O_3$) contaminate sewage, lower its pH and corrode concrete supply and drainage pipes [3]. Other problems associated with the use of sodium dithionite relate to costs and storage.

The problems associated with the use of $Na_2S_2O_4$ have led to the search for alternative, non-dithionite-based reduction systems. These include the application of iron (II) salts, together with gluconic acid and NaOH at 60 °C [3–5], and iron (II) salts in combination with tartaric or citric acid, triethanolamine and NaOH at room temperature [6–7]. All these reduction systems showed results comparable to sodium dithionite with some exceptions.

In recent years, the use of eco-friendly materials, such as enzymes for sustainable textile processing has emerged [9, 10]. Enzymes belonging to oxidoreductases and hydrolases categories play an important role in the reduction of dye in alkaline media. One of those enzymes, e.g. alkaline protease belonging to the hydrolases category with nomenclature 3.4.x, has been found to be useful in the reduction of sulphur dye [11, 12]. It is used for various industrial purposes, such as detergents, waste management, food, leather, silver recovery and textiles, to improve the shrinkage resistance of wool, for bioblasting and for the removal of sericin [13–23]. Alkaline protease possesses many characteristic features, such as its stability at high temperature at an alkaline pH [18, 24].

This work studied the application of alkaline protease, together with iron (II) sulphate as a reducing agent, for the dyeing of cotton with indigo. Pre-treated cotton was dyed with reduced and solubilised indigo using sodium dithionite and alkaline proteases separately using the '6 dip 6 nip' technique. The Box-Behnken response surface design was used to analyse the performance of alkaline protease, together with iron (II) sulphate, to achieve the optimised parameters and performance of both reduction systems in terms of pH, the reduction potential (mV) at various stages of dyeing, the surface colour strength (K/S) of dyed cotton, the stability of the reduction bath, and the fastness properties and tensile strength of dyed cotton. The characteristics and surface morphology of dyed cotton were evaluated using ATR-FTIR, XRD and SEM.

2 Materials and methods

2.1 Materials and chemicals

Thoroughly pre-treated and mercerised cotton fabric (35.4 ends/cm, 28.3 picks/cm, linear density of warp yarn of 19.7 tex, linear density of weft yarn of 29.5 tex and mass per unit area of 155 g/m^2) was used in this study.

Alkaline protease (EC 3.4.21.63) and indigo (C.I. vat blue 1) were procured from Maps Enzymes, Ahmedabad and Dystar, Mumbai respectively, while iron (II) sulphate (99.5%), sodium hydroxide (96%) and sodium dithionite (87–88%) were procured from SD Fine chemicals.

Preparation of padding liquor

a) Sodium dithionite and NaOH system

A stock vat and dilution liquor were used to prepare the required concentration of indigo padding liquor (Table 1). To prepare the stock vat, the required amount of sodium hydroxide (NaOH) and indigo were added to 100 ml water and heated to 50 °C. The required amount of sodium dithionite ($Na_2S_2O_4$) was then added and the solution left to sit for 15–20 minutes to complete the reduction of the indigo.

To prepare the dilution liquor, the required amount of NaOH and $Na_2S_2O_4$ was added to 1 litre of water at room temperature and stirred well until a clear solution was obtained.

A padding liquor with 3 g/l indigo was prepared from these two solutions. A total of 567 ml of dilution liquor was added to 100 ml of the reduced stock vat to make 667 ml of padding liquor solution. The concentrations of dye, NaOH and $Na_2S_2O_4$ to prepare the stock vat and dilution liquor were as detailed below (as per guidelines of BASF) to prepare control.

Table 1: BASF guidelines for preparing the stock indigo solution

Substance	Stock vat [g/l]	Dilution liquor [g/l]	Padding liquor [g/l]
Dye	20	–	–
NaOH	20	1.35	4.416
$Na_2S_2O_4$	20	2.0	4.698

b) Alkaline protease and iron (II) sulphate system
In this case, the padding liquor was prepared in the same manner used for the dithionite system, with only difference being the use of protease, together with iron (II) sulphate, instead of dithionite.

Dyeing of cotton with indigo
Cotton was dyed with reduced indigo from both reduction systems using the '6 dip 6 nip' padding technique. This included the dipping of cotton in the dye liquor for 30 seconds, followed by padding at a pressure of 1 kg/cm^2 for 75–80% of pick up and airing for 1 minute to complete the '1 dip 1 nip' cycle. The cotton fabric was dyed in six such consecutive cycles with final airing for 3 minutes to convert the reduced dye on the fabric to its oxidised form. The dyed samples were then thoroughly washed in hot water.

Statistical analysis of dyed cotton
The Box-Behnken response surface design was used to analyse and optimise process parameters. This included identifying the best suitable combinations of parameters and the levels thereof to achieve a dye strength (K/S) equivalent to that obtained in the dithionite system. Five dyeing parameters were studied: the concentration of $FeSO_4$, NaOH, alkaline protease, indigo and temperature. These factors, with their coded values according to the 3^5 Box-Behnken experimental design, are presented in Table 2. Using these five parameters (factors), each with three levels, a 3^5 Box-Behnken design was run to obtain a set of data (run), consisting of a total of 46 runs with six replicates at the central point. The design run is presented in Table 3. The results were analysed using response surface plots and equations were formed for a response at a 95% confidence level. Response surface figures were analysed to understand

Table 2: Inputs with coded values

Coded factor	Factors (independent variables)	Levels		
		low	medium	high
A	Ferrous sulphate	–1	0	+1
B	Sodium hydroxide	–1	0	+1
C	Alkaline protease	–1	0	+1
D	Indigo	–1	0	+1
E	Temperature	–1	0	+1

Table 3: Scheme of experimental runs

Run	$FeSO_4$	NaOH	Protease	Dye	Temperature
1	–1	–1	0	0	0
2	1	–1	0	0	0
3	–1	1	0	0	0
4	1	1	0	0	0
5	0	0	–1	–1	0
6	0	0	1	–1	0
7	0	0	–1	1	0
8	0	0	1	1	0
9	0	–1	0	0	–1
10	0	1	0	0	–1
11	0	–1	0	0	1
12	0	1	0	0	1
13	–1	0	–1	0	0
14	1	0	–1	0	0
15	–1	0	1	0	0
16	1	0	1	0	0
17	0	0	0	–1	–1
18	0	0	0	1	–1
19	0	0	0	–1	1
20	0	0	0	1	1
21	0	–1	–1	0	0
22	0	1	–1	0	0
23	0	–1	1	0	0
24	0	1	1	0	0
25	–1	0	0	–1	0
26	1	0	0	–1	0
27	–1	0	0	1	0
28	1	0	0	1	0
29	0	0	–1	0	–1
30	0	0	1	0	–1
31	0	0	–1	0	1
32	0	0	1	0	1
33	–1	0	0	0	–1
34	1	0	0	0	–1
35	–1	0	0	0	1
36	1	0	0	0	1
37	0	–1	0	–1	0
38	0	1	0	–1	0
39	0	–1	0	1	0
40	0	1	0	1	0
41	0	0	0	0	0
42	0	0	0	0	0
43	0	0	0	0	0
44	0	0	0	0	0
45	0	0	0	0	0
46	0	0	0	0	0

the effect of an individual parameter (factor) on dye strength (K/S). A regression equation was formed accordingly. All design formations and statistical analysis were carried out using Design Expert 7 software. A quadratic polynomial was used to analyse the relationship of dye strength (K/S) (response) with five independent variables (factors) for Box-Behnken design runs. The accuracy of the model was verified using the coefficient of determination (R^2) to the measure the goodness of fit to the model. When R^2 approaches unity, the empirical model fits the actual data. P-values of less than 0.05 were considered to be statistically significant. The lack-of-fit test was analysed to check the adequacy of the model. Two techniques, i.e. the response surface figures technique and the regression equation technique, were used to predict the optimised combination of the factors that result in maximum colour strength (K/S).

Evaluation of dye bath and dyed cotton

The surface colour strength (K/S) of dyed cotton was evaluated using a computer colour match (Datacolor Check, Datacolor International, US), while colour fastness properties, such as light, wash and rubbing, were evaluated using AATCC test methods 16–2004 (light), 61–2007 (wash), 8–2007 (rubbing) respectively. Reduction dye baths were evaluated in terms of pH and reduction potential using a digital pH cum ORP meter (Century Instruments, Chandigarh, India) at various stages of dyeing i.e. before and after the reduction of the dye, as well as after the completion of the dye.

Estimation of dye uptake

To study the amount of indigo uptake on cotton fabric after each dip and nip, the known weight of dyed cotton fabric was dissolved in dimethyl sulfoxide (DMSO) to extract indigo from the dyed cotton fabric. The extract was analysed using a UV-Vis spectrophotometer (Perkin Elmer) to evaluate the mass of indigo (g) per 100 g of cotton fabric after each padding-nipping-airing cycle.

Stability of reduction dye baths

Reduction baths in sodium dithionite and alkaline protease, together with iron (II) salt, were prepared in the absence of dye and stored for a specific period (0–24 hours) at room temperature, after which pH and reduction potential (–mV) were noted. Dye was added and the cotton fabric was dyed after reduction and solubilisation. To study the stability of reduction baths in the presence of dye, dye baths were prepared and stored for a specific period, and pH and mV were noted, followed by dyeing of the cotton fabric in these baths.

X-ray diffraction

Diffractograms were generated using a Malvern Pan analytical XRD. A small sample was clamped into a sample holder on a goniometer (radius 240 mm) in a scanning range of 10–60 with a step size of 0.008° and an X-ray radiation wavelength of λ = 0.15406 nm using Cu K_α. The X-ray generator was operated at 40 mA and 45 kV. ATR-FTIR spectra were obtained using an ALPHA FT-IR spectrophotometer (Bruker, USA).

Tensile strength of cotton fabric

A universal testing machine (Aimil, Delhi) was used to measure the tensile strength of cotton fabric using an ASTM D5035 test method after dyeing in both reduction systems.

3 Results and discussion

3.1 Dyeing of cotton with sodium dithionite

Cotton fabric was dyed with indigo using the '6 dip 6 nip' padding technique, followed by oxidation and washing. The K/S of the dyed cotton was determined to be 22.40 at λ max 590 nm. The range of pH and mV were 12.2 to 12.8 and (–640 mV to –780 mV) respectively at various stages of dyeing.

3.2 Dyeing of cotton with alkaline protease

Efforts to dye cotton fabric with indigo using alkaline protease instead of sodium dithionite could not generate the required reduction potential nor any reduction of dye leading to no dye strength (K/S) on cotton. The reduction potential of the bath was in the range of –330 mV to –370 mV. In contrast, indigo requires a reduction potential of around –650 mV and more for reduction. It was determined that enzyme activity is enhanced by the addition of metals to the bath [25, 26]. For this reason, indigo reduction baths were formulated with alkaline protease, together with iron (II) sulphate. Cotton fabric was dyed in this bath in the same manner that is used in the dithionite system. The reduction potential of the bath was raised to around –700 mV to –720 mV with the reduction of indigo. The cotton fabric was then dyed with a lower K/S. To improve the K/S, the levels of dyeing parameters were varied, and the reduction baths were prepared by dyeing cotton from each bath to attempt to achieve the same dye strength on cotton that was obtained in the dithionite system. The more suitable ranges were concentrations of $FeSO_4$ (20–25 g/l), NaOH (7.5–12/5 g/l), alkaline protease (1–2 g/l), indigo (7–8 g/l) and temperature (60–80 °C). The actual values of levels in the Box-Behnken design were formed accordingly (Table 4).

Table 4: Process parameters and the coded levels thereof

Coded factor	Factors (independent variables)	Levels		
		−1 (low)	0 (medium)	1 (high)
A	Ferrous sulphate [g/l]	20	22.5	25
B	Sodium hydroxide [g/l]	7.5	10	12.5
C	Alkaline protease [g/l]	1.0	1.5	2.0
D	Indigo [g/l]	7.0	7.5	8.0
E	Temperature [°C]	60	70	80

Putting these levels in the Box-Behnken design resulted in 46 separate runs. Indigo baths were prepared based on these sets of parameters and levels, while the cotton fabric was dyed and the K/S was evaluated. The results are presented in Table 5.
It was observed that the range of K/S was 12.26 to 23.9, while the highest K/S was observed if the bath

Table 5: Responses of Box-Behnken analysis

Run	$FeSO_4$ [g/l]	NaOH [g/l]	Protease [g/l]	Indigo [g/l]	Temperature [°C]	K/S
1	20	7.5	1.5	7.5	70	20.85
2	25	7.5	1.5	7.5	70	12.26
3	20	12.5	1.5	7.5	70	16.52
4	25	12.5	1.5	7.5	70	18.76
5	22.5	10	1	7	70	20.10
6	22.5	10	2	7	70	18.81
7	22.5	10	1	8	70	20.80
8	22.5	10	2	8	70	18.66
9	22.5	7.5	1.5	7.5	60	14.42
10	22.5	12.5	1.5	7.5	60	16.74
11	22.5	7.5	1.5	7.5	80	16.48
12	22.5	12.5	1.5	7.5	80	17.87
13	20	10	1	7.5	70	21.66
14	25	10	1	7.5	70	21.50
15	20	10	2	7.5	70	20.44
16	25	10	2	7.5	70	19.28
17	22.5	10	1.5	7	60	18.92
18	22.5	10	1.5	8	60	16.23
19	22.5	10	1.5	7	80	19.83
20	22.5	10	1.5	8	80	20.09
21	22.5	7.5	1	7.5	70	15.02
22	22.5	12.5	1	7.5	70	19.35
23	22.5	7.5	2	7.5	70	12.83
24	22.5	12.5	2	7.5	70	23.68
25	20	10	1.5	7	70	20.72
26	25	10	1.5	7	70	22.33
27	20	10	1.5	8	70	19.58
28	25	10	1.5	8	70	22.27
29	22.5	10	1	7.5	60	20.21
30	22.5	10	2	7.5	60	20.12
31	22.5	10	1	7.5	80	20.14
32	22.5	10	2	7.5	80	17.31
33	20	10	1.5	7.5	60	23.90
34	25	10	1.5	7.5	60	22.65
35	20	10	1.5	7.5	80	19.46
36	25	10	1.5	7.5	80	16.69
37	22.5	7.5	1.5	7	70	12.46
38	22.5	12.5	1.5	7	70	19.85
39	22.5	7.5	1.5	8	70	13.03
40	22.5	12.5	1.5	8	70	22.58
41	22.5	10	1.5	7.5	70	21.62
42	22.5	10	1.5	7.5	70	21.45
43	22.5	10	1.5	7.5	70	21.76
44	22.5	10	1.5	7.5	70	21.15
45	22.5	10	1.5	7.5	70	21.82
46	22.5	10	1.5	7.5	70	21.70

was prepared according to run 33, i.e. $FeSO_4$ (20 g/l), NaOH (10 g/l), alkaline protease (1.5 g/l), indigo (7.5 g/l) and temperature (60 °C). It should be noted that a 3 g/l indigo bath resulted in a K/S of 22.40 in dithionite system.

3.3 Influence of dyeing parameters on K/S

The influence of process parameters on concentrations of $FeSO_4$, NaOH, protease and indigo, and temperature on K/S was evaluated using the Box-Behnken design and response surface methodology. All of the main effects, two interaction factors and the cubic effect with R-square 0.97 obtained using ANOVA are presented in Table 6. The model was significant at a 95% confidence interval, as the value of 'Prob>F' was less than 0.05. In this case, the concentrations of $FeSO_4$, NaOH, protease and temperature were the significant model factors. The model equation is shown in coded form in equation 1.

$$K/S = +21.58 - 1.30 \times A + 0.73 \times B - 0.82 \times \times C - 0.26 \times D + 1.00 \times E + 2.71 \times A \times B - - 0.25 \times A \times C + 0.27 \times A \times D - 0.36 \times A \times \times E + 1.63 \times B \times C + 0.54 \times B \times D - 0.69 \times$$

Table 6: ANOVA table for K/S

Source	Sum of squares	df	Mean square	F value	p-value Prob > F	
Model	389.3755447	26	14.97598249	27.10551714	< 0.0001	significant
A-FeSO4	13.57205	1	13.57205	24.56449413	< 0.0001	
B-NaOH	4.3218	1	4.3218	7.822166195	0.0115	
C-alkaline protease	7.987008333	1	7.987008333	14.45594581	0.0012	
D-Dye	0.785408333	1	0.785408333	1.421536053	0.2478	
E-temperature	7.9401125	1	7.9401125	14.37106751	0.0012	
AB	29.322225	1	29.322225	53.07124744	< 0.0001	
AC	0.25	1	0.25	0.45248312	0.5093	
AD	0.2916	1	0.2916	0.527776311	0.4764	
AE	0.525625	1	0.525625	0.95134576	0.3416	
BC	10.6276	1	10.6276	19.23523843	0.0003	
BD	1.1664	1	1.1664	2.111105246	0.1626	
CE	1.8769	1	1.8769	3.397062273	0.081	
DE	2.1904	1	2.1904	3.964476106	0.061	
A^2	0.040751515	1	0.040751515	0.073757491	0.7889	
B^2	125.0288727	1	125.0288727	226.2938178	< 0.0001	
C^2	4.08509697	1	4.08509697	7.393749693	0.0136	
D^2	8.510454545	1	8.510454545	15.40334811	0.0009	
E^2	17.47396364	1	17.47396364	31.62669435	< 0.0001	
A^2E	34.72820417	1	34.72820417	62.85570472	< 0.0001	
AC^2	2.522016667	1	2.522016667	4.564679882	0.0459	
AD^2	15.07335	1	15.07335	27.28174576	< 0.0001	
B^2C	5.474252083	1	5.474252083	9.908026654	0.0053	
B^2D	3.504602083	1	3.504602083	6.343093143	0.0209	
BC^2	24.9696	1	24.9696	45.19329007	< 0.0001	
BD^2	32.66666667	1	32.66666667	59.12446104	< 0.0001	
C^2E	7.854704167	1	7.854704167	14.2164842	0.0013	
Residual	10.49762917	19	0.552506798			
Lack of fit	10.18989583	14	0.727849702	11.82598087	0.0065	significant
Pure error	0.307733333	5	0.061546667			
Cor total	399.8731739	45				
Model	389.3755447	26	14.97598249	27.10551714	< 0.0001	significant

$$\times C \times E + 0.74 \times D \times E + 0.068 \times A^2 - 3.78 \times \times B^2 - 0.68 \times C^2 - 0.99 \times D^2 - 1.42 \times E^2 - - 3.61 \times A^2 \times E + 0.97 \times A \times C^2 + 2.38 \times A \times \times D^2 + 1.35 \times B^2 \times C + 1.08 \times B^2 \times D + 3.06 \times \times B \times C^2 + 3.50 \times B \times D^2 - 1.72 \times C^2 \times E \quad (1),$$

where, different values of A, B, C, D and E are presented in Table 6. This equation can predict the theoretical K/S of dyed samples for given dyeing parameters.

3.3.1 Influence of $FeSO_4$ and NaOH concentrations

The combined effect of $FeSO_4$ and NaOH concentrations on K/S at a constant alkaline protease concentration, indigo concentration (moderate level) and temperature (lower level) is shown in Figure 1(a). A moderate level of NaOH (10 g/l) and $FeSO_4$ (20 g/l) resulted a maximum K/S of 23.9. Increasing the concentration of $FeSO_4$ resulted in a decrease in the dye strength (K/S) of cotton. An increased concentration of $FeSO_4$ may have decreased the concentration of NaOH in the dye bath due to the formation of insoluble $Fe(OH)_2$, which may affect the solubility of reduced indigo.

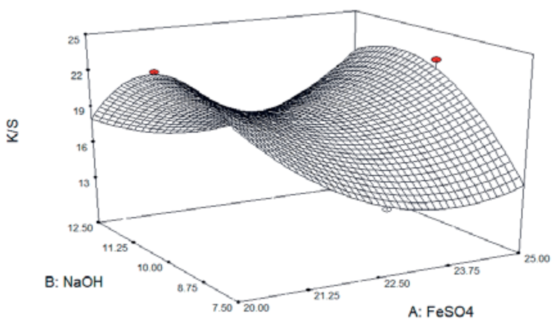


Figure 1a: Influence of dyeing parameters on K/S value of $FeSO_4$ and NaOH concentrations,

3.3.2 Influence of $FeSO_4$ and protease concentrations

The combined effect of $FeSO_4$ and alkaline protease concentrations on K/S at constant indigo and NaOH concentrations (medium level) and temperature (lower level) is shown in Figure 1(b). A lower level of $FeSO_4$ concentration (20 g/l) and a moderate level of protease concentration (1.5 g/l) resulted in a maximum K/S of 23.9 with a reduction potential in the range of (–660 to –720) mV before and after the reduction of the dye, and at the end of dyeing. Increasing the concentration of $FeSO_4$ decreased the K/S of dyed cotton to 22.6, which may be due to the partial reduction of indigo. $FeSO_4$ reacts with NaOH

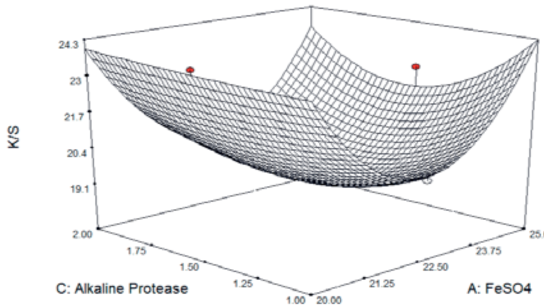


Figure 1b: Influence of dyeing parameters on K/S value of $FeSO_4$ and protease concentrations

to form $Fe(OH)_2$, resulting in a decrease in the effective concentration of sodium hydroxide (moderate level) in dye baths.

3.3.3 Influence of $FeSO_4$ and temperature

The combined effect of $FeSO_4$ concentration and temperature on K/S at constant alkaline protease, indigo and NaOH concentrations (moderate level) is shown in Figure 1(c). A lower level of $FeSO_4$ concentration and temperature resulted in a maximum K/S of 23.9. Increasing the $FeSO_4$ concentration and temperature resulted in a decrease in the K/S of dyed cotton to 16.69. In this case, protease was probably not completely activated to reduce indigo.

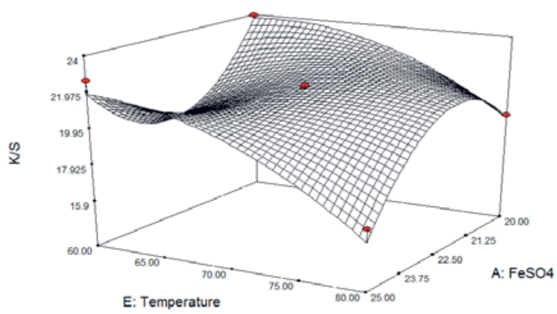


Figure 1c: Influence of dyeing parameters on K/S value of $FeSO_4$ and temperature

3.3.4 Influence of protease concentration and temperature

The combined effect of protease concentration and temperature on K/S at constant indigo and NaOH concentrations (moderate level) and $FeSO_4$ (lower level) is shown in Figure 1(d). A moderate level of protease concentration and a lower temperature level resulted in a maximum K/S of 23.9. Increasing the temperature resulted in a decrease in K/S to

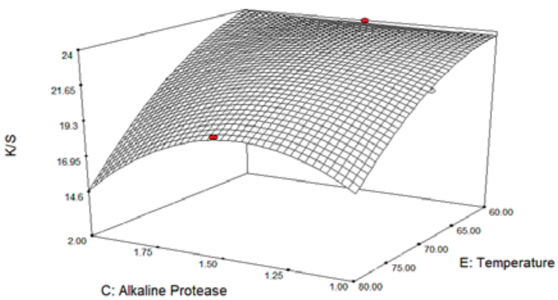


Figure 1d: Influence of dyeing parameters on K/S value of protease concentration and temperature

19.46 at a moderate level of protease concentration. The hydrolytic property of alkaline protease was activated at a specific temperature, resulting in a reduction in indigo.

3.4 Indigo uptake and surface colour strength

The dye uptake (g of dye/100 g cotton) after each dip/nip was evaluated and is shown in Figure 2(a). The respective K/S after each dip/nip against that of indigo uptake is shown in Figure 2(b). K/S and dye uptake both increased proportionately. Although final K/S was nearly identical in both reduction systems, total dye uptake was found to be higher in the protease system despite a lower K/S in the protease system after the first dip/nip compared to that in the dithionite system. The same K/S in both the cases with a variation in dye uptake facilitated more diffusion of dye into cotton in the protease system.

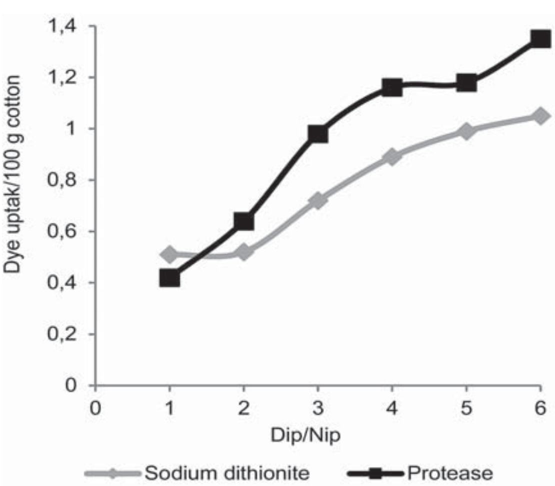


Figure 2a: Indigo uptake and surface colour strength dye uptake of cotton after each dip/nip

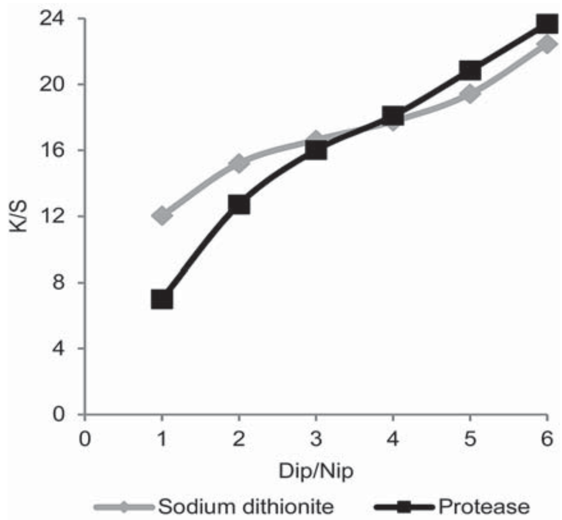


Figure 2b: Indigo uptake and surface colour strength dye strength (K/S) of cotton after each dip/nip

3.5 Stability of reduction baths

3.5.1 In the absence of dye

The stability of reduction baths with $Na_2S_2O_4$ and alkaline protease was studied in the absence of dye for up to 24 hours. Reduction baths were prepared and covered. After storing them for a specific period of time, the pH and reduction potential of the baths were measured. Indigo was then added to the baths. Dyeing was carried out, with the results presented in Table 7. Both of the reduction systems retained their reduction capability for up to 24 hours. There was a progressive drop in mV and pH in both reduction baths with the passage of time. K/S gradually decreased with an increase in storage time in both reduction systems and is shown in Figure 3(a). Although reduction baths in both systems showed good stability over a 24-hour period, maximum surface colour strength was observed for dyeing at 0 hours.

3.5.2 In the presence of dye

Reduction baths with $Na_2S_2O_4$ and alkaline protease were prepared, followed by the addition of indigo. The baths were covered and stored for up to 24 hours. The results were noted in terms of pH and reduction potential, and are presented in Table 8.
Both of the reduction systems retained their reduction capability for 24 hours. There was a steady drop in the mV and pH of both reduction baths with the passage of time, while the proportionate drop in K/S

Table 7: Stability of reduction baths in the absence of dye

Time (h)	Before reduction of dye				After reduction of dye				After completion of dyeing			
	pH		Reduction potential [mV]		pH		Reduction potential [mV]		pH		Reduction potential [mV]	
	Hydro	Pro	Hydro	Pro	Hydro	Pro	Hydro	Pro	Hydro	Pro	Hydro	Pro
0	12.74	12.64	–772	–715	12.60	12.53	–760	–709	12.30	12.34	–748	–695
1	12.74	12.58	–765	–712	12.38	12.46	–755	–703	12.18	12.26	–750	–692
2	12.73	12.47	–770	–720	12.29	12.40	–767	–705	12.09	12.35	–720	–690
4	12.72	12.55	–782	–705	12.5	12.45	–740	–695	12.10	12.29	–730	–685
8	12.70	12.51	–776	–706	12.30	12.36	–720	–698	12.19	12.32	–697	–682
12	12.72	12.55	–780	–718	12.34	12.48	–729	–707	12.12	12.42	–695	–670
24	12.66	12.50	–776	–701	12.2	12.35	–714	–690	12.05	12.24	–685	–680

Table 8: Stability of reduction baths in the presence of dye

Time (h)	Before reduction of dye				After reduction of dye				After completion of dyeing			
	pH		Reduction potential [mV]		pH		Reduction potential [mV]		pH		Reduction potential [mV]	
	Hydro	Pro	Hydro	Pro	Hydro	Pro	Hydro	Pro	Hydro	Pro	Hydro	Pro
0	12.51	12.66	–709	–720	12.48	12.45	–701	–714	12.35	12.32	–612	–667
1	12.49	12.49	–716	–715	12.45	12.35	–705	–712	12.35	12.25	–610	–655
2	12.49	12.55	–703	–722	12.45	12.49	–699	–719	12.26	12.42	–605	–676
4	12.48	12.48	–705	–705	12.44	12.33	–695	–698	12.13	12.29	–600	–655
8	12.48	12.55	–718	–709	12.44	12.35	–707	–701	12.04	12.25	–590	–686
12	12.49	12.61	–701	–712	12.42	12.5	–689	–710	11.8	12.35	–550	–664
24	12.48	12.52	–704	–706	12.41	12.47	–685	–690	11.5	12.40	–489	–676

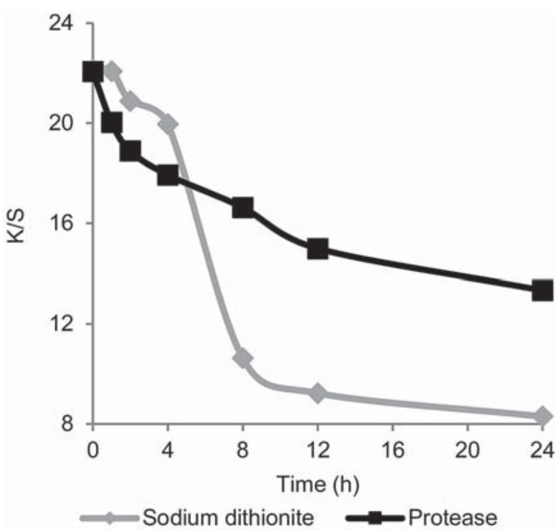


Figure 3a: Surface colour strength of cotton after storage in the absence of dye

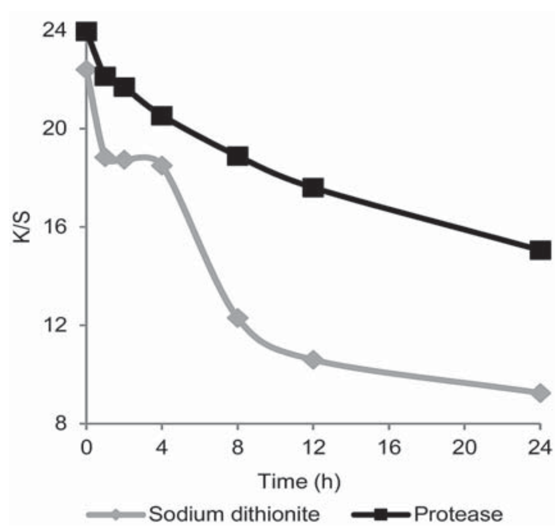


Figure 3b: Surface colour strength of cotton after storage in the presence of dye

is also shown in figure 3(b). Reduced dye baths showed a maximum dye strength for dyeing at 0 hours, although good stability was observed for up to 24 hours.

3.6 Characterisation

3.6.1 SEM analysis of dyed cotton fabric

The surface morphology of dyed cotton was characterised using an SEM (Zeiss EVO 50) at a voltage of 10 kV and a 5,000-x magnification. The surface of the cotton fibre was considered damaged due to dyeing. The SEM images of undyed cotton as well as cotton dyed using sodium dithionite and protease systems are shown on Figure 4. The images show marginal damage on the surface of cotton dyed in the sodium dithionite system, which was not prominent in the protease system.

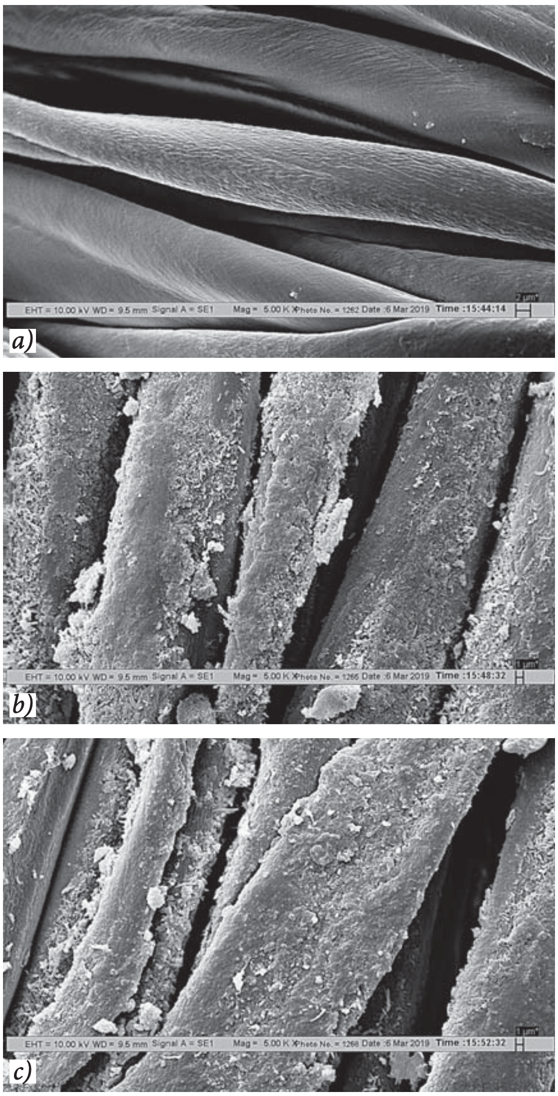


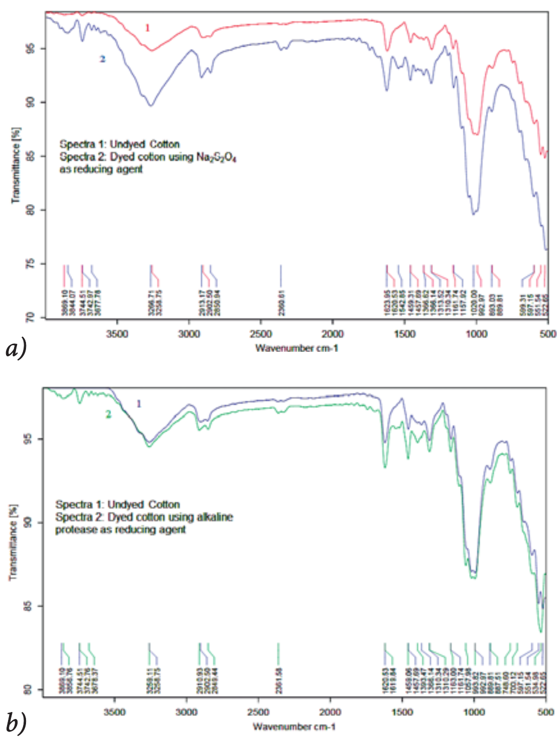
Figure 4: SEM images of: a) undyed cotton, b) dyed cotton using sodium dithionite and c) dyed cotton using alkaline protease

3.6.2 ATR-FTIR of dyed cotton

The spectra of dyed cotton with sodium dithionite and alkaline protease are compared with undyed cotton (control) and are shown in Figures 5(a) and 5(b) respectively. The absorption bands were mainly observed in the ranges of 3,869 to 2,850 cm^{-1} and 1,623 to 522 cm^{-1}.

Strong band spectra were found in a range of 3,869–2,900 cm^{-1}, as the result of the stretching vibration of O–H and C–H bonds, while the band peak at around 3,266–3,258 cm^{-1} is due to the stretching vibration of R–OH in cellulose. This peak also includes inter- and intra-molecular hydrogen bonds [27–29]. The band peak of around 2,913 cm^{-1} to 2,849 cm^{-1} is due to the symmetrical and asymmetrical stretching of $-CH_2$ groups in cellulose [30, 31]. A typical band in the range of 1,623 cm^{-1} to 522 cm^{-1} was observed. The absorption band at 1,623 cm^{-1} to 1,619 cm^{-1} is characterised for the stretching of C=C [18]. The

a)



b)

Figure 5: FTIR spectra of: a) undyed versus dyeing in dithionite system, and b) undyed versus dyeing in alkaline protease system

band peaks at 1,459 cm^{-1}, 1,393 cm^{-1}, 1,366 cm^{-1}, 1,310 cm^{-1}, 1,161 cm^{-1} and 1,057 cm^{-1} are characterised for the deformation or stretching vibrations of C=O, C–H, C–O–C, C–O, C—N, C=C and N–H groups in cellulose, as well as indigo [32–34]. In Figure 5(b), differences were observed in the spectrum of dyed cotton using alkaline protease. There are changes in the absorption band in the range of 748 cm^{-1} to 700 cm^{-1}, which is assigned to the in-plane bending of the methyl group in cellulose [31]. The band spectra of both the sodium dithionite and alkaline protease systems were found to be nearly the same. It can thus be concluded that no chemical changes occurred in the new proposed reduction system.

3.6.3 XRD of dyed cotton

The X-ray diffractograms of undyed and dyed cotton are shown in Figure 6. The purpose of x-ray diffraction was to identify the loss in crystallinity of cotton due to a loss in tensile strength after dyeing. The degree of crystallinity is one of the most important parameters for a crystalline structure and was evaluated using Herman's method [28–35]. In this method, the crystallinity index was calculated by the ratio of crystalline area to the total area of the X-ray diffraction curve, as given equation 2.

$$\text{Crystallinity index} = \frac{A_{Crystalline}}{A_{Total}}\ (\%) \qquad (2),$$

where, $A_{Crystaline}$ is the crystalline area and A_{Total} is area of X-ray diffraction curve.

The oxidation reaction of indigo may lead to a decrease in the degree of polymerisation of cellulose and may cause a loss in the tensile strength of cotton. This study revealed that crystallinity remained unchanged in the warp of dyed cotton in both reduction systems, although there was a marginal (7%) drop in crystallinity in dyed cotton with dithionite, while the protease system did not result in a drop in the crystallinity of cotton (Table 9). Interestingly, the drop in tensile strength in the weft direction was similar in both systems, but marginal. The drop in the crystallinity index was also found to be around 7% in the dithionite system and 4% in the protease systems. This indicates that no significant damage occurred in the newly proposed protease-based reduction system.

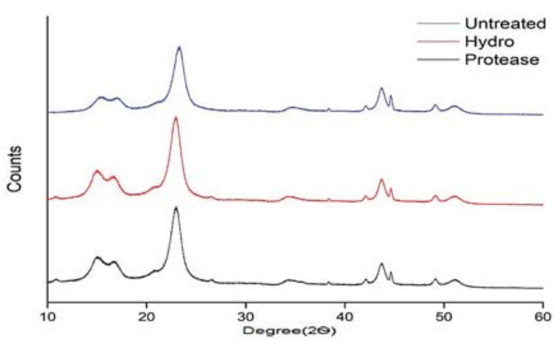


Figure 6: XRD diffractograms of undyed and dyed cotton in dithionite and alkaline protease systems

3.7 Fastness performance

The light, rubbing and wash fastness of indigo-dyed cotton in the $Na_2S_2O_4$ and alkaline protease systems were evaluated and compared. The results are presented in Table 10. Light fastness remained very good to excellent in both the $Na_2S_2O_4$ and alkaline protease reduction systems. Wash fastness was also very good to excellent (4–5) in the alkaline protease system. Rubbing fastness was excellent, and very good to excellent in dry and wet conditions respectively. It can be concluded from the data that the new proposed alkaline protease-based reduction system proved to be a good and comparable match with the commercial sodium dithionite reduction system.

Table 9: Tensile strength and crystallinity index % of undyed and dyed cotton

Sample	Warp way		Weft way		Crystallinity index [%]
	Breaking strength [N]	Loss in strength [%]	Breaking strength [N]	Loss in strength [%]	
Undyed cotton	527	–	448	–	70.06
Dyed with sodium dithionite	498.8	5.35	414.2	7.54	63.56
Dyed with alkaline protease	501	4.93	433.8	3.17	66.62

Table 10: Fastness performance of dyed cotton

Dyeing method	Wash fastness		Rubbing fastness		Light fastness
	Fading	Staining	Dry	Wet	
Sodium dithionite	5	5	5	4	6
Alkaline protease	4–5	4–5	5	4–5	6

4 Conclusion

The work presented in this study illustrates the use of alkaline protease, together with iron (II) sulphate, as a promising reducing agent for the dyeing of cotton with indigo. Both sodium dithionite ($Na_2S_2O_4$) and alkaline protease demonstrated comparable K/S, with few variations. Dye strength with 3 g/l indigo in the sodium dithionite system was a complete match with that of cotton dyed in the protease system for an indigo concentration of 7.5 g/l, although dye uptake with an increased concentration of indigo was found to be on the higher side. The stored baths in both the absence and presence of indigo showed good stability for up to 24 hours. However, the maximum dye strength was obtained at 0 hours of dyeing, i.e. just after the reduction and solubilisation of the dye. Damage on the surface of dyed cotton was less prominent in the alkaline protease-based reduction system. The change in the crystallinity index was around 4%, meaning no significant damage was observed. The drop in the tensile strength of dyed cotton using alkaline protease was less significant than that using dithionite, as less damage to the cotton occurred. The colourfastness of dyed cotton was similar in both reduction systems. Thus, alkaline protease, together with iron (II) salt, could serve as a substitute for sodium dithionite.

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Influence of Textile and Environmental Parameters on Plant Growth on Vertically Mounted Knitted Fabrics

Vpliv tekstilnih in okoljskih parametrov na rast rastlin v navpično nameščenih pletivih

Original Scientific Article/*Izvirni znanstveni članek*

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Abstract

Vertical farming is of major interest in research and development to enable the production of food in the quantity sufficient for the growing world population under the weather conditions, which are increasingly becoming more and more extreme. Especially in cities, vertical farming allows for growing vegetables and other plants locally. Apart from industrial applications of vertical farming, new ideas are being developed to make cities "greener", often related to the maker culture. In the study, we concentrated on the second approach by investigating the possibilities to grow plants on textile fabrics placed vertically, e.g. along a balcony railing, but also as structural elements in agricultural areas. Our investigations revealed, using the example of cress, that steadily irrigated knitted fabrics enable plant growth on them, indicating no significant differences between differently knitted stitch dimensions and different illumination intensities. Finally, we discuss the possibilities to measure the time-resolved plant growth reliably and suggest additional possibilities to evaluate the growth success.

Keywords: vertical farming, textile fabrics, plant growth, knitted fabrics, hydroponics, measurement technology, cress, illumination, irrigation

Izvleček

Vertikalno kmetovanje je zelo pomembno za raziskave in razvoj, saj omogoča pridelavo dovolj hrane za rastoče svetovno prebivalstvo v čedalje bolj ekstremnih vremenskih razmerah. Zlasti v mestih omogoča vertikalno kmetovanje lokalno pridelavo zelenjave in drugih rastlin. Poleg teh industrijskih aplikacij vertikalnega kmetovanja se razvijajo nove ideje za ozelenitev mest, ki so pogosto povezane s kulturo pridelovalcev. Članek se osredotoči na drugačen pristop z raziskovanjem možnosti gojenja rastlin na ploskovnih tekstilijah, postavljenih navpično, npr. ob balkonski ograji, pa tudi kot strukturni elementi na kmetijskih območjih. Naše raziskave na primeru kreše kažejo, da stalno namakanje pletiva omogoča rast rastlin na njih, pri čemer ni pomembnih razlik med različnimi dimenzijami zank pletiv ter različnimi intenzivnostmi osvetlitve. Na koncu je podana razprava o možnostih zanesljivega merjenja rasti rastlin in predlagane so dodatne možnosti za oceno uspeha rasti.

Ključne besede: vertikalno kmetovanje, ploskovne tekstilije, rast rastlin, pletiva, hidroponika, merilna tehnologija, kreša, osvetlitev, namakanje

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1 Introduction

Textile fabrics are applied in diverse areas, from garments and home textiles to a broad range of technical textiles. In agriculture, woven fabrics, warp or weft knitted fabrics can often be found [1], typically produced from polyester, polyamide [1], polyethylene [2, 3] or other man-made fibres. These technical textiles can protect early outdoor plants from harsh environmental conditions and herbivores [4, 5], from contaminations [6–8] etc.

In spite of the frequent use of textile fabrics in agriculture, there are not many reports in the literature on letting plants grow on textile substrates [9]. Recently, our group investigated the growth of *Pleurotus ostreatus* mycelium on nanofibre mats [10] and knitted fabrics [11], respectively, as well as microalgae growth on nanofibre mats [12]. In this study, the growth of higher plants on weft knitted fabrics was investigated to enable plant growth on vertically positioned substrates for the application in vertical farming.

The developed method can be defined as a combination of hydroponics – where plants are grown in water supplemented with macro- and micro-nutrients – and aeroponics – where plants are grown in humid air or water vapour without a water reservoir [13]. Generally, the main aim of vertical farming is to grow plants with increased yield per unit area [14]. This is especially important in large cities where not enough agricultural areas are available to deliver food for the local population [15]. The so-called farmscrapers may offer an alternative to long transport distances [16]. Due to the possibility of recycling the necessary water, to avoid biocides and reduce transport energy, vertical farming can be even more sustainable than conventional farming, besides avoiding the growing danger of extreme weather events [17].

While "vertical" in the case of such farmscrapers is usually defined as vertically stacked horizontal reservoirs of water with nutrients in which plants are growing, vertically positioned substrates for plant growth are only sometimes used by makers and hobby gardeners. However, the latter has not yet been reported in the scientific literature. Therefore, in this paper, we give the first overview of the influence of different environmental factors and substrate parameters on plant growth, serving as the base for future experiments on vertical farming in the literal sense. We thus mostly aim at suggesting possible substrates for makers and others who want to use as much of their balcony or other small spaces to grow flowering plants, herbs, moss or other plants, making their environment "greener" etc.

2 Materials and methods

Single-jersey fabrics of dimensions 5 cm × 5 cm were knitted on a hand flat knitting machine Silver Reed SK 280 (Knittax, Darmstadt, Germany) with needle gauge E5.6 (i.e. needle distance 4.5 mm), using the stitch dimension settings 3, 5, and 7, which were found well knittable. Polyacrylonitrile (PAN) yarn of 45.5 tex × 2 (Nm 22/2) (Andreas Hoffmann Garnhandel & Textilspulerei, Engstingen, Germany) was used to enable a comparison with previous experiments dealing with micro-algae [12] or mushroom mycelium [10] on PAN nanofibre mats. Furthermore, pre-experiments revealed the hydrophilic, hygroscopic properties of knitted fabrics from PAN, while some other materials showed reduced water transport abilities. Finally, this material was chosen to create the test environment with long-time stability, opposite to for example jute or wool, both of which were found to be more prone to mildew and rotting under continuously wet conditions. The fabrics used, however, did not change their mechanical properties significantly during the study, making them re-usable for a sustainable setup.

Table 1 gives an overview of knitted fabric parameters. Thickness was measured using a digital gauge J-40-T (Wolf-Messtechnik GmbH, Freiberg, Germany) and areal weight with an analytical balance SE-202 (VWR International GmbH, Darmstadt, Germany). The microscopic images to distinguish the course and wale densities were taken with a digital

Table 1: Parameters of knitted fabrics used in this study (n = 3)

Parameter	Stitch size		
	3	5	7
Thickness [mm]	1.78	1.82	1.85
Areal weight [g/m²]	211	196	181
Apparent density [kg/m³]	118	107	98
Stitch length [mm]	10.3	12.0	13.7
Course density [cm⁻¹]	5.1	4.4	3.7
Wale density [cm⁻¹]	4.6	4.4	4.1

microscope VHX-600K (Keyence, Neu-Isenburg, Germany).

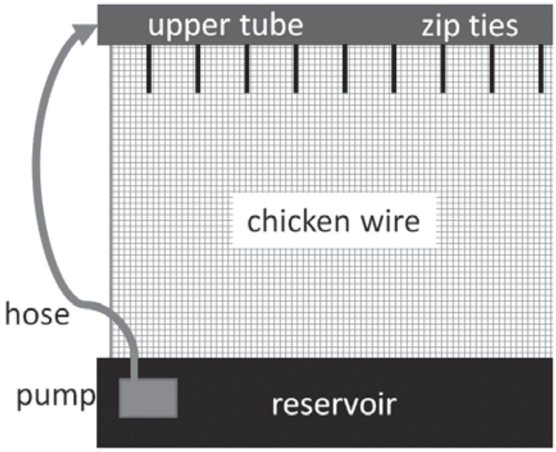
The sample borders were seamed to avoid the unravelling of fabrics. Then, all samples were hand-coated with Konjac Gum Powder (Special Ingredients, Chesterfield, UK) solution (2 g Konjac Gum Powder dissolved in 240 ml deionized water) with the aid of a doctor blade. This method was found more accurate than common rolling knives, box-type doctor knives or a foulard. Konjac Gum Powder contains konjac glucomannan, a polysaccharide extracted from *Amorphophallus konjac* [18] with high water binding and gelation abilities and is typically used in the food industry [19].

Using this polysaccharide is a compromise between using fully biodegradable fabrics – which would work very well when thinking about using the fabric to position the seed only for a limited time, e.g. when placing it on a steep slope where the plants should fix the ground – and using a fully stable fabric. The latter is necessary here or the seeds would lose their footing if the fabrics degraded. The biodegradable Konjac Gum Powder dissolves with time so that the seeds can germinate without problems, while the time-stable PAN forms the base in which the roots can be fixed.

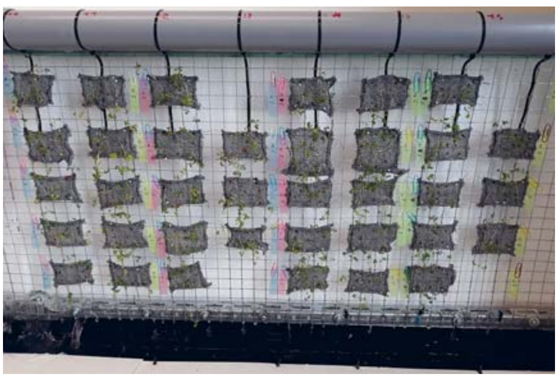
Immediately afterwards, 9 cress seeds (*Lepidium sativum* L., Kiepenkerl, Everswinkel, Germany) per sample were placed in a matrix of 3 × 3 seeds with similar distances on a wet coating and thus glued to the fabric. Afterwards, the coating was dried in air at room temperature for 2 h, before the samples were fixed on the vertical test stand.

The sketch and image of the test stand (45 cm high, 180 cm long) are presented in Figure 1. The textile fabrics were mounted on the metal grid visible in Figure 1 (left panel). Each column of samples was irrigated constantly with supply water (water hardness level 16 °d, i.e. 16 degrees of hardness or "hard" water), using a pump INDOOR P300-i (Heissner, Lauterbach, Germany) with the power of 3.6 W, positioned in a water reservoir below the samples, pumping the water constantly from the reservoir into the upper tube (black half-tube). The measurement results of the spatially resolved flow rate for different columns are given in Results and Discussion. Additional nutrients were not used since only the germination process was examined and no nutrient supply is necessary for it.

For illumination, 2 LED tubes "TubeKIT LED 1.5 m 21.5W/830" (Osram, Munich, Germany) with 150 cm in length with the colour temperature of 3000 K, 21.5 W power, 150° angle of irradiation and 1890 lm luminous flux were used for 16 h per day. They were positioned horizontally in front of the test stand (not visible in Figure 1). The spatially resolved light intensity measurements, performed with a solarimeter KIMO SL-200 at the positions of samples, are given in Results and Discussion.



a)



b)

Figure 1: Vertical test stand: a) sketch of left part (columns 1–9 in Figure 2) of vertical test stand with pump inside water reservoir and zip ties as flow direction control; b) real test stand (columns 10–17 in Figure 2) with knitted fabrics and cress growing on samples

The arrangement of samples on the test stand is depicted in Figure 2. It allows for comparing different stitch dimensions of knitted fabrics (cf. colour codes), different light intensities and irrigations, in this way enabling the evaluation of the influence of these three parameters. The free fields (white in colour) are used as indicators to support a fast orientation among sample positions.

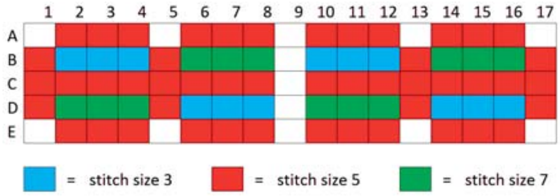


Figure 2: Arrangement of samples with different stitch sizes on vertical test stand and numbering of sample positions

During the experiments, the relative humidity in a not air-conditioned laboratory varied between 35% and 50%, while the temperature varied between 20.6 °C and 23.1 °C. The plant growth was examined for 27 days, starting with the measurements 2 days after placing the seeds on the textile fabrics. Plant lengths were measured using sliding callipers, measuring the distance between the fixing point in the fabric and end point without stretching the plant to avoid any possible disturbance and damage. To evaluate this measurement method, on the last day of experiments, all plants were cut directly above the textile fabric, stretched and in this state glued on a sheet of paper for measuring.

3 Results and discussion

Figure 3 shows the measurements of illumination per sample position, given in W/m². Firstly, it must be mentioned that these values are low, as compared to sunlight, which can reach up to 700 W/m² in the summer and up to 250 W/m² in the winter in the middle Europe, but correspond approximately to typical light intensities in offices and other rooms [20]. Next, it is also visible that the light intensities vary strongly between different sample positions. In this way, the evaluation of the influence of the light intensity is possible. The flow rate through each of the 17 holes is depicted in Figure 4 (n = 3). Apparently, a few of these holes do not work properly (nos. 1, 4, 14). Nevertheless, the variations of the flow rate enable the estimation of the influence of this factor.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
A	5	7	9	10	10	10	10	10	10	10	10	9	9	6	5	4	2
B	5	7	9	10	10	10	10	10	10	10	11	9	9	7	6	4	2
C	5	7	8	9	10	10	10	10	10	11	10	8	9	6	6	4	2
D	5	6	8	8	8	8	8	10	9	10	9	8	8	6	6	3	3
E	5	5	7	7	7	8	8	8	8	9	8	6	6	5	5	3	3

Figure 3: Illumination in W/m², measured in middle of each sample position

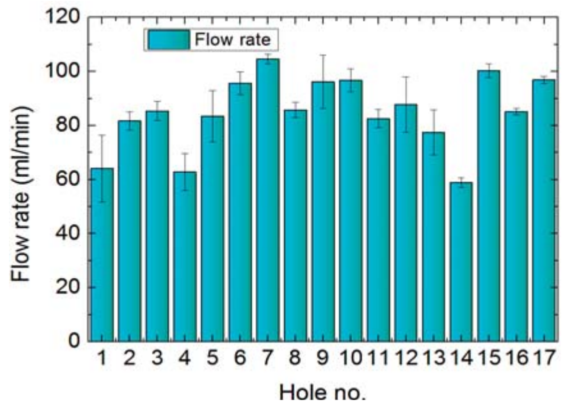


Figure 4: Flow rate, measured per irrigation hole

The Konjac Gum Powder used to glue seeds on textile fabrics is not long-time water-resistant, i.e. it starts swelling when exposed to water, and enables contact between seeds and water as well as growing of roots of germinating cress through the konjac coating. This may, on the other hand, be problematic if the coating is dissolved faster than the root can anchor itself in the knitted fabric. This effect is depicted in Figure 5, where the numbers of lost seeds are given.

It should be mentioned that no correlation is apparent with either the flow rate (cf. Figure 4) or illumination (cf. Figure 3), indicating that the seed positioning should be improved, e.g. by pressing the seed deeper into the konjac coating. However, the number of established seedlings cannot be improved by modifying the longevity of the coating, which would be the case if slow-growing seeds were disadvantaged. This conclusion is supported by the finding that indeed most seeds were lost during the first few days of the experiment, before any seedling managed to stabilize its roots inside the knitted fabric.

Another important factor is the total amount of seedlings which developed further to a plant. Figure 6 shows the number of seeds which did not start growing. Interestingly, these numbers are clearly not correlated with the flow rate (cf. Figure 4), otherwise large numbers of dormant seeds would be expected in columns 1, 4 and 14.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
A		0	2	2		3	1	1		1	2	3		2	2	1	
B	1	3	1	1	2	1	1	2		0	2	1	1	1	0	0	1
C	4	2	2	1	1	1	1	2		2	0	1	1	6	2	1	1
D	0	1	2	1	1	1	3	1		0	1	0	1	0	4	1	2
E		2	2	1		2	3	0		2	2	0		1	2	1	

Figure 5: Numbers of seeds/seedlings lost during experiment

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
A		2	0	1		2	0	0		1	1	1		1	3	0	
B	2	1	4	0	1	1	3	2		2	0	2	1	3	1	1	1
C	0	1	2	0	0	2	0	2		1	2	0	1	0	0	2	2
D	4	0	0	1	1	1	0	0		2	1	1	2	3	0	2	1
E		2	4	0		1	2	1		3	1	3		1	0	1	

Figure 6: Numbers of seeds not grown during experiment

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
A		25	21	25		22	11	16		25	23	24		18	24	26	
B	22	26	14	20	13	17	12	20		21	22	22	24	24	26	17	24
C	17	17	18	18	21	20	12	14		20	26	10	22	23	17	22	28
D	25	27	15	18	17	29	10	19		16	15	22	27	16	26	27	22
E		13	14	22		21	13	32		24	23	20		20	19	24	

Figure 7: Average shoot lengths in mm on 27th (final) day of experiment

Similarly, seeds in the areas with the lowest illumination (esp. columns 16 and 17) do not necessarily have smaller chances of growing. Apparently, the percentage of growing seeds is randomly distributed, i.e. dependent on stochastic variations of the seed quality and not on experimental parameters.

Next, the average lengths of plants (measured from the fabric to the end of the plant without stretching it) on the last day is given in Figure 7 and compared with the actual, true lengths in their fully linearized state, depicted in Figure 8. The average length, measured as mentioned above, can be measured daily to follow the growth process, while stretching the shoot to evaluate its true length may impede and possibly break the plant. Thus, our aim was to evaluate whether there is a clear correlation between both values and to show whether taking the average length without stretching is a useful measure of daily changes in plant growth.

Firstly, Figure 7 clearly shows that reduced flow rates (columns 1, 4 and 14) did not lead to reduced growth. Estimating the influence of the amount of water available for plants is not easy since the flow rate measurements (cf. Figure 4) are only valid for the highest samples per column, while the samples at lower places can be expected to be reached by less water due to the evaporation in the upper part of the test stand. Nevertheless, an estimate of this influence will be given later on.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
A		50	56	52		39	21	31		44	35	50		69	33	38	
B	40	47	27	39	15	64	31	42		47	71	45	23	51	52	29	46
C	55	37	57	54	39	44	32	33		54	50	41	28	54	32	65	46
D	34	37	63	80	56	45	50	37		36	65	48	31	49	35	34	51
E		29	36	65		50	25	54		44	33	55		51	58	53	

Figure 8: Average true lengths in mm on 27th (final) day of experiment

Next, Figure 8 does not show any correlations with illumination or irrigation. This means that the average real length does not depend on these factors. It should be noted that the light intensity was close to the light compensation point reported for other plant species of the family *Brassicaceae*, e.g. radish with 29 μmol photons$\cdot m^{-2} \cdot s^{-1}$ [21], corresponding to about 7 W/m^2. Below the light compensation point, respiratory CO_2 release of the plant exceeds the photosynthetic CO_2 assimilation and the plant fails to increase its dry mass. In the case of cress, the carbon-rich oil seed provides a carbon and energy source for extended growth which was measured in this experiment.

The quotient of true length and length measured in the experiment, not taking into account the bent stems of plants, can be regarded as a measure of the degree of bending and may be expected to be higher for plants the roots of which are either less strongly fixed inside the substrate or which are more strongly trying to grow into the direction of light. Figure 9 depicts these values. Again, while quotients vary strongly between different samples, no correlation to illumination or irrigation is visible. The offered light intensity, despite being near the light compensation point for growth, is entirely sufficient to trigger the so-called phototropism, i.e. the oriented growth of plants in the direction of incident light [22].

Finally, Figures 10 and 11 depict the correlations between the true lengths (cf. Figure 8) and the three experimental parameters, i.e. illumination, irrigation (only calculated for the highest sample per column) and stitch dimensions.

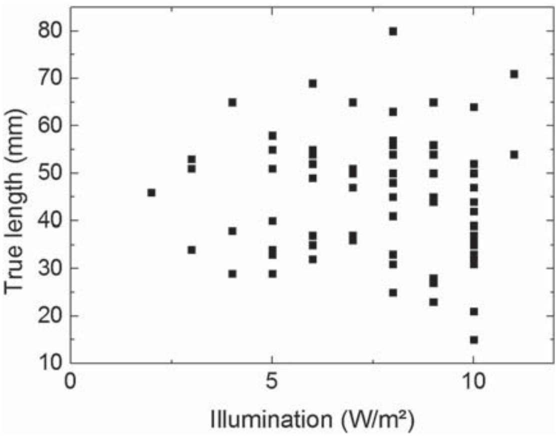
These point clouds clearly indicate that there is no correlation between the true lengths and illumination, while a small negative correlation between the true length and the flow rate cannot be excluded; nevertheless, the latter is not significant either.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
A		2	2.7	2.1		1.8	1.9	1.9		1.8	1.5	2.1		3.8	1.4	1.5	
B	1.8	1.8	1.9	2.0	1.2	3.8	2.6	2.1		2.2	3.2	2.0	1.0	2.1	2.0	1.7	1.9
C	3.2	2.2	3.2	3.0	1.9	2.2	2.7	2.4		2.7	1.9	4.1	1.3	2.3	1.9	3.0	1.6
D	1.4	1.4	4.2	4.4	3.3	1.6	5.0	1.9		2.3	4.3	2.2	1.1	3.1	1.3	1.3	2.3
E		2.2	2.6	3.0		2.4	1.9	1.7		1.8	1.4	2.8		2.6	3.1	2.2	

Figure 9: Average quotient of true lengths and experimental length on 27th (final) day of experiment

The large range of values given in Figure 9 also suggests that measuring the average length without stretching the plant is no reliable measure of the growth process.

Moreover, stitch dimensions do not show an influence on the true lengths either (cf. Figure 11). It should be mentioned that according to Table 1, this also means that the areal weight, fabric thickness and other parameters changing with the stitch dimension do not significantly alter the results. This finding can be explained by the konjac gum coating which is sufficient to fix most of the seeds on each textile fabric at the beginning of experiments so that the impact of the stitch dimension on the initial fixation of the seed is negligible.



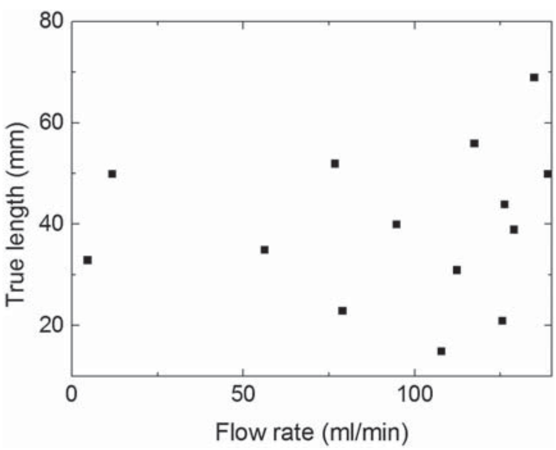


Figure 10: Dependence of true lengths on illumination (all samples) and irrigation (highest mounted samples only), measured on 27th (final) day of experiment

This finding can be interpreted as a negligible influence of examined parameters on the growth of cress on vertically mounted textile fabrics. Nevertheless, it must be mentioned that this result can also be interpreted as the true length of a plant stem not being fully indicative of the plant growth, i.e. that other biological and biochemical parameters should be taken into account during the evaluation of the growth process of diverse plants on textile substrates. One of these possible parameters is the dry mass at the end of the experiment, which is also going to be evaluated in the forthcoming study.

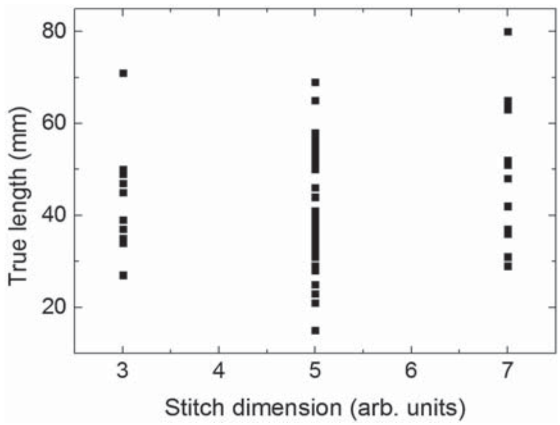


Figure 11: Dependence of true lengths on stitch dimension, measured on 27th (final) day of experiment

4 Conclusion and outlook

Cress seeds were grown on vertically mounted knitted fabrics with different stitch dimensions. By varying also illumination and irrigation for overall 72 samples with 9 seeds each, no significant influence of these three parameters on the true length of cress stems was found after 27 days, whereas strong fluctuations occurred between single seeds. In addition, further studies need to involve the optimization of irrigation. It is sufficient to keep the fabrics moist and over-wetting should be avoided.

It should be mentioned that while fabric thickness, areal weight, illumination etc. did not show a substantial influence on plant growth, it cannot be excluded that a stronger modification of these parameters, e.g. by comparing finest knitted fabrics with thick plush fabrics or by illuminating far above the light compensation point, would show an influence in future investigations.

Our study shows on the one hand that it is generally possible to grow plants like cress on vertically oriented knitted fabrics, especially if combined with a slowly dissolving coating which fixes the seeds at the beginning of the experiment. On the other hand, further growth parameters, e.g. dry mass of plants, should also be taken into account in future experiments to avoid missing possible relevant measures for the success of plant growth. Moreover, other plants of agricultural interest which are more difficult to grow than cress, e.g. spinach, thyme or marjoram, should be examined in terms of their suitability for vertical farming.

After this proof-of-principle underlining that plant growth on textile fabrics is generally possible, future experiments could examine the possibilities to tailor the textile substrates for the requirements of selected plants. In this way, new paths get opened to a fully vertical farming technology, providing new spaces to be used for plant growth.

Acknowledgments

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Influence of Different Colourants on Properties of Cotton Fabric, Printed with Microcapsules of Photochromic Dye

Vpliv različnih kolorantov na lastnosti bombažne tkanine, potiskane z mikrokapsulami fotokromnega barvila

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Abstract

In this study, the influence of the addition of classical pigment, phosphorescent pigment and microcapsules of thermochromic dye on the photocolouration as well as on physical-mechanical properties of cotton fabric printed with microcapsules of photochromic dye was studied. Seven printing pastes of different compositions were prepared. Printing pastes were applied onto 100% cotton fabric using a flat screen printing technique. The thickness, mass per unit area, stiffness, tear strength and elongation, and air permeability of printed samples were measured, whilst colour and colour fastness to rubbing, washing and light were spectrophotometrically evaluated. The thickness, mass per unit area, stiffness and tear strength and elongation of printed fabric increased, whilst air permeability decreased by at least a third in comparison with unprinted fabric. The addition of classical pigment, phosphorescent pigment or microcapsules of thermochromic dye into printing paste that already includes microcapsules of photochromic dye decreases the photocolouration of printed fabric, among which classical pigment has the smallest and microcapsules of thermochromic dye has the largest impact. Photocolouration of fabric decreases with increasing numbers of rubbing cycles; the addition of classical pigment has the smallest and the addition of microcapsules of thermochromic dye has the largest influence. The colour fastness to washing of printed fabric was decreased by increases in the number of washing cycles. The addition of any pigment into printing paste that already contains microcapsules of photochromic dye impairs its colour fastness to washing. By lengthening the time of exposure of printed fabric to the Xenotest apparatus, a reduction of colour fastness to light of printed fabric is produced. The addition of classical pigment, phosphorescent pigment or microcapsules of thermochromic dye into printing paste that already contains microcapsules of photochromic dye slightly slows down the reduction of colour fastness to light exposure of fabric printed with microcapsules of photochromic dye.
Keywords: photocolouration, microencapsulated photochromic dye, cotton, flat screen print

Izvleček

V raziskavi je proučevan vpliv dodatka klasičnega pigmenta, fosforescenčnega pigmenta in mikrokapsuliranega termokromnega barvila na fotoobarvanje in fizikalno-mehanske lastnosti bombažne tkanine, potiskane z mikrokapsulami fotokromnega barvila. Pripravljenih je bilo sedem tiskarskih past različnih sestav. Tiskarske paste so bile nanesene na 100-odstotno bombažno tkanino s tehniko ploskega filmskega tiska. Potiskanim vzorcem so bili izmerjeni debelina, ploščinska masa, togost, pretržna sila in raztezek, zračna prepustnost, barva in barvne obstojnosti pri drgnjenju, pranju in na svetlobi. Slednji sta bili spektrofotometrično ovrednoteni. Potiskanim tkaninam so se povečali debelina, ploščinska masa, togost, pretržna sila in pretržni raztezek, medtem ko se je zračna prepustnost v primerjavi z nepotiskano tkanino za več kot tretjino zmanjšala. Dodatek klasičnega pigmenta, fosforescenčnega

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pigmenta ali mikrokapsuliranega termokromnega barvila v tiskarsko pasto, ki je že vsebovala mikrokapsule fotokromnega barvila, je zmanjšal fotoobarvanje tkanine, med katerimi je imel klasični pigment najmanjši vpliv, mikrokapsule termokromnega barvila pa največjega. Fotoobarvanje tkanine se je zmanjšalo z naraščajočim številom ciklov drgnjenja. Na to je najmanj vplival dodatek klasičnega pigmenta, najbolj pa dodatek mikrokapsuliranega termokromnega barvila. Barvna obstojnost potiskanih tkanin pri pranju se je zmanjšala z naraščajočim številom ciklov pranj. Dodatek kateregakoli pigmenta v tiskarsko pasto, ki je že vsebovala mikrokapsule fotokromnega barvila, je poslabšal barvno obstojnost tkanin pri pranju, potiskanih z mikrokapsulami fotokromnega barvila. S podaljševanjem časa osvetljevanja vzorcev v aparatu Xenotest se je zmanjševala barvna obstojnost vzorcev na svetlobi. Dodatek klasičnega pigmenta, fosforescenčnega pigmenta ali mikrokapsuliranega termokromnega barvila v tiskarsko pasto nekoliko upočasni poslabšanje barvne obstojnosti bombažne tkanine na svetlobi, potiskane z mikrokapsulami fotokromnega barvila.
Ključne besede: fotoobarvanje, mikrokapsulirano fotokromno barvilo, bombaž, ploski filmski tisk

1 Introduction

Interest in colour-active textiles has significantly increased. The specific structure of some dyes allows them to be responsive to changes in electromagnetic waves (visible light, UV and IR radiation), electric current, temperature, pressure, pH value and other environmental factors. The change in dye structure can be visually perceived by the formation of or change in colour. Therefore, several types of chromism exist according to the external factors that activate the dye, namely, photochromism (UV radiation), thermochromism (heat), solvatochromism (solvent), halochromism (pH change), piezochromism (pressure), ionochromism (ions), metallochromism (coordination of metal ions with ligands), and electrochromism (electric current or electric potential) [1]. To date, photochromic dyes, which are responsive to UV radiation, have been rarely used in textile products for commercial purposes, due to their low light fastness properties, but they are more often used for technical purposes. Photochromic dyes are already used for prints to increase security and to protect brands, as well as in textile sensors [2, 3]. Photochromic dyes are capable of changing their chemical structures and, thus, their colour due to UV radiation. Under UV light, molecules of photochromic dye pass from the ground state (colourless form) to the excited state (coloured form). The change in the absorption spectrum of the dye is the result of a chemical change in the dye. When the dye passes from the ground to the excited state, the bathochromic shift of the absorption spectrum is noticed, i.e., a shift to longer wavelengths.

In previous studies, different factors that affect the intensity of the photocolouration of textiles that were dyed or printed with photochromic dyes, were explored. The following factors were investigated: the type of textile substrate (different degree of fibre crystallinity), photochromic dye structure, dye concentration, type of solvent, type of fixation and after-treatments and the influence of UV-absorbers and different stabilizers [1–16]. Since the photocolouration also depend on irradiated light and irradiation time, researchers also studied the influence of those factors [5, 6]. In the literature, no studies were found that evaluate how the addition of classical pigment, microcapsules of thermochromic dye or phosphorescent pigment affects the photocolouration of cotton fabric printed with microcapsules of photochromic dye using the flat screen printing technique. It was assumed that different pigments (classical or phosphorescent) or microencapsulated thermochromic dye would reduce the photoresponsiveness of printed fabric and offer some additional effect. After printing, physical-mechanical changes of the printed fabric are also expected.

2 Experimental

2.1 Materials

2.1.1 Fabric

Chemically pre-treated 100% cotton fabric with mass of 124 g/m^2, warp density of 50 threads/cm and weft density of 30 threads/cm, in plain weave, produced by Tekstina, Ajdovščina was used.

2.1.2 Dyes, pigments and auxiliaries

Cotton fabric was printed with microcapsules of photochromic dye (MFC) Itofinish UV BLUE (Lj Specialities, UK), classical pigment (KP) Minerprint RED RTL HC (Achitex Minerva, Italy), ready-to-use printing paste with phosphorescent pigment (FS) Itoglow in Dark Neutral (Lj Specialities, UK) and microcapsules of thermochromic dye (TK) Itothermochromic Lime (Lj Specialities, UK).

For the preparation of printing pastes, the following auxiliaries were used: a synthetic thickening agent for pigments with good stability to electrolytes (Clear CP), a self-crosslinking binding agent (Legante SE Conc.), a highly stable silicone softening agent for improvement of both printing handling and dry rubbing (Finish S), and a non-formaldehyde self-crosslinking agent (Fixator NFO). The producer of above listed auxiliaries is Achitex Minerva, Italy.

2.1.3 Preparation of printing paste and printing

Stock thickening agent (MZ) was prepared in accordance with the producer's instructions using the following recipe: 740 g cold distilled H_2O, 40 g Clear CP, 200 g Legante SE conc., 10 g Finish S and 10 g Fixator NFO.

Seven printing pastes (TP) with different concentrations of dyes, pigments or their mixtures were prepared. Their compositions are presented in Table 1.

Samples of cotton fabric were printed with printing pastes of different compositions, using a laboratory magnetic printing machine Mini MFD R 390 (J. Zimmer, Austria). Prints were made by two passages of a squeegee with a diameter of 6 mm, velocity of 80%, and a degree of magnetic force of 3. An unpatterned screen stencil with mesh of 42 threads/cm, was used. After printing, the samples were dried for 2 min at 100 °C and then cured for 4 min at 150 °C in a laboratory dryer (Mathis, Switzerland).

2.2 Methods

Thickness

Measurements of the thicknesses (*d*) of the printed samples were performed with a Metrimpex TYP 6-12-1/B micrometer apparatus (Mitutoyo Corp., Japan) using the EN ISO 5084:1996 standard [17]. Measurements were taken with a pressure of 25 cm² and a 20 cN/cm² load.

Mass per unit area

Mass per unit area of unprinted and printed samples was determined using the EN 12127:1997 standard [18]. Mass per unit area (*T*), expressed in g/m², was determined from the average value of all measurements.

Stiffness of fabric

The stiffness of unprinted and printed samples was determined according to the ASTM D 1388-64 standard [19].

Air permeability

The EN ISO 9237:1995 standard [20] was used for the determination of the air permeability of the fabric using an Air Tronic 3240B apparatus (Mesdan, Italy). Measurements of airflow were performed with a measuring area of 100 cm² and an air pressure of 150 Pa. It should be emphasized that the face of the printed sample was turned to the air aperture during the measurements.

Table 1: Sample labels and compositions of printing pastes

Sample	Printing paste	MZ[a)] [g/kg]	MFC[b)] [g/kg]	KP[c)] [g/kg]	FS[d)] [g/kg]	TK[e)] [g/kg]
VZ0	/	/	/	/	/	/
VZ1	TP1	800	200	/	/	/
VZ2	TP2	995	/	5	/	/
VZ3	TP3	995	/	/	5	/
VZ4	TP4	995	/	/	/	5
VZ5	TP5	795	200	5	/	/
VZ6	TP6	795	200	/	5	/
VZ7	TP7	795	200	/	/	5

[a)] Stock thickening agent, [b)] Microcapsules of photochromic dye, [c)] Classical pigment, [d)] Ready-to-use printing paste with phosphorescent pigment, [e)] Microcapsules of thermochromic dye

Breaking force and elongation
Measurements of breaking force and elongation were performed on an Instron 5567 apparatus (Instron, UK) according to the EN ISO 13934-1:1999 standard [21]. The method was modified with the measurements performed at a fasten length of 50 mm, velocity load of 100 mm/min and sample size of 15 cm × 2.5 cm. From each printed sample, five test pieces in the warp direction and five test pieces in the weft direction were cut out.

Resistance to rubbing
The printed samples were exposed to rubbing on a Martindale M235 apparatus (SDL International LTD, UK). Rubbing was performed only on samples printed with MFC, namely, VZ1, VZ5, VZ6 and VZ7. The test pieces were rubbed for 100, 300, 500 and 1,000 cycles at a load of 9 kPa. The number of rubbing cycles was selected according to the study Ocepek et al. [22]. Resistance to rubbing was spectrophotometrically evaluated by the determination of the colour difference of the rubbed test pieces before and after irradiation of the test peace with ultraviolet A (UV-A) light and compared to unrubbed pieces. Exposure of test peace to UV-A light last 1 min using two Philips TL-D 18 W actinic bulbs. The distance between the bulbs and the test peace was 11 cm.

Colour fastness to washing
The EN ISO 105-C06:2010 [23] standard was used to determine the colour fastness of the printed samples to domestic and commercial laundering. Washing was performed in a Gyrowash apparatus (James Heal, UK). Three test pieces with dimensions of 10 cm × 4 cm were cut out of samples VZ1, VZ5, VZ6 and VZ7. The first test piece was washed using the A1S method, whilst the other two were washed using the A1M method. The third test piece was subjected to the A1M washing method twice, which corresponds to ten domestic washing cycles.

Colour fastness to artificial light
Printed samples were subjected to the EN ISO 105-B02:2014 [24] standard in a Xenotest Alpha apparatus (Atlas, USA). One test piece of each sample was illuminated for 1, 6, 12 and 24 h.

Colour measurements
The colour of the printed samples was analysed using a Datacolor Spectraflash 600 PLUS-CT spectrophotometer. Measurements were performed in the range of 400–700 nm, with a d/8° measuring geometry, under D_{65} illumination, 10° standard observer, with specular reflectance included and the UV component excluded (0% UV, filter FL40 on), with a 9-mm aperture. Four layers of sample were used for the measurements. An average of five measurements was taken for each sample. CIE $L^*a^*b^*$ colour values were measured before and after irradiation of the samples with UV-A light for 1 min.
The total colour difference (ΔE^*) between the samples, tested to rubbing, washing and light, before and after irradiation with UV-A light, were calculated in accordance with the Equation 1 [25] and compared to untested samples:

$$\Delta E^*_{ab} = \sqrt{(L^*_v - L^*_{st})^2 + (a^*_v - a^*_{st})^2 + (a^*_v - a^*_{st})^2} \qquad (1),$$

where L^* is lightness, a^* is the red/green coordinate and b^* is the yellow/blue coordinate. Index *st* presents the sample before irradiation and index *v* after irradiation with UV-A light.

Scanning electron microscopy (SEM)
Test pieces of samples VZ1, VZ6 and VZ7 subjected to different numbers of rubbing cycles in the Martindale apparatus were also investigated using a JSM-7600F scanning electron microscope (JEOL, Japan) at 1500x magnification.

3 Results and discussion

In Table 2, measurements of thickness, mass per unit area, stiffness and air permeability of the studied samples are collected. From the values of thickness, it can be seen that the application of printing paste slightly increases the fabric thickness (samples VZ1-VZ7) since all printing paste ingredients stay on fabric surface after printing. Among the studied samples, no crucial difference between values of thickness is noticed. They are in the range of an experimental error.
From Table 2, it can also be seen that there is an increase of mass per unit area in all printed samples, irrespective of the printing paste composition. When MFC or pigment was added into the printing paste (samples VZ1, VZ2, VZ3 and VZ4), the addition of MFC (sample VZ1) has a greater influence on the increase of mass per unit area than the addition of

Table 2: Thickness, mass per unit area, stiffness in the warp and weft directions, overall flexural rigidity and air permeability of the studied samples

Sample	Thickness [mm]	Mass per unit area [g/m²]	Stiffness in the warp direction [mg·cm]	Stiffness in the weft direction [mg·cm]	Overall flexural rigidity [mg·cm]	Air permeability [mm/s]
VZ0	0.230	124	307.32	110.16	184.00	307.30
VZ1	0.237	143	525.32	144.12	275.15	19.47
VZ2	0.236	136	490.46	138.83	260.94	84.77
VZ3	0.236	137	506.62	139.78	266.11	99.50
VZ4	0.236	137	490.80	137.35	259.64	76.94
VZ5	0.237	146	608.07	150.52	302.53	23.15
VZ6	0.242	144	669.90	145.85	312.58	18.55
VZ7	0.242	143	575.75	144.09	288.03	26.30

pigment. The reason could lie in larger concentration of MFC than concentration of KP, FS or TK. For printing pastes that include mixtures of MFC and pigment, printing paste TP5 contributed the most to the increase of mass per unit area, but it only increased 2 g/m² compared to printing pastes TP6 and TP7. Due to the very small amount of classical pigment, phosphorescent pigment or microcapsules of the thermochromic dye added to MFC, the differences in mass per unit area are almost negligible among the VZ5, VZ6, VZ7 samples and the VZ1 sample. Concentration of microcapsules in printing paste influences mass per unit area of printed fabric, published by Golja et al. [26]. They proved that the mass per unit area of printed fabric increases with the increase number of microcapsules in the printing paste [26]. The stiffness of the printed samples significantly differs in the warp and weft directions; it is higher in the warp direction due to the higher number of treads in warp than in weft direction. The same is observed for the unprinted sample, which is in accordance with fabric density. The highest stiffness in the warp direction was observed for the VZ5, VZ6 and VZ7 samples, whilst the lowest was observed for the VZ2 and VZ4 samples. The stiffness of the printed samples in the weft direction is in some cases more than half the stiffness in the warp direction. VZ5, VZ6 and VZ7 samples in the weft direction are the stiffest, followed by the VZ1 sample. The results of the overall flexural rigidity of the samples printed with MFC or pigment show that the VZ1 sample is the stiffest, followed by the VZ3 and VZ2 samples, whilst the VZ4 sample is least stiff. The reason lies in both the printing paste composition and the concentration of dye or pigment (Table 1). The TP1 printing paste includes the highest concentration of MFC comparing to the TP2, TP3 and TP4 printing pastes, which contain lower concentrations of KP, FS or TK. The results of the overall flexural rigidity also indicate that the combination of MFC and pigment affects the fabric stiffness to a greater extent than the application of MFC or pigment itself. Unlike the results of the measurements of stiffness in the warp and weft directions, the VZ6 sample has the highest overall flexural rigidity. The lowest impact on the overall flexural rigidity was for the sample printed with TK (VZ4 sample). The same observation was noticed by Golja et al. [26], when different concentration of microcapsules with essential oils were applied onto cotton fabric by screen printing. The researchers established stepwise increase of stiffness of printing fabric with increase number of microcapsules in the printing paste [26].

From the air permeability results, it can be seen that the unprinted fabric (VZ0 sample) is the most air permeable. The application of any printed paste decreased the air permeability of cotton fabric by more than a third. The lowest impact of printing paste on air permeability of fabric is noted in the VZ2, VZ3 and VZ4 samples, which were printed with only one pigment or dye. An exception is the VZ1 sample. This is due to the low concentration of TK, FS or KP (5 g/kg) in comparison with the VZ1 sample, where the concentration of MFC is 200 g/kg. The comparison of the air permeability measurements of the samples that were printed with one microencapsulated dye or pigment with the samples that were printed with a mixture of microencapsulated dye and pigment shows that the combination of microencapsulated dye and pigment in the printing paste significantly reduces the air permeability of the fabric. Among samples VZ5, VZ6 and VZ7, sample VZ6 has the lowest air permeability. The printing paste of the VZ6 sample contains a combination of MFC and phosphorescent pigment as a ready-to-use printing paste. Although the concentration of the phosphorescent pigment is low, we conclude that the ingredients in the ready-to-use printing paste contribute to the reduction of fabric air permeability. The content of both thickener and binder, beside pigment and additives in the ready-to-use printing paste cause the formation of binder layer during curing process and thus close the pores between the fibres and consequently hinders the air flow through the fabric.

In Table 3, the values of breaking force and elongation of the studied samples are presented.

In accordance with the construction parameters of the fabric, differences in the breaking force and in the elongation of the fabric in the warp and weft directions are noticed. From Table 3, it can be seen that the breaking force in the warp direction is much higher than that in the weft direction. The application of the printing paste caused an increase in the breaking force in both directions, which was attributed to the formation of a binder layer on the fabric surface. The application of the printing paste onto the cotton fabric does not significantly affect breaking elongation in both directions, but slightly improve it at all samples, with the exception of VZ4. For this sample, significant fluctuation in the values of breaking elongation in the weft direction is observed (19.40% ± 1.96%). To claim with certainty that the binder significantly increases breaking elongation of printed fabric more measurements should be done on each sample. In our case only ten measurements (five in warp and five in weft direction) were done, therefore the obtained results should be taken only as a rough estimate.

The testing of fastness to rubbing showed that the total colour difference (*ΔE**) between samples before and after exposure to UV-A irradiation decreases irrespective of the printing paste type, which can be seen in Figure 1.

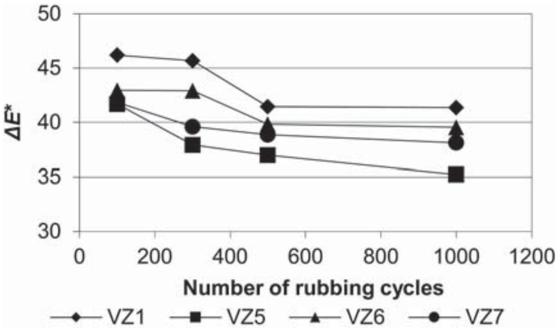

Figure 1: Colour difference (ΔE) vs. the number of rubbing cycles of printed samples*

For the VZ1 sample, no essential difference in fastness to rubbing is noticed at 100 and 500 rubbing cycles compared to the VZ5, VZ6 and VZ7 samples, for which printing pastes include a combination of MFC and pigment. Among them, the classical pigment (VZ5 sample) has the highest impact on the reduction of values of *ΔE** at a low number of rubbing cycles. Between 300 and 500 cycles, the greatest reduction of

Table 3: Breaking force and elongation of samples in the warp and weft directions

Sample	Breaking force [N]		Breaking elongation [%]	
	Warp	Weft	Warp	Weft
VZ0	316.10	195.24	16	20.47
VZ1	353.40	229.16	22.2	23.07
VZ2	370.22	200.21	19.13	20.17
VZ3	334.96	203.00	20.53	21.97
VZ4	348.88	219.34	22.63	19.40
VZ5	360.17	198.90	22.03	23.37
VZ6	389.68	207.78	23.70	23.80
VZ7	406.46	210.18	23.53	21.17

ΔE^* is noticed in the VZ1 sample. Further comparison of values of ΔE^* after 500 and 1,000 rubbing cycles showed a very small, almost imperceptible colour difference for all samples with the exception of the VZ5 sample, where a slight decrease in the values of ΔE^* is observed between 500 and 1,000 rubbing cycles. The latter was attributed to the very low fastness of classical pigment to rubbing. The addition of TK or FS into the printing paste, which already includes MFC, has no significant influence on colour change at a higher number of rubbing cycles. The low fastness of MFC to rubbing was confirmed by SEM micrographs of samples VZ1, VZ6 and VZ7 before and after 300 and 1,000 rubbing cycles (Figures 2–4). It can be seen from those figures that the microcapsules of photochromic dye are damaged or removed. Before rubbing, the shells of the microcapsules are undamaged, but after 300 rubbing cycles, they show signs of injury. After 1,000 rubbing cycles, no untouched microcapsules can be found, since they burst and flatten. The same phenomenon was noticed by Ocepek et al. [22] but at much lower number of rubbing cycles and without additional load

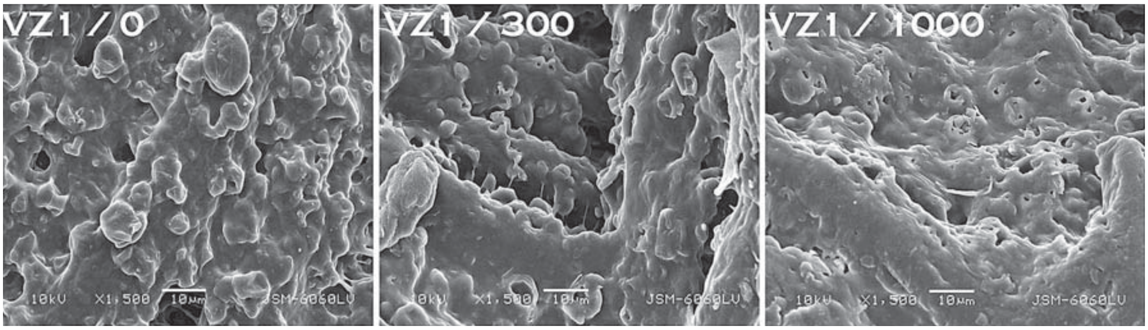

Figure 2: SEM micrographs of the VZ1 sample before and after 300 and 1,000 rubbing cycles at 1500x magnification

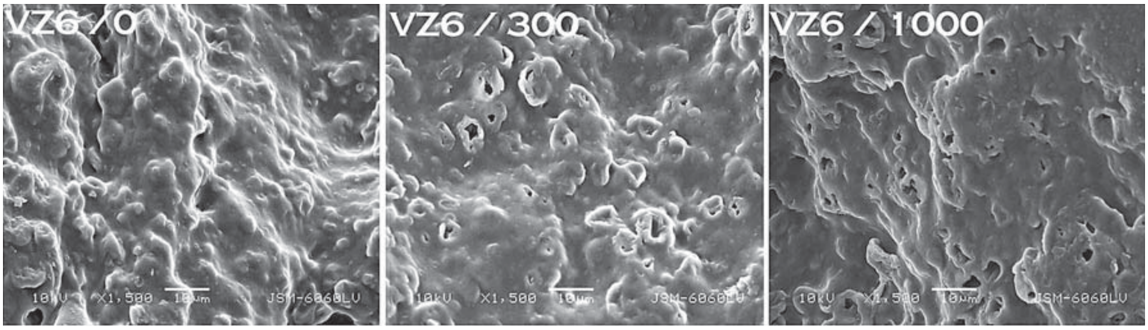

Figure 3: SEM micrographs of the VZ6 sample before rubbing and after 300 and 1,000 rubbing cycles at 1500x magnification

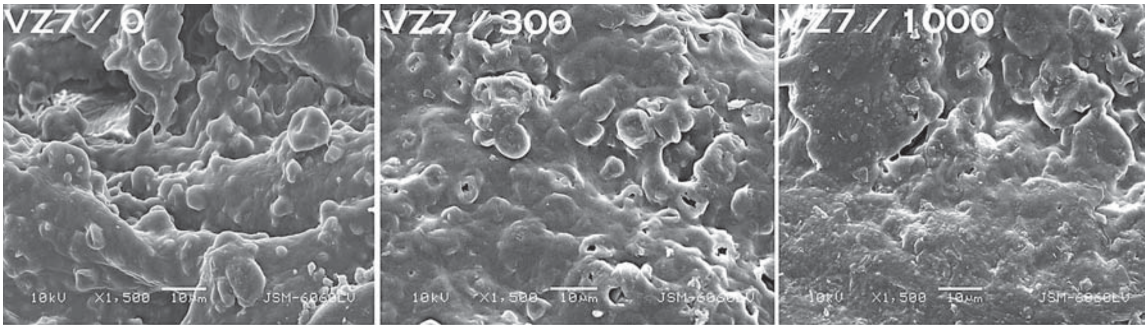

Figure 4: SEM micrographs of the VZ7 sample before rubbing and after 300 and 1,000 rubbing cycles at 1500x magnification

at Martindale apparatus. Since no data is available for the material, used for preparation of microcapsule shell of the commercial product Itofinish UV blue, the obtained results clearly show that the shell of microcapsules is less resistant to mechanical action. However, higher resistance to rubbing was expected, since commercial product was used in the research.

CIE $L^*a^*b^*$ colour values (Table 4) indicate that the application of MFC (VZ1 sample) changes the background colour of the fabric. The fabric becomes darker, greener and bluer compared to the VZ0 sample. The addition of a very small concentration (5 g/kg) of KP or FS pigment or TC microcapsules into printing paste affects the CIE $L^*a^*b^*$ values of the samples printed with MFC. After the addition of KP, the sample becomes darker, redder and yellower, whilst upon the addition of FS or TK, it becomes darker, greener and yellower in comparison with the VZ1 sample. After the samples are irradiated with UV-A light, the CIE $L^*a^*b^*$ values of the VZ1, VZ5, VZ6 and VZ7 samples change significantly. The VZ5 sample becomes redder, less blue, and the VZ6 and VZ7 samples become greener and less blue compared to the VZ1 sample. The greatest colour change between UV-A unexposed and exposed samples is obtained for sample VZ1, as seen in Table 5. This is attributed to the TP1 printing paste, which contains only MFC without any addition of pigments that could influence the intensity of the fabric photocolouration and colour change. Sample VZ5 has the second most pronounced colour change after UV-A irradiation. Because the classical pigment is not photoresponsive, a different colour effect is obtained on the printed sample. The photo-induced colour of the VZ5 sample is darker, due to the addition of classical pigment, whilst the colour difference is smaller than in the case of the VZ1 sample. This proves that classical pigment decreases the photoresponsiveness of photochromic dye, but to a lesser extent than phosphorescent pigment (VZ6 sample) and microcapsules of thermochromic dye (VZ7 sample). For samples VZ5, VZ6 and VZ7, the addition of microcapsules of thermochromic dye has the

*Table 4: CIE L*a*b* colour values, chroma (C*) and hue (h) of samples before UV-A irradiation*

Sample	L^*	a^*	b^*	C^*	h [°]
VZ0	94.21	−0.33	3.17	3.19	95.96
VZ1	90.00	−9.39	13.54	16.48	124.73
VZ2	54.98	54.62	19.58	58.03	19.72
VZ3	93.49	−0.45	6.08	6.10	94.19
VZ4	93.11	−1.78	7.38	7.60	103.46
VZ5	54.09	53.25	22.61	57.86	23.01
VZ6	90.30	−9.20	13.62	16.43	124.06
VZ7	89.69	−10.06	13.89	17.15	125.90

*Table 5: CIE L*a*b* colour values, chroma (C*), hue (h) and colour difference (ΔE*) of samples after UV-A irradiation*

Sample	L^*	a^*	b^*	C^*	h [°]	ΔE^*
VZ1	56.90	−18.16	−22.64	29.05	231.25	49.82
VZ2	55.27	53.98	19.05	57.24	19.43	/
VZ3	93.46	−0.41	5.74	5.76	94.10	/
VZ4	93.36	−0.87	6.70	6.75	97.36	/
VZ5	36.54	20.58	−4.85	21.17	346.67	46.15
VZ6	62.48	−19.83	−18.85	27.37	223.52	44.06
VZ7	63.06	−19.76	−18.10	26.82	222.46	42.74

greatest impact on the reduction of photoresponsiveness of the photochromic dye on cotton fabric. The latter is understandable, since thermochromic dye can be discoloured due to heat emission of the UV-A lamp during a one-minute exposure of sample to UV-A irradiation, which consequently affects the CIE $L^*a^*b^*$ colour values and colour difference. The results of colour fastness to washing of the printed fabric, presented in Figure 5, show that the values of ΔE^* decrease with an increasing number of washing cycles, indicating that MFC is removed from cotton fabric during washing due to weak adhesion of both the thickener and binder into which the microcapsules are entrapped. Similar results were obtained with the washing of cotton, cotton/polyester and polyester fabric coated with MFC using the pad-dry-cure process [27]. The addition of KP, FS or TK into the printing paste, which already contains MFC, reduces the photoresponsiveness of the fabric and impairs colour fastness to washing since a greater slope of the line is observed between the first and tenth washing cycles for the VZ5, VZ6 and VZ7 samples than for the VZ1 sample. It can also be seen from Figure 5 that the slope of the line decreases in the following order VZ6>VZ7>VZ5>VZ1.

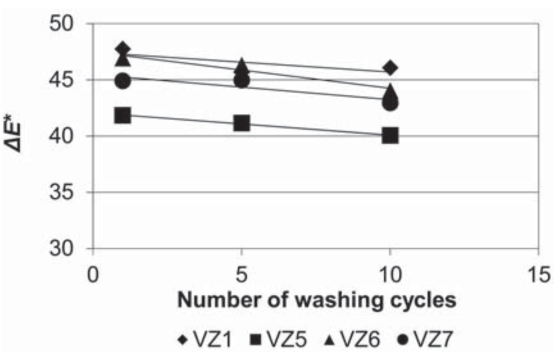

Figure 5: Colour difference (ΔE) vs. the number of washing cycles of printed samples*

The results of colour fastness of printed fabric exposed to light for different lengths of time in the Xenotest apparatus are presented in Figure 6. From Figure 6, it can be observed that values of ΔE^* decrease with increasing time of exposure in the Xenotest apparatus irrespective of the printing paste type. The addition of KP, FS or TK into printing paste that already includes MFC reduces the photoresponsiveness of the fabric and consequently affects the colour fastness of photochromic dye to light. In the case of TP5, TP6 and TP7 printing pastes, the colour fastness of MFC on printed fabric is dependent on both the contributions of colour fastness of the photochromic dye and on the colour fastness of the classical pigment, phosphorescent pigment and thermochromic dye. The results, presented in Figure 6, also show that the highest slope of the line is obtained for the VZ1 sample, whilst the slopes of the lines for the other samples decrease in the following order: VZ6>VZ7>VZ5. According to these results, it can be concluded that the addition of KP, FS or TK slightly slows the deterioration of the colour fastness properties of photochromic dye to light.

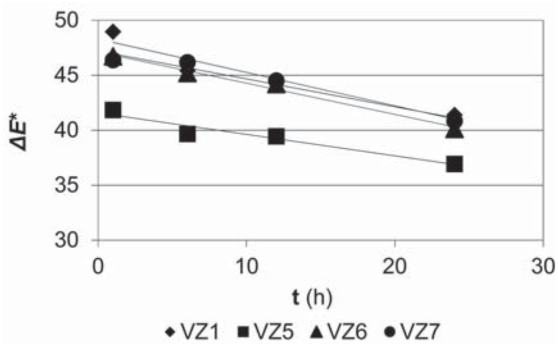

Figure 6: Colour difference (ΔE) vs. the time of exposure (t) of the studied printed samples to the Xenotest apparatus*

4 Conclusion

According to the obtained results, the following can be concluded:

- Cotton fabric was successfully printed with the prepared printing pastes.
- The application of printing pastes to cotton fabric caused changes in the mechanical-physical properties of the fabric, irrespectively of the printing paste type and composition. Thickness, mass per unit area, stiffness, breaking force and elongation were increased, whilst the air permeability of the printed fabric decreased by more than a third. Printing pastes that include a combination of MFC and KP, FS or TK have the highest impact on the alteration of physical-mechanical properties of the printed fabric.
- All added pigments (KP or FS) or microcapsules of thermochromic dye reduce the photocolouration of cotton fabric printed with microcapsules

of photochromic dye. Among them, the classical pigment has the least and the microcapsules of thermochromic dye have the most influence.

- With increasing numbers of rubbing cycles, the lightness of the samples increases, whilst the values of ΔE^* decrease. The smallest decrease in ΔE^* values was noticed with the addition of phosphorescent pigment in the form of ready-to-use printing paste, and the largest decrease was noticed with the addition of classical pigment. Microcapsules were damaged and removed to a greater extent after 500 rubbing cycles, whilst there was only a slight decrease in values of ΔE^* after 1,000 rubbing cycles.
- Values of ΔE^* for all printed samples decreased with increasing number of washing cycles. The addition of classical pigment, phosphorescent pigment or microcapsules of thermochromic dye reduces the photocolouration of printed cotton and simultaneously reduces the colour fastness of printed fabric to washing.
- The time of irradiation of samples in the Xenotest apparatus affects the colour fastness of printed fabric to light. By extending the irradiation time, the colour fastness of printed fabric to light is reduced. The addition of classical pigment, phosphorescent pigment or microcapsules of thermochromic dye moderates the photocolouration of cotton fabric printed with microcapsules of photochromic dye and slightly slows the impairment of colour fastness of printed fabric to light.

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The Influence of Consumers' Perception on Perceived Value and Purchase Intention with respect to Regional Products Based on a C-A-B Model

Vpliv dojemanja potrošnika na zaznano vrednost in na namero nakupa regionalnih izdelkov – na podlagi modela C-A-B

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Abstract
Consumer interest has been moving progressively toward local regional clothing products in many countries. Hence, this study endeavours to examine consumer perception and purchase intention, and their interrelationship in the context of regional clothing products. A framework built on the basis of a C-A-B model and a questionnaire were used to collect data through online and offline sources. The proposed model was empirically evaluated based on 407 respondents. The results reveal that both consumer perception and the perceived value of regional clothing products have a positive influence on consumers' purchase intentions, while perceived value also plays a role in the purchase process. Nevertheless, word-of-mouth plays a predominant role among other influential factors of consumer perception, such as uniqueness and regionality.
Keywords: regional clothing products, consumers' perception, C-A-B model, purchase intention

Izvleček
V številnih državah je bilo opaziti, da se zanimanje potrošnikov za izdelke iz blaga iz njihove regije postopoma povečuje. Zato si v tej študiji avtorji prizadevajo preveriti zaznavanje in namero potrošnikov in njihovo povezavo v okviru regionalnih oblačil. Za zbiranje podatkov so bili uporabljeni ogrodje, ki temelji na modelu C-A-B, ter vprašalniki po spletu in brez povezave. Predlagani model je bil empirično ovrednoten, podatke pa je zbiralo 407 anketirancev. Rezultat razkriva, da tako zaznavanje potrošnikov kot zaznana vrednost regionalnih oblačilnih izdelkov pozitivno vplivata na kupčeve namene, medtem ko zaznana vrednost posreduje pri nakupu. Kljub temu ima ustno sporočilo prevladujočo vlogo med drugimi vplivnimi dejavniki dojemanja potrošnikov, kot sta edinstvenost in regionalnost.
Ključne besede: regionalni oblačilni izdelki, dojemanje potrošnikov, model C-A-B, namen nakupa

1 Introduction

The prospering economy and the growing desire for regional clothing products have attracted growing interest in recent years. The online revolution also contributes increasingly to the accessibility of regional clothing products, which helps lift geographical limits on regional clothing products to make them more visible to consumers around the country [1, 2]. The improving reputation of regional clothing

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products has also been strengthened by more convenient modes of transportation and the telecommunications network [3–6]. It has thus become essential to have a better understanding of how the perception of the value of regional clothing products influence consumers' purchase intentions.

Every city or region across the country has its own regional clothing products rooted in the regional environment. Whatever the categorisation of those regional clothing products may be, they are distinguished by their uniqueness [7, 8]. Numerous researchers define regional clothing products in many different contexts as they relate to products manufactured locally with special characteristics in terms of style or artisanship [4, 9–11]. In China, however, regional clothing products comprise the Guangzhou Baima Costume Market, Shenzhen Yiwu Smallware Wholesale Mansion, Ladies Market, Huangyuan Wholesale Garment Market-Jardine's Crescent Market and many more. In a word, regional clothing products have recognisable characteristics in terms of locality, nationality, unique processing technologies, unique and innovative handling techniques, historical preservation and a rich cultural legacy [12–14].

Most recent studies focus on packaging design and brand marketing, and neglect the uniqueness of regional clothing products [15–19]. It therefore makes sense to construct a framework based on the cognition-affect-behaviour (C-A-B) model. The C-A-B model is an information-processing approach, where the purchase decision and brand choice are the key outcomes. This interpretation of responses is closely aligned with, but expands on, the behaviour component of the C-A-B model, which focuses on brand choice or purchase decisions to study the factors that affect consumers' purchase intentions and a company's marketing strategy in an effort to promote the relationship between companies and consumers, and boost regional clothing products [20]. This study entails two contributions: (1) an analysis of the uniqueness of regional clothing products and how word-of-mouth influences perceived value and consumers' purchase intentions; and (2) the application of the C-A-B model to explore factors that influence consumers' purchase intentions, with the aim of expanding the applicability of the C-A-B model.

Holbrook [21] proposes an innovative model to describe consumer's behaviour, a process that ranges from perception to behaviour. Consumers are thought to be target-oriented problem solvers who search for product information, weigh all available evidence and then make a purchase decision after several rounds of reconsideration. Degirmenci [22] believes that consumers are logical thinkers whose aim is to select the best available products from different options. Hirschman [23] proposed that cognition in the C-A-B model is only one component of the psychological factors that affect consumers' behaviour. Cognition embodies concepts, ideas or perceptions that derive from interaction with products (merchandise, service, consumption environment, etc.) and the process of handling less important information (advertisement, reviews from friends, blogs, online merchandise reviews, etc.) [24]. However, as part of the information-processing based C-A-B model, effect differs from emotion. Effect is defined as a favourable disposition toward a stimulus that leads to a relative preference for stimulus from a group of options. Blackwell et al. [25] and Andrei et al. [17] proposed a multi-dimensional construct for behavioural intentions composed of word-of-mouth, price insensitivity, purchase intentions, and complaint behaviour toward a retailer. The approach response has also been operationalised as a measure of satisfaction with the shopping experience and brand loyalty.

2 Research hypothesis and model building

2.1 Uniqueness

Regional clothing products are unique, which might be attributable to a specific natural environment, history, a special processing technique or art. Tian [26] and Liu [27] find that product uniqueness relates to the perceived attributes consumers feel that can distinguish a product from generic merchandise. Eisend [28] and Jang [29] find that highlighting the specific uniqueness of a certain product could reduce the risk associated with the launch of a new product on the market. For this reason, emphasising product uniqueness becomes an inseparable part of building a brand asset. Product uniqueness is a vital component of a brand asset, which presents uniqueness by virtue of an exclusively possessed attribute or excellence. When consumers have certain demands, distinctive products easily stand out. By and large, a product brand is also useful in practical terms. Markets test a product category, and consumers' loyalty and trust might derive from such a test. Irmak [30], as an advocate of cognition theory, claims that augmenting product uniqueness will promote consumers' purchase intentions. This means that consumers have a distinctive purchase motivation to separate themselves from ordinary consumers through purchase choices. Thus, uniqueness in regional clothing products will influence consumers' purchase intentions. Wu [31] finds that product uniqueness becomes a predominant factor in determining what motivates consumers to make purchase decisions. Barat [32] asserts that the scarcity perceived by consumers will influence perceived uniqueness, which in turn is very influential in purchase decisions. The uniqueness of regional clothing products can be attributed to a specific environment, meaning product scarcity is the result of the inability to mass produce a product or products. We thus hypothesise that uniqueness and scarcity will influence consumers' trust in product quality and have a positive influence on a brand.

H1: The uniqueness of regional clothing products has a positive influences on consumers' perceived value.

H2: The uniqueness of regional clothing products has a positive influences on consumers' purchase intentions.

2.2 Regionality

Regionality refers to the features that distinguish a product from others, and can be attributed to the distinctiveness of a certain region's specific natural or cultural environment. Nallaperuma [33] argues that regionality is found to have a special appeal to consumer in marketing regional clothing products. When consumers are insufficiently familiar with products, Ehmke [34] finds that they are unable to make informed decisions about such products and are prone to make inferences about quality in terms of a manufacturing region's image. For regional clothing products, natural and geological conditions are a decisive factor in the perceived quality and taste of manufactured products. Terano et al. [35] find that regionality might improve product image and thus influence consumers' purchase decisions: the better a region's image is, the better consumer reviews tend to be, and that all beliefs regarding a product will influence the overall opinion about that product. Knight [36] and Bosona [37] determined that consumers have different attitudes regarding regional clothing products from various regions, Bloemer [38] determined that, depending on perceptions brought about by regional attributes, consumers' ultimate purchase intentions are influenced by perceived values. For this reason, regional cultural products must take regionality into consideration to help consumers distinguish regional clothing products from others, and to link consumers with other relevant regional cultural images. Cultural images are, to a great extent, intangible or virtual, which thus literally mirrors the in-depth psychological demand of consumers.

H3: Regionality has a positive influence on consumers' perceived value.

H4: Regionality has a positive influence on consumers' purchase intentions.

2.3 Word-of-mouth

In the 1960s, Arndt [39] pointed out that word-of-mouth (interpersonal and non-commercial verbal or non-verbal communication about certain products) could promote the marketing of products or services. In marketing, promotion refers to any type of marketing communication used to inform or persuade target audiences of the relative merits of a product, service, brand or issue. The aim of promotion is to increase awareness, create interest, generate sales or create brand loyalty.

In the social network of consumers, Anderson [40] finds that word-of-mouth carries verbal information and has a major influence on word-of-mouth communication because consumers are not only pioneers in sharing their experiences regarding products or services, but also serve as administrators of information communication. Due to asymmetric information, potential consumers' cognition about products could be enhanced by word-of-mouth through the effort of those pioneering consumers whose behaviour reduces that asymmetry. Chevalier [41] finds that this increases consumers' perceived value and improves product marketing. Gupta [42] finds that word-of-mouth is the most powerful motivating factor in consumers' purchase intention among marketing approaches. Word-of-mouth reduces consumers' risk and uncertainty in making purchase decisions. Lee [43] finds that over half of US consumers asked friends or relatives for advice when purchasing durable consumer goods, while more than one third of consumers consulted with family members about the durable consumer goods of a certain brand. The power of word-of-mouth is that much more important in the purchase of regional clothing products or services.

H5: Word-of-mouth has a positive influence on consumers' perceived value

H6: Word-of-mouth has a positive influence on consumers' purchase intentions.

2.4 Perceived value and purchase intentions

There is a great deal of literature about perceived value and purchase intentions, which justifies the choice to focus our study on purchase intentions. Tam [44] finds that perceived value is the primary factor influencing consumers' purchase intentions. Zeithaml [45] concludes from abundant research that the better consumers' perception about a product or service is, the more value they feel, which in turn enhances consumers' purchase intentions. Hsu [46] notes that consumer's satisfaction is important, but that perceived value is the ultimate trigger in consumers' purchase behaviour. El-Adly [47] notes that purchase intention is determined by perceived values. In his research, Huijgens [48] points out that consumers' purchase behaviour is motivated more by perceived value than consumer satisfaction. In a word, contemporary research has confirmed that consumers' purchase intentions are decided by the perceived value of perceived benefits and potential costs. From the point of view of consumers, the more perceived benefits there are, the higher perceived value is, and the higher perceived value is, the stronger the purchase intention will be.

H7: Perceived value has a positive influence on consumers' purchase intentions.

2.5 Model building

Based on all proposed hypothesis, a conceptual model involving cognition, perceived value and purchase intention was constructed, as shown in Figure 1.

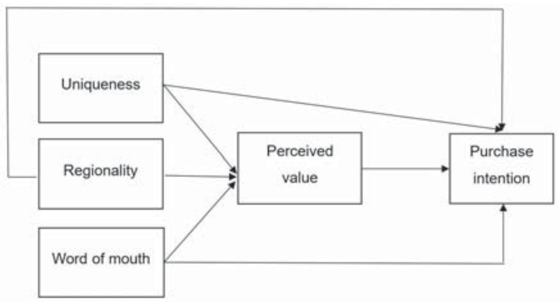

Figure 1: Model of conceptual framework

2.6 Research design

2.6.1 Questionnaire

In order to achieve an accurate measurement of regionality (R), uniqueness (U), word-of-mouth (WOM), perceived value (PV) and purchase intention (PI), this study developed and used a scale in which items were tested, refined and purified. The final scale was developed in the form of a Likert five-point scale, where 1 means 'strongly disagree' and 5 means 'strongly agree', using 16 refined items. Regionality, a key variable, is measured using a scale developed by Nallaperuma [33]. Word-of-mouth is measured using a scale developed by Arndt [39] and perceived value is measured based on a modified scale developed by Zeithaml [45]. Purchase intention is measured using a modified scale proposed by Tam [44]. This study used SPSS 23 and SmartPLS 3.0 software to process and analyse data.

2.6.2 Data collection

The population of our study comprises self-earning and self-spending people. This study follows a quantitative method, while a combination of online and offline methods at retail outlets that sell regional clothing products was used to obtain data from customers who had bought regional clothing products. Data was collected from customers in the period April to June 2018. Data were collected in the Hubei province of China. A total of 407 responses to our questionnaire were received. Of that number, 375 were considered correct and used in further analysis. After eliminating unqualified questionnaires, the effectiveness rate was 92% of the total. In terms of respondents, 45.78% were male and 54.22% were female. Those 18 years and younger accounted for 10.42% of respondents, those 18–30 years age for 51.87%, those 31–40 years of age for 24.74%, and those 41–50 years of age for 12.97%. A total of 5.32% of respondents' per capita household income was below €125 (RMB), 35.57% of respondents' per capita household income ranged from €125–379 (RMB), 41.94% of respondents' per capita household ranged from €380–570 (RMB), and 17.27% of respondents' per capita household income was higher than €570. A total of 4.63% of respondents finished primary school, 11.35% of respondents finished middle school, 26.32% of respondents finished high school or three-year tertiary education, and 57.70% of respondents finished higher tertiary education.

Table 1: Measurement items and content

Variable	Measu-rement	Content
Uniqueness (U)	U1	Regional clothing products are different from other similar products
	U2	Regional clothing products stand out from other similar products
	U3	Regional clothing products are unique compared with other similar products
Regionality (R)	R1	I can identity the majority of familiar regional clothing products with the region to which they belong
	R2	I can place regional clothing products I am are familiar with in the region to which they belong
	R3	Regional clothing products are judged by their location
Word of mouth (WOM)	WOM1	I tend agree with people familiar with purchasing regional clothing products
	WOM2	I would recommend regional clothing products to others
	WOM3	I would recommend regional clothing products to those who ask for purchasing advice
Perceived value (PV)	PV1	I like regional clothing products very much
	PV2	I think a specific local product is superior to other products of the same type
	PV3	I think a specific local product is of superior quality at a reasonable price
	PV4	I think regional clothing products are of good quality
Purchase intention (PI)	PI1	Regional clothing products are highly attractive to me
	PI2	I think it pays to purchase regional clothing products
	PI3	I would recommend regional clothing products to others

3 Results

3.1 Reliability and validity test

Bartlett's test of sphericity and the Kaiser-Meyer-Olkin (KMO) test preceded the principal component analysis (PCA) to test if the KMO value was relevant for the PCA that followed. The results showed that the value of KMO was 0.824 and KMO test significance was 0.001, meaning that the PCA was suitable. After rotating the factor loading matrix, five factors were extracted, while the percent variance was 69.499%. As a rule, the AVE value, as a base criterion, should be more than 0.5, while the total variance explained should be higher than the base standard of 50%, and factor loading should be higher than 0.5. The results using SmartPLS 3.0 software showed that Cronbach's alpha values for uniqueness, regionality, word-of-mouth, perceived value and consumer purchase intention were 0.795, 0.808, 0.814, 0.741 and 0.837 respectively. Cronbach's alpha coefficient was utilised in this study, together with composite reliability values to examine the inter-item consistency of the measurement of items. The Cronbach's alpha and composite reliability (CR) values should be higher than 0.70 [49]. With respect to Cronbach's alpha and composite reliability value, Koonce and Kelly [50] pointed out that a reliability value in excess of 0.9 is regarded as excellent, a value higher than 0.8 is good, a value higher than 0.7 is adequate, a value higher than 0.6 is doubtful and a value lower than 0.5 is substandard. This demonstrated the good internal consistency of questionnaire items. Thus, items in this scale were deemed highly reliable.

In terms of discriminative validity, if the square root of AVE for every factor is higher than coefficient of the factor to other factors, this means that the test items in this scale demonstrated good discriminative validity. Table 3 shows that values in diagonal lines are higher than the values in the same volume, which demonstrates good discriminant validity.

Table 2: Reliability and validity analysis

Variable	Measurement	Standard load	AVE[a)]	CR[b)]	Cronbach's alpha
Uniqueness (U)	U1	0.762	0.711	0.880	0.795
	U2	0.873			
	U3	0.783			
Regionality (R)	R1	0.802	0.722	0.886	0.808
	R2	0.840			
	R3	0.797			
Word-of-mouth (WOM)	WOM1	0.838	0.728	0.889	0.814
	WOM2	0.840			
	WOM3	0.730			
Perceived value (PV)	PV1	0.690	0.560	0.836	0.741
	PV2	0.828			
	PV3	0.709			
	PV4	0.642			
Purchase intention (PI)	PI1	0.806	0.754	0.902	0.837
	PI2	0.826			
	PI3	0.807			

[a)] Average variance extracted; [b)] Composite reliability.

Table 3: Discriminant validity

Construct	U[a)]	R[b)]	WOM[c)]	PV[d)]	PI[e)]
U	0.853				
R	0.308	0.849			
WOM	0.410	0.277	0.748		
PV	0.317	0.388	0.286	0.843	
PI	0.451	0.346	0.391	0.346	0.868

[a)] Uniqueness; [b)] Regionality; [c)] Word-of-mouth; [d)] Perceived value; [e)] Purchase intention.

3.2 Hypothesis test

This SEM iteration operation using Smart PLS 3.0 software showed that iteration convergence occurs after seven hypothesis operations. It also showed the obtained significance and path coefficient values illustrated in Table 4 and Figure 2.

The first hypothesis is uniqueness (U), which has a positive influence on perceived value (PV), while literature usually supports this relationship. Similarly, the relationship between these constructs was also deemed significant (β = 0.144, t = 2.945, p < 0.005) in the context of clothing products. The second hypothesis of uniqueness (U) had a positive and significant impact on purchase intention (PI). The findings showed that the path coefficient from U to PI was statistically significant with a very strong standardised estimation, as well as a high t-value of more than 2.58 (p < 0.001). The coefficient between regionality (R) and perceived value (PV) was (β = 0.124, t = 2.345, p < 0.023). That value indicated that regionality (R) has a positive influence on perceived value (PV). The fourth hypothesis of regionality (R) had a positive influence on purchase intention (PI). The results obtained from Smart PLS software indicated that there was a significant connotation between regionality (R) and purchase intention (PI) (P < 0.005). The coefficient between word-of-mouth (WOM) and perceived value (PV) was (β = 0.329, t = 6.755, p < 0.000). That value demonstrated that word-of-mouth (WOM) has a positive influence on perceived value (PV). The coefficient between word-of-mouth (WOM) and purchase intention (PI) was (β = 0.279, t = 5.030, p < 0.000). That value showed that regional clothing products have a positive influence on purchase intention. The last hypothesis (H7) postulates a significant relationship between perceived value

(PV) and purchase intention (PI), where past studies typically support this relationship. Similarly, the relationship between these constructs was also found to be significant (β = 0.194, t = 3.735, p < 0.000) in the context of clothing products. The value showed that perceived value (PV) has a positive influence on purchase intention (PI).

This study finds that cognition of regional clothing products influences perceived value and purchase intention. Based on the data we obtained, we built a model to study cognition impact on purchase intention in terms of the C-A-B model. The empirical study showed that uniqueness, regionality and word-of-mouth have a significant influence on perceived value and purchase intention, which illustrates the cognition level of consumers in their purchase decision behaviour. This conclusion is in line with studies conducted by other researchers. It could be explained by the fact that the more consumers know about regional clothing products, the more they will realise the advantages of regional clothing products, and the stronger their purchase intentions might be.

Table 4: Summary of the direct results of hypotheses testing

Hypotheses	Path	β	t-value	p-value
H1	U[a)] → PV[b)]	0.144	2.945	0.005
H2	U → PI[c)]	0.134	3.212	0.001
H3	R[d)] → PV	0.124	2.345	0.023
H4	R → PI	0.150	2.762	0.005
H5	WOM[e)] → PV	0.329	6.755	0.000
H6	WOM → PI	0.279	5.030	0.000
H7	PV → PI	0.194	3.735	0.000

[a)] Uniqueness; [b)] Perceived value; [c)] Purchase intention; [d)] Regionality; [e)] Word-of-mouth

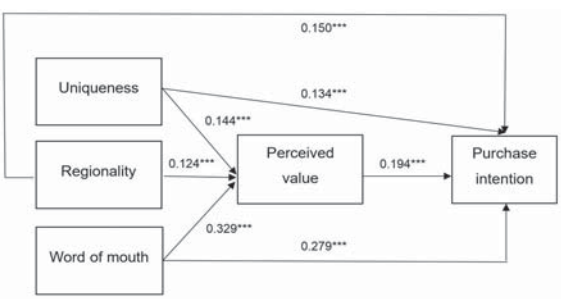

Figure 2: PLS algorithm results

4 Conclusion

The marketing strategy associated with regional clothing products should focus more on uniqueness to reinforce consumers' purchase intensions. Brand names could deliver the unique value of regional clothing products to consumers, which in turn can help to increase their worth and identity. Regional clothing product companies must improve overall product image through an innovative packaging strategy to reinforce the uniqueness of regional clothing products. It should be emphasised that overall product image, in particular visual identity, name and packaging, are fundamental for building a brand image, which in will turn help consumers to distinguish a product from others and also support companies in the establishment of their own unique image.

Consumers' perceived value for regional clothing products can be greatly improved by enhancing a regional clothing product design. Regional clothing products could reflect the local culture, which appeals to a growing number of consumers. It should to be pointed out that regional clothing products could deliver a unique culture that endorses regional properties. From the consumers' perspective, consumers purchase not only the product itself; cultural value also leads to increased consumption. Regional clothing products could explore regional and historical culture based on geographical and cultural conditions in order to find a niche that could satisfy\ both consumers and companies.

Word-of-mouth can be used as a marketing strategy to attract consumers. The media can contribute positively by helping to create an agreeable image about regional clothing products through word-of-mouth publicity and thus induce positive comments about products. Those strategies can greatly enhance consumers' cognition about regional clothing products and enhance their purchase intentions. However, TV ads, search engine rankings, public advertisement boards, tourist spot marketing, trade fairs and sales exhibitions are useful tools to promote the image of regional clothing products. To make this approach more operational, the promotion of local cultural customs and geological features should be encouraged. The Wuhan Municipal government serves as a very successful example in this respect by promoting Wuhan clothing and the Xinyang clothing culture through marketing activities. Another good example comes from Hubei, which promotes hundreds of designed artworks for different countries. All designs have been positively accepted by the market.

One considerable limitation to this study is the fact that there is very limited literature available with in-depth discussions relating to this target area. In most previous studies, the consumption pattern is not stated as a variable in constructing any model. Although, in theory, correlation with purchase intention precedes purchase behaviour, we should still consider the fact that behaviour might counteract attitude. Thus, for future research, it is strongly recommended that the behaviour factor be included in model construction to gain more insightful understanding. The small amount of data might also influence the validity of model construction, while point-to-surface data analysis is still disputable. It is thus quite difficult to propose operational strategies with great pertinence. Lastly, this empirical and hypothetical study only constructed a framework of consumers' purchase intentions, which calls for the inclusion of additional variables to build innovative models. We therefore think that future research could focus on including consumers' emotions and attitudes in a model, and introduce additional medium and moderating variables to better explain consumers' behaviour.

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