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LITERATURE REVIEW

Literature review on artificial intelligence in dyeing and finishing processes

Revisión bibliográfica sobre la inteligencia artificial en los procesos de tintura y acabado

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ABSTRACT

The finishing process in the textile sector is recognized as one of the most complex. This complexity arises from the diversity of structures, the multiple steps involved, the use of complex machinery, the variety of materials, chemicals and dyes, and the need to combine creativity and precision. Therefore, it is crucial to have tools that can improve efficiency, flexibility, and decision-making in this complex area. This literature review aims to provide relevant information on the use of digital engineering in the field of textile finishing. In this review, we used a systematic literature review methodology to examine how digital engineering is applied in the dyeing and finishing process. The data for this study was collected from reputed databases such as Science Direct, IEEE Xplore, Textile Research Journal and Google Scholar. We used the Prisma framework to select relevant articles, which led to the exclusive inclusion of journal articles in our literature review. A comprehensive framework has been developed to understand the impacts of using digital engineering. The approach presented in this framework provides a comprehensive and highly effective approach to addressing the complex challenges associated with ambiguity, modifications and subtleties frequently observed in the ennobling process. The results of various studies explored different aspects, such as properties of textile materials, chemicals and dyes, performance of finishing machines, organizational performance of finishing companies, as well as health concerns and safety at work. Although these studies have provided valuable solutions, they unfortunately remain insufficient to meet the requirements of the finishing process, which remains a complex area characterized by uncertainties, variations, and subtleties inherent to the practice. This particularity of each dyed and finished product promotes an environment conducive to experimentation and continued research.

Keywords: Fuzzy Logic; Artificial Neural Network; Genetic Algorithm; Expert System; Dyeing; Finishing.

RESUMEN

El proceso de acabado en el sector textil está reconocido como uno de los más complejos. Esta complejidad se debe a la diversidad de estructuras, los múltiples pasos implicados, el uso de maquinaria compleja, la variedad de materiales, productos químicos y tintes, y la necesidad de combinar creatividad y precisión. Por lo tanto, es crucial disponer de herramientas que puedan mejorar la eficacia, la flexibilidad y la toma de decisiones en este complejo ámbito. Esta revisión bibliográfica pretende aportar información relevante sobre el uso de la ingeniería digital en el campo del acabado textil. En este estudio, hemos utilizado una metodología sistemática de revisión bibliográfica para examinar cómo se aplica la ingeniería digital en el proceso de tintura y acabado. Los datos para este estudio se recogieron de bases de datos reputadas como Science Direct, IEEE Xplore, Textile Research Journal y Google Scholar. Se utilizó el marco Prisma para seleccionar los artículos pertinentes, lo que llevó a la inclusión exclusiva de artículos de revistas en nuestra

revisión bibliográfica. Se ha desarrollado un marco exhaustivo para comprender las repercusiones del uso de la ingeniería digital. El planteamiento presentado en este marco ofrece un enfoque global y muy eficaz para abordar los complejos retos asociados a la ambigüedad, las modificaciones y las sutilezas que se observan con frecuencia en el proceso de ennoblecimiento.
Los resultados de diversos estudios exploraron diferentes aspectos, como las propiedades de los materiales textiles, los productos químicos y los tintes, el rendimiento de las máquinas de acabado, el rendimiento organizativo de las empresas de acabado, así como las preocupaciones en materia de salud y seguridad en el trabajo. Aunque estos estudios han aportado soluciones valiosas, lamentablemente siguen siendo insuficientes para satisfacer los requisitos del proceso de acabado, que sigue siendo un ámbito complejo caracterizado por incertidumbres, variaciones y sutilezas inherentes a la práctica. Esta particularidad de cada producto teñido y acabado promueve un entorno propicio para la experimentación y la investigación continua.

Palabras clave: Lógica Difusa; Red Neuronal Artificial; Algoritmo Genético; Sistema Experto; Tintura; Acabado.

INTRODUCTION

Artificial intelligence (AI) is a computer science field that explores intelligent tasks like human abilities, aiming to replicate human cognition and create comparable cognitive processes. It encompasses various methods like neural networks and fuzzy logic. Coined by McCarthy in 1956, AI's significance was highlighted by Turing's "Computing Machinery and Intelligence"(1) proposing the Turing test to evaluate machine intelligence.(2) AI is applied across multiple sectors, including robotics and natural language processing.

In the textile industry, colouring or dyeing has always been a precise process. Before the advent of computers and automation, people prepared dye mixtures, applied the dyes to fabrics, and controlled the dyeing. Initially, soft computing replaced human-driven procedures. AI, the next generation of soft computing, can now do anything humans can do. Thanks to AI, it is now possible to formulate reliable dyes, match colours and detect defects without human intervention. Besides colour recipe prediction, various researchers have focused on dyeing defects and dyeing difficulties. Huang et al.(3) classified seven categories of dyeing errors using image processing and fuzzy neural networks. Inconsistent colouring on the edge and fill band in the shade are among the defects. Construction of a fuzzy neural classification system by an expert system using a neural network as a fuzzy inference engine. The engine is trained on sample data.

Huang et al.(3) described the application of fuzzy logic to cotton colour grading to improve the acceptance of machine grading for cotton colours. Cotton colour grades are a few classes in colour space (Rd, b). Adjacent colour classes have fuzzy, overlapping boundaries, making sharp delineation methods ineffective for cotton colour grading. Fuzzy logic is specialised in dealing with uncertainty and imprecision in the decision-making process, and thus offers a new approach for cotton colour grading. In this paper, we present the procedures for building an inference system (FIS) using fuzzy logic to classify the main classes of cotton colours, and preliminary results to demonstrate the effectiveness of the FIS in reducing disagreements in colour grading. The FIS results show a high degree of consistency in cotton colour data over several years.(4) The performance of FIS e error and coefficient of determination (R 2) between the predicted and experimental values were found to be 0,536, 0,798 and 0,959, respectively. The results confirm that the model can be appropriately applied for the prediction of fabric whiteness index in textile. The performance of FIS mainly depends on the selections of input and output fuzzy sets, the design of membership functions and the establishment of fuzzy rules that guide the input-output relationships. These settings can be initially selected based on an analysis of a small data set, then refined through trial and error with more data. The workbooks' knowledge of colour grading can be incorporated into the fuzzy rules for improve overall agreement with visual calibration. The Fis can perform consistent classifications for samples from different years. Preliminary results showed great potential as a more reliable way to classify cotton colours.

The Kubelka-Munk (K-M) model was used in recipe prediction systems of the early 1940s. In K-M theory, dyes are characterized by their absorption and diffusion coefficients, K and S. K-M theory is a two-stream version of a multiple-stream technique. Despite the existence of more accurate theories, the K-M theory is still widely used due to its simplicity and the ease with which it can determine the K and S coefficients. The K-M hypothesis is used to predict the colour of textiles, paints, and printing inks. The version of the theory used in this study concerns transparent printing inks, for which K and S must be fixed absolutely.(5) Westland showed in 2002 that K-M theory can map a colour vector c and a reflection vector r to represent the question of colour prediction. Multilayer perceptron's (MLPs) can correctly reproduce any continuous feature to any degree. MLP stands for multi-layer processing unit. Units in the first layer (or input layer) are fed a real-world vector, while units in the final or output layer use the network output. Between the input and output layers there may be hidden levels of units. The results show that while ANNs can learn to map dye concentrations and spectral reflectance in theory, they struggle to beat the K-M model in practice. They showed the benefit of using separate training and testing sets to evaluate overall network performance. Computer programs based on artificial intelligence, called expert systems, have received a lot of attention and have been used to solve an impressive number of problems in various fields. Diagnosing dye problems was one of the first topics studied after the advent of digital computers, with the advent of artificial intelligence and expert systems. The performance of the system was tested and evaluated by human experts and was found to be very satisfactory. This provides a starting point for further improvements in the field of cotton dyeing. Knowledge can be taught to the expert system in several ways. In the article, they introduced knowledge in the form of rules. A rule has an antecedent and a result. The antecedent is the "if" component of a rule. The right side of the rule is called "then".

Hussain et al.[6] evaluated their system: thus, although the Expert system is not flawless, it is better than individual experts. The main reason for the superiority of the expert system over human experts is that the expert system evaluates all probable causes, whether they are less prevalent or not. As a result, human experts are more likely to ignore probable reasons for an error than expert systems. The expert system beat human experts in identifying difficult dye defects.

SenthilKumar et al.[7] suggested using a neural network to create the desired colour depth. Expected colour depth is an important factor to achieve for batches. The batch must be returned for rework or rejected if the colour depth produced does not conform to the reference. The neural network, which was trained using input and output parameters related to the reactive HE dyes on the cotton fabric, has an error of 1 % in the dyeing time. The trained network provides the same percentage error when tested with a different colour and fabric. This was verified even as selected input and output parameters were beyond the range used to train the network. Therefore, the neural network can predict the main depletion and fixation times of high reactive dyes on cotton fabrics. SenthilKumar[8] found results from research on the use of neural networks to model CIELAB values. The L*a*b* values of the neural network constructed using the input and output parameters are less than 2,0 % for vinyl sulfone dyes. The trained network has the same percentage error when tested with dyes that were not used for training. The trained network provides the same percentage error even when the input and output parameters are beyond the range used for training. A value of DE* between 0-1,5, the difference between the calculated values and the predicted values, was obtained. Most samples have a brightness difference between 0,7 and 0,4, which is acceptable. The built-in neural network model can be used to optimize dyeing parameters for any vinyl sulfone dye. Golob et al.[9] demonstrated the possibility of using counter-propagation neural networks to identify dye combinations in textile printing paste formulations. An existing collection of 1430 printed samples produced with 10 dyes was used for training the neural networks. Reflectance values served as input data and known concentrations of one or two dyes. Dyes were used to print each sample. Some variations of the neural network parameters were tested to determine the best model, and a cross-validation method was used to estimate the generalization error. Additionally, some changes to input and output data have been made to improve learning capabilities.

In the present work, the effectiveness of artificial neural networks in assisting colorists in determining the appropriate colorants for obtaining the required color has been demonstrated. Although the initial effort of training a neural network and finding the optimal parameters are greater compared to other methods, the advantage of the neural network approach is that once the training phase is completed, Determination of new unknown samples is very simple and fast Further improvements could be made by transforming the reflectance values so that the concentration influence of different dyes is eliminated.

In a study by Khataee et al.[10], Chlamydomonas species demonstrated the ability to remove the triphenylmethane dye C.I. Basic Green 4 (BG4) through biosorption. The study examined various operational parameters such as initial dye concentration, temperature, pH, reaction time, and algae concentration and developed an artificial neural network (ANN) model to predict the bio-sorptive decolorization of BG4 solution. The ANN model showed a high predictive performance (R2 = 0,979) and identified initial dye concentration as the most significant factor, followed by temperature. An alkaline solution was found to be optimal for decolorization. The ANN model effectively captured the complex interaction process under different experimental conditions, enabling estimation of process behavior through simulation. The importance of input variables on color elimination efficiency was also assessed using the connection weights of the neural network.

Guruprasad et al.[11] conducted a review on the utilization of computational techniques in textile processes and products. They explored the concept of soft computing, which offers a flexible and simplified computing methodology. The review examines three primary branches of soft computing: fuzzy logic, neural networks, and genetic algorithms, focusing on their applications in solving diverse textile problems. These problems range from fibre classification and color grading to predicting yarn and fabric properties, optimizing products and processes, and even searching for aesthetically pleasing garment designs. The review highlights that these soft computing tools are not in competition but rather complementary to each other. The authors also discuss the development of hybrid prediction models that combine the strengths of these techniques. These hybrid models have the potential to establish smarter and more efficient prediction systems for problem-solving in the textile industry.

In a study conducted by Yadav et al.[12], the application of fuzzy logic in the textile industry was investigated.

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The study presented two examples that focused on utilizing fuzzy logic for process control in the sizing process and the condensation reaction of crosslinking agents. The primary aim was to achieve enhanced process control, leading to improved productivity and quality of the final textile product. Additionally, the study highlighted the potential indirect environmental benefits, including energy and chemical savings, that could be achieved through the implementation of improved process control methods.

In his thesis, Kalav[13] developed an expert system for troubleshooting inkjet printing on cotton substrates. The system addressed defects occurring before and after printing by examining the entire process from cotton production to fixing. Thirteen common symptoms and sixty-one potential causes were identified through literature review and expert input. Using a five-point scale, fifteen experts rated the likelihood of each cause matching each symptom. The system integrated this knowledge and employed a user-selected approach to problem-solving, effectively addressing multiple faults by starting with the common cause. The study aimed to create a cost-effective expert system for troubleshooting inkjet printing on cotton, serving as a training tool for new printers and reducing costs by detecting defects without additional fabric printing.

In their study, Nasiri et al.[14] proposed a novel approach called fuzzy pattern trees for modeling fuzzy systems. This approach was developed as an alternative to rule-based system architectures that are commonly used but have perceived limitations. Fuzzy pattern trees utilize a hierarchical and modular structure, employing various types of non-linear aggregation operators. This allows for a more flexible and concise representation of functional dependencies, striking a balance between model accuracy and transparency. The researchers evaluated this new model class in the context of a specific case study focused on modeling color yield in high-temperature polyester dyeing, considering factors such as disperse dye concentration, temperature, and time. They compared three different model building approaches: a purely knowledge-based approach, a purely data-driven approach, and a hybrid approach combining the two. The results demonstrated that fuzzy model trees outperformed conventional fuzzy modeling using Mamdani's rules in terms of precision and interpretability, regardless of whether the models were built using knowledge-based or data-driven approaches. Furthermore, the study showed that the hybrid modeling approach, which combines expert knowledge and model calibration, outperformed both the purely data-driven and purely knowledge-driven approaches.

In his article, Banchero[15] aimed to offer readers an up-to-date overview of Supercritical Fluid Dyeing for both synthetic and natural textiles. The article covered a range of topics, including the solubility and equilibrium distribution of dyes, mass transfer phenomena, and interactions between solvents and polymers during the coloring process. Additionally, the article provided insights into the latest advancements in dyeing process technology. While the most promising results have been achieved in the dyeing of synthetic textiles, the author also emphasized the importance of dyeing natural textiles, which currently presents a limitation in this technology.

In a study conducted by Radhakrishnan[16], the aim was to investigate how varying experimental parameters such as pH, enzyme dosage, and temperature could impact the removal of natural and accidental impurities from knitted cotton and Lycra fabrics, with the goal of preparing them for dyeing and finishing processes. The researchers employed response surface methodology using the Box-Behnken model to determine the optimal experimental conditions and assess their effects. The optimal values were identified as a pH of 8,5, an enzyme dosage of 0,4 % (based on the fabric's weight), and a temperature of 55°C. The obtained R2 values and F values demonstrated the significant combined effect of all parameters. The study's findings indicated that the bio-scouring process executed under these optimized conditions was appropriate. The optimized conditions successfully fulfilled the pre-treatment requirements of achieving desirable absorbency and maintaining an acceptable weight loss range (between 3 % and 6 %). Since these conditions underwent statistical evaluation, they can be considered as the recommended treatment conditions for biological pretreatment. This research provides valuable insights for the textile industry by offering optimal parameters for effectively removing impurities prior to dyeing and finishing knitted cotton and Lycra fabrics.

Hossain et al.[17] employed a fuzzy logic expert system to model the color intensity of knitted cotton blend fabrics. The model considered dye concentration, dyeing time, and process temperature as factors influencing color intensity. The expert system was developed by translating the knowledge and experience of a dry cleaner into a set of expert system rules. The fuzzy logic toolbox in MATLAB was utilized to build the model, enabling the prediction of color intensity in textile dyeing operations based on specific requirements. The developed fuzzy expert system was flexible, allowing easy modifications in response to changes in dyeing process parameters.

Two years later, Hossain et al.[18] extended their research by developing color strength models for viscose/Lycra blended fabrics using a fuzzy logic approach combined with artificial neural networks. This approach required a large amount of experimental data, which can be time-consuming to acquire. To address this challenge, they proposed using a fuzzy logic expert system (FLES) that performs exceptionally well in nonlinear and complex systems, even with limited experimental data. To validate the developed fuzzy model, a laboratory-scale experiment was conducted, and various numerical error criteria were analysed. The results showed an average relative error of 3,80 %, a correlation coefficient of 0,992, and a goodness of fit of 0,986 between the actual

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and predicted color strengths of the fabrics. These findings demonstrated the effectiveness of the developed model in accurately predicting color strengths.

Hossain et al.[19] conducted a study focusing on the optimization of dyeing process parameters and the prediction of color strength for viscose/Lycra blended knitted fabrics using the Taguchi method. The primary objective was to determine the optimal dyeing conditions and forecast the color strength of these fabrics using the Taguchi method. The study considered controllable factors such as dye concentration, temperature, time, alkali concentration, salt concentration, and bath ratio as input variables, while fabric color strength served as the response variable for constructing the Taguchi model. An L25 orthogonal network model was selected, involving 25 experiments with three trials for each experiment. The mean absolute error and coefficient of determination (R2) between the actual and predicted color strength were found to be 3,48 % and 0,88, respectively. The results led to the conclusion that the Taguchi method is effective for optimizing and predicting fabric color strength in nonlinear and complex dyeing processes.

Hossain et al.[20] developed an intelligent model using a fuzzy knowledge-based expert system (FKBES) to predict color intensity in cotton knitwear. By considering dye concentration, dyeing time, and process temperature, the model addressed the nonlinearity and interdependencies of these factors, which posed challenges for traditional mathematical and statistical methods. Unlike approaches such as artificial neural networks and fuzzy neural models that require extensive experimental data, the FKBES performed exceptionally well with limited test data, similar to human experts. Laboratory-scale experiments on three types of cotton knitwear validated the model, demonstrating a high level of agreement between predicted and actual color intensity values, with an absolute error of less than 5 %.

Hossain et al.[21] aimed to predict the color intensity of viscose knitwear using a fuzzy logic (FL) model. The model incorporated the concentration of dye, salt concentration, and alkali concentration as input variables. The study also compared the performance of the FL model with an artificial neural network (ANN) model using the same parameters and data. The experimental results revealed that the dye concentration had the most significant impact on the color strength of viscose knitwear.

The FL model demonstrated a coefficient of determination (R2) of 0,977, a root mean square (RMS) error of 1,025, and a mean absolute error (MAE) of 4,61 % when comparing the predicted color intensity with experimental data. On the other hand, the ANN model showed an R2 of 0,992, an RMS error of 0,726, and an MAE of 3,28 %. Both models exhibited the ability to effectively predict fabric color intensity in a nonlinear domain, but the ANN model displayed higher prediction accuracy compared to the Fuzzy model.

In their study, Kabbari et al.[22] investigated the effects of an anti-stain treatment on the hydrophobic characteristics of knitted plush fabrics. They compared two modeling methods: a multi-criteria analysis using a response surface method, and a fuzzy logic modeling approach based on artificial intelligence. The study aimed to analyse the influence of operational parameters and intrinsic fabric characteristics on the outcomes, specifically the contact angle and air permeability.

To determine the most significant parameters, the researchers proposed an innovative approach employing fuzzy logic. The results indicated that air permeability is primarily influenced by parameters associated with the knitted structure, while variations in processing parameters have a substantial impact on the contact angle. As a result, the authors concluded that the implementation of artificial intelligence systems could effectively enhance the comprehension, evaluation, and prediction of hydrophobic properties in plush knitted fabrics within the knitting industry, surpassing the capabilities of multi-criteria analysis.

For dyeing planning whose optimization is very important for productivity, Huynh et al.[23], opted for a multi-subpopulation hybrid genetic algorithm for batch dyeing planning of textiles. Multifunctional textile is increasingly used for various purposes in sports, outdoor, urban, casual and industrial materials. Due to the shortening of product life cycles in the consumer era, the scheduling problem of textile batch dyeing which can be modeled as parallel batch processing machines with arbitrary working size, family incompatible jobs, different due date and sequence-dependent setup time has increasingly complicated product mixing, hence the need for intelligent production. To migrate to Industry 4.0, this study aims to develop a multi-subpopulation genetic algorithm with integrated heuristics (MSGA-H) to minimize the manufacturing time to improve the planning of batch dyeing of textiles which constitutes the bottleneck. Additionally, an approach combining state-of-the-art batch scheduling methods is developed for reference solutions. To estimate the validity of the proposed MSGA-H, an empirical study was conducted in a large vertically integrated textile manufacturer in Taiwan with different scenarios based on real-world settings. The results showed the practical viability of the proposed MSGA-H. This study concludes with a discussion of contributions and future research directions for smart production in emerging countries.

Tadesse et al.[24] conducted a study with the objective of predicting hand values (HV) and total hand values (THV) of functional tissues using a fuzzy logic model (FLM) and an artificial neural network (ANN) model. The evaluation of functional tissues was performed through subjective evaluation scenarios carried out by trained panels. Initially, the FLM was employed to predict HV based on finishing parameters. Subsequently, both FLM and ANN models were utilized to predict THV using the HV values.

The FLM demonstrated efficient estimation of HV, as evidenced by low root mean square error (RMSE) and mean relative percentage error (RMPE) values, except for bipolar descriptors which exhibited extremely low values within the fuzzy model. On the other hand, the prediction performance of both FLM and ANN models for THV was effective, with RMSE values of approximately 0,21 and 0,13, respectively. These values fell within the range of experimental variation. Additionally, the RMPE values for both models were below 10 %, indicating the robustness and efficiency of the models in accurately predicting THVs of functional tissues. Therefore, the FLM and ANN models hold promise as reliable tools for THV prediction in functional tissue analysis.

Haque et al.[25] conducted a study on the prediction of cotton whiteness index in cotton knitwear using a fuzzy inference system based on bleaching process variables. The researchers observed that the process parameters influencing the whiteness index of cotton knitwear exhibit highly nonlinear behavior. The fuzzy inference system was chosen as a promising modeling tool due to its ability to efficiently map nonlinear relationships with limited experimental data. Triangular-shaped membership functions were employed for the variables, and a total of 48 rules were generated for the system.

The study revealed that the impact of hydrogen peroxide concentration alone on whiteness was relatively small, but it was significantly influenced by temperature, even when the hydrogen peroxide concentration remained constant. To validate the proposed model, additional experimental data were used. The evaluation metrics, including root mean square error, mean absolute percentage error, and coefficient of determination (R2), between the predicted and experimental values were determined to be 0,536, 0,798, and 0,959, respectively. These results confirm the suitability of the model for predicting fabric whiteness index in the textile industry.

Haque et al.[26] investigated the prediction of burst strength in cotton knitted fabrics through the utilization of a fuzzy modeling approach based on bleaching process variables. The model incorporated hydrogen peroxide concentration, bleaching temperature, and bleaching time as input variables, while the variable of interest was the burst strength of the fabrics. By employing fuzzy expert systems, the study aimed to effectively capture the nonlinear relationships within the limited experimental data available. To validate the developed model, new sets of experimental data were used. The assessment metrics, including root mean square error, mean absolute percentage error, and coefficient of determination (R2), were calculated and yielded values of 4,89, 0,707, and 0,965, respectively. These findings demonstrate the successful application of the model in accurately predicting the bursting resistance of fabrics in textile dyeing workshops.

Yu et al.[27] developed three models combining least square support vector machine (LSSVM) and particle swarm optimization (PSO) to predict the K/S values of dyed cotton fabrics. The models utilized easily obtainable variables such as dye concentration and processing conditions as inputs. The predicted K/S values from the PSO-LSSVM model showed good agreement with the actual measurements. Comparisons with other models demonstrated the superior performance of the PSO-LSSVM approach. This study highlights the effectiveness of the PSO-LSSVM model as a powerful tool for predicting K/S values in reactive dye-dyed cotton fabrics, offering potential benefits in optimizing production processes and reducing costs in the textile industry.

Haji et al.[28] undertook a study to predict the color strength of plasma-treated wool yarns dyed with natural dye, aiming to overcome the challenge of low substantivity between Fibers and natural dyes. The study involved treating wool Fibers with oxygen plasma under different conditions and subsequently dyeing them with grape leaf extract. To evaluate the effects of plasma processing parameters on color intensity and their predictive capabilities, artificial neural network (ANN) and adaptive fuzzy neuro-inference system (ANFIS) models were employed. Variable factors such as oxygen flow, power, and duration were adjusted during the plasma treatment of wool yarns. The dyed samples underwent consistent conditions during the dyeing process using grape leaf extract. The ANN and ANFIS models were utilized to analyse and model the influence of plasma processing parameters on color intensity. The findings demonstrated that increasing the variables in the plasma treatment process, including oxygen flow, power, and duration, led to improved color strength in the dyed samples. The developed ANN and ANFIS models exhibited accurate predictions of the experimental data, with correlation coefficients of 0,986 and 0,997, respectively. ANFIS outperformed the ANN and a previous response surface methodology (RSM) model, achieving a higher correlation coefficient of 0,902.

Sarkar et al.[29] aimed to develop and validate a fuzzy logic-based model for predicting the GSM (grams per square meter) and crease recovery angle of laser-engraved denim. Laser engraving is a popular technique used to achieve a faded appearance on denim, offering advantages over conventional bleaching methods, such as improved productivity and reduced rejection rates. However, laser parameters like pixel time and dots per inch (DPI) have an impact on the GSM and wrinkle recovery angle of the treated denim. Despite the non-linear relationship between these parameters, a fuzzy logic-based model was created to demonstrate their effectiveness as input variables and predict GSM, warp ply recovery angle, and weft ply recovery angle as output variables. The model was validated through testing, with average relative errors of 1,68, 2,18, and 2,25 for GSM, warp ply recovery angle, and weft ply recovery angle, respectively. The determination coefficients (R2) were found to be 0,966, 0,952, and 0,958 for GSM, warp ply recovery angle, and weft ply recovery angle, respectively. The authors concluded that the developed model represents a novel approach for predicting GSM and crease recovery angle in laser-engraved denim, serving as a valuable decision support tool for garment design and clothing manufacturing, thereby saving process designers from extensive trial and error.

Kassim et al.[30] designed and implemented a straightforward water level indicator and controller based on fuzzy logic for industrial applications like nuclear power plant boilers and textile dyeing machines. The electronic level indicator used LEDs to define two levels, minimum and maximum. Their fuzzy logic controller (FLC), based on the Mamdani type fuzzy inference system, utilized level error and rate of change of error as inputs to determine the valve position. The FLC was implemented in MATLAB and simulated in Simulink to observe its behavior with changing inputs. Performance and reliability were verified by comparing the fuzzy controller's response to that of a conventional PID controller. The results showed that the fuzzy logic controller achieved minimal overshoot and steady-state error, quickly stabilizing, and providing precise water level control. It proved suitable for rapid control with coarse adjustment. The designed controller is applicable for applications with periodically varying liquid levels. To further enhance accuracy, an optimized fuzzy logic controller with adjusted fuzzy parameters can be employed in future designs.

Ulucan-Altuntas et al.[31] conducted a study focused on the treatment of textile wastewater from industrial sources using an electrocoagulation process. The results were assessed using fuzzy logic, an artificial intelligence-based modeling technique widely employed in various environmental engineering applications, ranging from wastewater treatment to air pollution estimation. The study considered three variables: current density, initial pH, and electrolysis time, which were used to predict the efficiency of removing COD, total organic carbon (TOC), and color. Lower pH values were found to be more effective in COD and TOC removal, while higher pH values were effective in color removal. Among the variables, electrolysis time was identified as the most influential parameter for the electrocoagulation treatment, and the optimal reaction time was determined to be 15 minutes. The results were further evaluated using a multiple regression model, and the resulting equations were maximized to identify the optimal conditions. The optimal conditions determined were a current density of 60 mA/cm^2, pH 5, and a reaction time of 20 minutes. By implementing these parameters, the study achieved color, TOC, and COD removal efficiencies of 89 %, 86 %, and 61 %, respectively.

Farooq et al.[32] devised a shade prediction system utilizing artificial neural networks to quantify the change in shade resulting from the application of crease recovery finishing. Finishes are commonly applied to enhance the appearance, performance, and texture of fabrics. Anti-crease finishes create a three-dimensional cross-linking network on the surface of cotton knits to control their dimensions. However, the application of anti-crease finishes often leads to color changes in dyed fabrics. This article elucidates the phenomenon of tint change for various colors and tint percentages and proposes the use of an artificial intelligence-based prediction system to anticipate the tint behavior following the final finishing process. Individual neural networks were trained to predict the color of finite samples, represented by delta color coordinate values (ΔL, Δa, Δb, Δc, and Δh). The input variables for training the networks consisted of reflectance values (in the visible range of 400-700 nm) of the dyed samples, along with color, tint percentage, and finish concentration. The trained neural networks were validated using techniques such as "cross-validation" and "hold" methods. By combining the individually trained artificial neural networks, a hue prediction model was developed, which achieved a prediction accuracy of over 90 % for hue change. This system enables dyers to forecast shade alterations prior to dyeing and finishing, allowing them to adjust their recipes accordingly. Ultimately, this approach can reduce rework and reprocessing in the textile wet processing industry.

A study encountered challenges in developing predictive models due to the highly nonlinear mapping between observed dry and wet colors. To address this, they constructed a three-layer neural network model capable of predicting the color of dry cotton fabric based on its wet state. Multiple models were created based on the spin pressure, where the wet reflectance values in Lab* color space served as the input data for the models, and the neural network outputted the predicted Lab* values in the dry state. In the absence of the neural network, the color difference between the wet and dry fabric was found to range from 5 to 20 units of E2000 color difference. However, by incorporating the neural network, the model achieved accurate predictions of the dry fabric color from its wet state, with a color difference within one unit (as measured by the DE2000 equation) over 90 % of the time. The DE2000 color difference equation was utilized as a measure for training and testing the model, leading to faster convergence and improved accuracy. Importantly, this methodology is not limited to reactive dyes on woven cotton but can be generalized to different types of dyes and fabrics. It can be applied to generate prediction models and databases for various dye classes, including direct dyes, acid dyes, and other series of reactive dyes. Furthermore, with appropriate modifications, this approach holds potential for use in finishing processes such as coating and post-processing.[33]

De Sausa Causta et al.[34] conducted a systematic literature review in the field of production planning and control (PPC) tools/activities and their impact on eco-efficiency. The aim was to explore how integrating eco-efficient practices with conventional PPC tools/activities can lead to environmental and economic benefits. The study employed bibliometrics and a systematic review of literature to analyse the relationship between PPC and eco-efficient practices. Additionally, the authors utilized ucinet-Draw to examine the connection between conventional PPC tools/activities and eco-efficiency. The findings of the study revealed both theoretical and practical contributions. One notable contribution is the evolution of PPC utilization in conjunction with eco-efficiency in various industries. The study also identified potential areas for future research. Overall, the research indicated that PPC plays a crucial role in improving operational eco-efficiency. This is achieved through several mechanisms, including facilitating the remanufacturing, recycling, and reuse of materials, promoting the use of renewable resources, reducing waste generation, and minimizing energy and water consumption. The research serves as a valuable resource for further exploration and understanding of the relationship between PPC and eco-efficiency.

Luo et al.[35] undertook a comprehensive analysis titled "Evaluation Methods for Environmental Sustainability of Textiles and Apparel" in the Environmental Impact Assessment Review. The study emphasizes the significance of environmental sustainability in the decision-making process of textile and apparel companies, as it involves balancing economic productivity and environmental impact. However, assessing the environmental sustainability of textile products is challenging due to the intricate nature of their production and consumption processes. The article critically examines various evaluation methods that have the potential to measure environmental sustainability. These methods encompass life cycle analysis, environmental footprint, eco-efficiency, and the Higg index. The researchers thoroughly reviewed the methodologies employed by these approaches and discussed their limitations within the specific context of the textile and apparel industry.

In the Fibers and Polymers journal, Haji et al.[36] carried out a study titled "Modeling Environmentally Benign Dyeing of Polyester Fabric with Madder using Artificial Neural Network and Fuzzy Logic Optimized by Genetic Algorithm." The research aimed to explore the dyeing process of polyester fabric with madder, a natural and eco-friendly dye. Using the Box-Behnken experimental design, the researchers dyed 46 samples of polyester fabric, varying five parameters: dye concentration, dye bath pH, temperature, duration, and liquor ratio. They measured the color strength (K/S) of the dyed samples and conducted multiple analyses of variance to assess the impact of each parameter on color intensity. To predict K/S values, they employed artificial neural network (ANN) and fuzzy logic models, each utilizing different parameters. The accuracy of the models was enhanced through the application of a genetic algorithm. The findings indicated that the best ANN model achieved an average absolute percentage error of 2,52, while the optimal fuzzy model achieved 3,01. Moreover, the researchers identified the most influential parameter on the ANN as dye concentration, whereas the liquor ratio had the least impact. Ultimately, the study examined the effects of each dyeing parameter on color intensity based on the established optimal ANN model.

Farooq et al.[37] present a paper that introduces an intelligent prediction method for estimating the shade change of dyed knitted fabrics after applying finishing. The method utilizes artificial neural networks (ANN) to predict the shade change of the dyed samples after the application of finish. Individual neural networks were trained to predict the delta values (ΔL, Δa, Δb, Δc, and Δh) of the finished samples based on the reflection values of the knitted dyed samples, as well as the color, dye percentage, and finish concentrations of the knitted dyed samples, which were used as input parameters. The trained ANNs were validated using holdout and cross-validation techniques and then combined to develop the model. The developed system demonstrates a color change prediction accuracy of over 90 %, offering potential benefits in reducing rework and reprocessing in the wet processing industries.

Alam et al.[38] assert that artificial intelligence (AI) possesses the potential to bring about a revolutionary transformation in the wastewater treatment process. This review provides a comprehensive summary of the key AI tools utilized in water treatment, specifically focusing on the absorption of diverse pollutants. Various AI models, ranging from simple to hybrid, have effectively predicted the performance of different adsorbents in removing dyes, metals, organic compounds, pharmaceuticals, drugs, pesticides, and PCPs from water. Despite the numerous advantages offered by AI tools, certain limitations still persist.

Sarkar et al.[39] the primary aim of this study was to develop and assess a fuzzy expert model capable of predicting the tensile strength resistance of bleach-washed denim clothing. Based on the experimental results and a comparison with the model's predicted values, the following conclusions can be drawn: the average relative error of tensile strength between the predicted and experimental values was found to be 2,82 % for the warp direction and 3,92 % for the weft direction, both within the acceptable range of 5 % confidence interval. Analysis and calculations revealed a high correlation coefficient (R) of 0,99 between the predicted and experimental values of tensile strength. The coefficient of determination (R2) for the tensile strength in both the warp and weft directions was 0,99, indicating a strong alignment between the model data and experimental data, demonstrating the model's compatibility. The developed model offers the advantages of being time-efficient, highly customizable, and efficient in terms of materials and processes, thereby reducing the environmental footprint. Additionally, the model can be extended to model parameters other than bleach washing.

For future research, the effectiveness of fuzzy logic modeling can be explored for fabric types other than denim, considering other physical, mechanical, and color properties, and incorporating a wider range of processing values.

Sarkar et al.[40] conducted a study aiming to develop a fuzzy logic-based model for predicting the tear strength of laser-etched denim garments. The tear resistance of the warp and weft directions of laser-engraved denim clothing was predicted using two crucial laser parameters: dots per inch (DPI) and pixel time (PT). Laser engraving is a commonly employed method in clothing washing factories due to its lower health risks, speed, and precision compared to other processes. However, precise control of laser parameters is crucial because insufficient tear strength in treated garments may lead to rejection. In this research, a fuzzy logic-based approach was utilized to develop a prediction model for determining the tear resistance of laser-engraved denim. The model exhibited a consistent trend with the experimental results, indicating that tear strength decreases as DPI, PT, or both decreases. The average relative errors for warp and weft tear strength were found to be 3,34 % and 3,53 %, respectively, which fall within acceptable limits. The coefficient of determination (R2) for both warp and weft tear strength was 0,98 (R=0,99), suggesting that approximately 98 % of the total changes in tear strength for both directions can be attributed to the model.

Based on the results, it is evident that the proposed model can satisfactorily predict the tear strength of laser-etched denim garments. This has significant implications for the laser engraving denim industry and can aid in optimizing laser parameters to ensure adequate tear resistance.

Vadood et al.[41] studied the dyeing process of cotton fabrics using alum as a mordant and natural dyes, solder and madder. They examined the impact of different combinations of mordant, solder, and madder on color coordinates. The goal was to develop an accurate model for predicting cotton fabric color coordinates. They compared regression methods with weighted artificial neural network (ANN) models using optimization algorithms such as PSO-FMIN, BP, genetic algorithm, particle swarm optimization, gray wolf optimization, and FMINCON. The mean square error (MSE) was used for comparison.

The results showed that using the PSO-FMIN algorithm improved the accuracy of the ANN model in predicting color coordinates. The MSE values obtained for the l*, a*, and b* coordinates were 2,02, 1,68, and 1,39, respectively. These values were 44 %, 23 %, and 26 % better than using BP alone. Statistical analysis confirmed a significant relationship between the independent parameters (mordant, solder, and madder) and all color coordinates. Initially, linear regression was attempted but did not provide satisfactory accuracy. Therefore, an ANN model was employed, combining BP and optimization algorithms to determine the weights and biases. Using only optimization algorithms did not yield high accuracy, indicating a limitation of the method. However, when the weights and biases obtained from BP were used as the starting point for the optimization algorithms, the accuracy of color coordinate prediction significantly improved compared to using BP or the optimization algorithms alone.

Ghanmi et al.[42] conducted a study comparing fuzzy logic and response surface methodologies for predicting the dyeing behavior of wool and polyamide Fibers using Juglans R. extract. The study focused on examining the effects of extract concentration (0,05 % to 0,5 %), dyeing time (5 to 45 minutes), and temperature (50°C to 95°C) as input variables, with color intensity (K/S) measured as the output variable. The performance of the models was evaluated using root mean square error (RMSE), relative mean absolute error (RMAE), and mean relative percentage error (MRPE) as criteria.

The results showed that the MRPE values ranged from 0,25 % to 0,6 %, which is considered low and significant based on existing literature. The RMSE values were lower than the standard deviation of K/S, indicating a good fit of the models. Both methodologies demonstrated their ability to predict color intensity measurement. However, when comparing their performance criteria, the fuzzy logic methodology outperformed the response surface methodology, yielding lower error values. This suggests that the fuzzy logic approach was more effective in predicting the dyeing behavior of wool and polyamide Fibers with Juglans R. extract.

Cournoyer et al.[43] authored a review article titled "Electrodialysis Processes an Answer to Industrial Sustainability: toward the Concept of Eco-Circular Economy?" which was published in the journal Membranes. The review article examines a range of electrodialysis (ED) processes, including conventional ED, selective ED, ED with bipolar membranes, and ED with filtration membranes. These processes have consistently demonstrated their potential and eco-efficiency over the past few decades. The article specifically highlights the recent opportunities for resource valorisation in diverse industrial sectors such as water, food, mining, and chemistry. By implementing electrodialysis processes, these sectors can effectively manage waste or by-product resources, thus contributing to enhanced global industrial sustainability. The adoption of electrodialysis processes facilitates the transition from linear production systems to circular processes, aligning with the principles of an eco-circular economy.

Pervez et al.[44] conducted a study titled "Optimization and prediction of cotton fabric dyeing process using machine learning approach integrated with Taguchi design" published in Scientific Reports. The research aimed to propose a sustainable and beneficial cotton fabric reactive dyeing process by combining design of experiments and machine learning prediction models.

The study utilized a least squares support vector regression (LSSVR) model based on the Taguchi orthogonal statistical design (L27) to predict various dyeing performance parameters, including exhaustion percentage

(E%), fixation rate (F%), total fixing efficiency (T%), and color strength (K/S). The results indicated the potential of the LSSVR model as a prediction tool in the textile industry during the dyeing process stage. The study introduced the LSSVR model specifically for cotton fabric dyeing process optimization, highlighting its suitability for such applications, and recommending its use in similar cases. Further research is needed to explore the incorporation of other algorithms to enhance the prediction ability of the LSSVR model. Additionally, attention should be given to new features and expenses associated with improving the dyeing process of cotton textiles within the context of the Sustainable Textile Industry 4.0 framework.

Vadood et al.[45] studied the prediction of color coordinates for cotton fabric dyed with natural madder and solder dyes using artificial intelligence. They explored various models, including regression, artificial neural networks (ANN), fuzzy logic, and support vector machines (SVM), to establish the relationship between material concentration and color coordinates. Optimization techniques like genetic algorithm, particle swarm optimization (PSO), and Gray wolf optimization (GWO) were employed to enhance model accuracy. The results showed high accuracy for all color coordinates, with the ANN optimized by GWO performing best for L* and b*, and the ANN optimized by PSO achieving the lowest mean absolute percentage error (MAPE) for a*. This study demonstrates the potential of AI models in predicting color coordinates for dyed cotton fabric, offering practical applications.

Irshad et al.[46] conducted research on textile finishing, which is the final step in enhancing fabric aesthetics and functionality. However, it can lead to undesirable effects like color change and variations in mechanical properties, causing significant losses for the textile industry. To address this problem, the researchers developed an artificial intelligence-based system to predict color behavior before finishing. The system utilized artificial neural networks trained with input data including color, tint percentage, finish type, finish concentration, and reflectance values in the visible range. Five networks were trained individually for color coordinates Δ (△L, △a, △b, △C, and △h). The networks were tested and cross-validated with 85 % accuracy. The developed models successfully predicted color variations (△L, △a, △b, △C, and △h) with mean absolute errors indicating a close correlation between actual and predicted values. The research highlights the potential of artificial intelligence in predicting color behavior during textile finishing, providing valuable insights to reduce losses and improve decision-making processes in the industry.

El Bakkali et al.[47] in his paper he investigates about the prediction of the weavability of a new fabric at the time of its creation. Using artificial intelligence (fuzzy logic), he shows the feasibility of a decision support model for designers and production experts.

Messnaoui et al.[48] investigated the exploration and employment of fuzzy logic in such applications have continued to evolve over time. It also uses fuzzy rules to express and justify inaccurate or heuristic knowledge. The realm of artificial intelligence, with its vast breadth and scope, permeates a diverse array of disciplines and sectors, traversing numerous spheres such as automation, decision-making, process control, planning, resource management, and healthcare, among a multitude of others.

METHOD

This study uses the Prisma framework and systematic literature review method to conduct an in-depth literature review. Mateo[49] proposed a series of specific steps for conducting a literature review systematically in 2020; these steps were rigorously followed in our research project. These procedures mainly include the development of a search strategy, the specification of selection criteria and the implementation of a comprehensive quality assessment and data extraction process. Then, in the following sections, we provide an in-depth explanation of each of these steps. Understanding the structure of the Prisma framework is essential to carrying out this research. Therefore, we developed a research paradigm:

- Section 2 – Research Technique: this section details the research method used in the study. It may include information on the data sources used, article selection, inclusion and exclusion criteria, and search strategies used to identify relevant studies. It provides a solid basis for understanding how the study was conducted.
- Section 3 – Literature Review: in this section, a literature review is presented. It highlights the articles that were retrieved for the study, and which deal with the use of artificial intelligence in finishing processes. The literature review may include a synthesis of key findings, trends, and gaps identified in the articles reviewed. It allows readers to familiarize themselves with the current state of knowledge on the subject.
- Section 4 – Discussion: the discussion section is where the results of the study are interpreted and discussed in depth. Researchers can analyse the implications of the results, compare them with other similar studies, discuss the limitations of the study and possible future research directions. This section allows the authors to present their thoughts and critical analyses on the results obtained.
- Section 5 – Future Research Perspectives: in this section, the authors explore future research perspectives in the studied area. They may identify unresolved questions or problems that merit

additional attention, suggest promising avenues of research, or propose methodological improvements for future studies. This section draws attention to upcoming research opportunities and encourages readers to continue investigation.

- Section 6 - Conclusions: the conclusions section summarizes the main points covered in the study. It may include a summary of key results, an assessment of whether the objectives set at the outset have been achieved, as well as recommendations or practical implications arising from the study. The conclusions provide closure to the article and allow readers to grasp the main conclusions of the study.

To obtain the first results, exhaustive research was carried out by consulting different academic and scientific resources. Platforms such as ScienceDirect, IEEE Xplore, Journal of Textile Research, and Google Scholar were used to identify relevant articles around study. Once the preliminary data was collected, it was subjected to various circumstances and selection criteria. Researchers had to consider specific restrictions related to the research area, such as the geographic or thematic scope of the study. Additionally, the language of the articles was taken into consideration, generally choosing articles available in English for ease of understanding and accessibility. Also among the selection criteria was the nature of the articles, which included both original research articles and review articles. This made it possible to obtain a global and in-depth vision of the subject. In addition, time constraints were considered, focusing on articles published in a specific period, depending on the relevance and timeliness of the information sought. The researchers carefully analysed and evaluated each article to determine whether it met the study objectives and criteria. Only the most relevant, applicable, and high-quality studies were selected for inclusion in the comprehensive review of existing literature. However, any research article that did not meet the criteria of the established selection process was not included in this investigation. This ensures that only the most reliable and relevant sources are considered in the study, enhancing its credibility and quality.

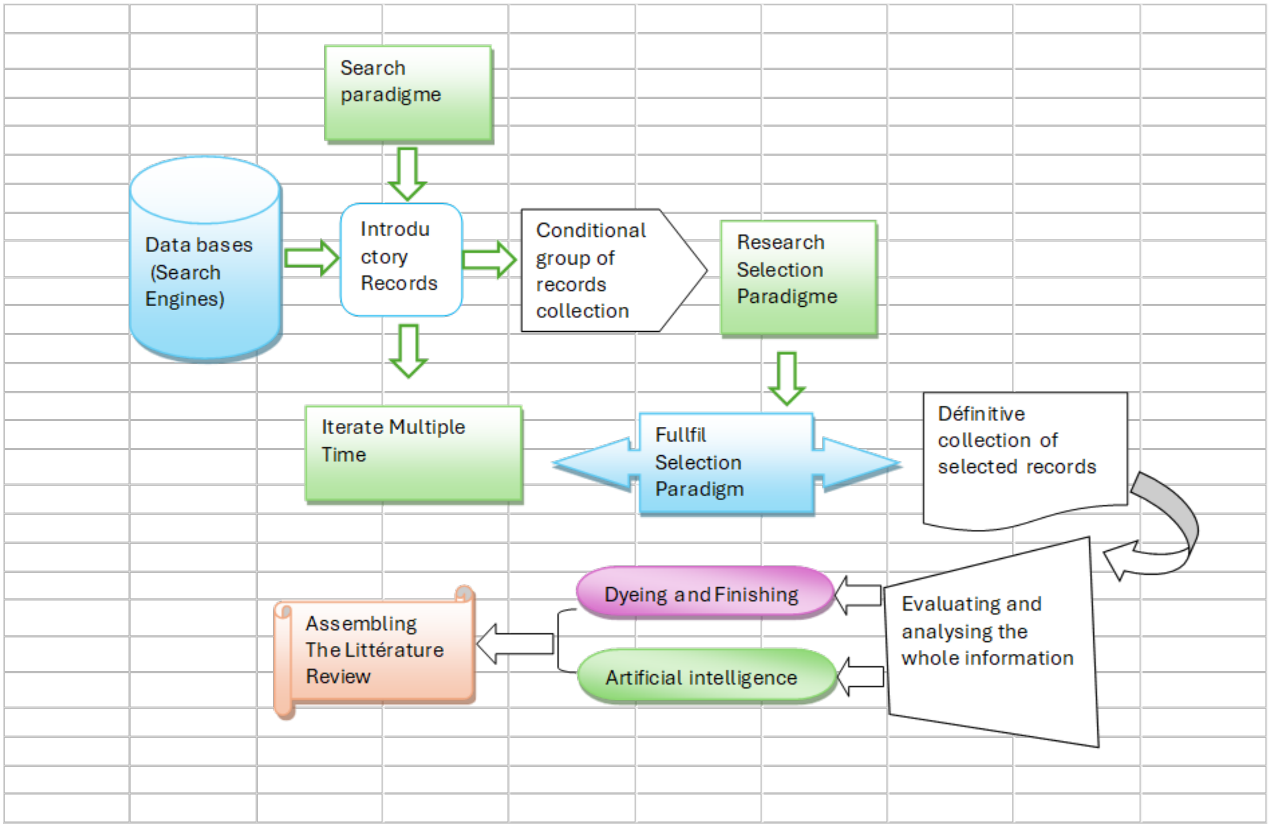

Figure 1. Structure of the Scientific Review Process Used

Prisma Framework

Step 1. Identification

First, we need to develop a research strategy suitable for this study. For this, we used four databases: ScienceDirect, IEEE Xplore, Textile Research Journal and Google Scholar. The search keywords used are as follows: digital engineering, fuzzy logic, artificial neural network, genetic algorithm, machine learning, expert system, dyeing, finishing, textile, dye. Initially, 2087 documents were identified using this search strategy. Figure 2 illustrates the process of identifying the Prisma command, which was used to develop the search strategy.

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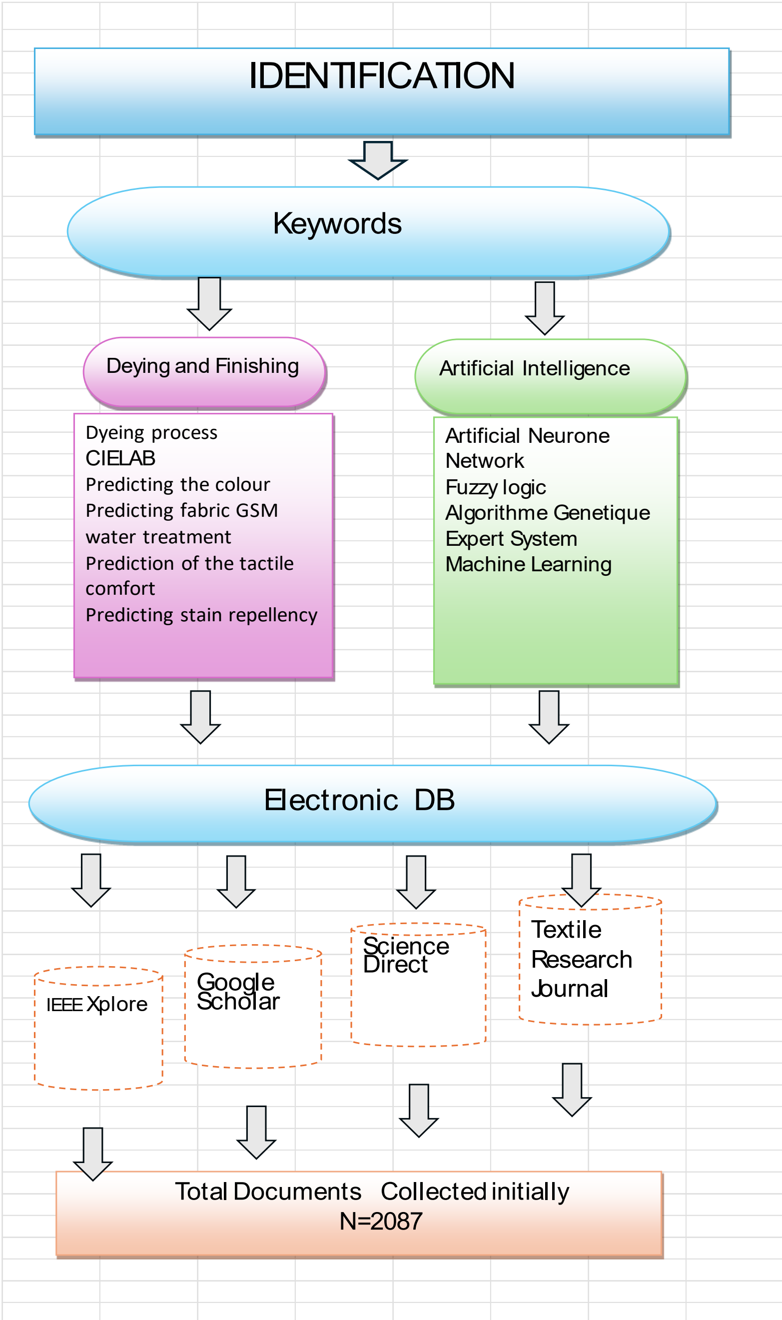

Figure 2. Identification phase of Prisma framework

Step 2. Evaluation

In the second stage of the Prisma model, we assess and filter out pertinent information. This critical step involves establishing search criteria and effectively implementing them. Our primary objective is to compile a comprehensive collection of literature that explores artificial intelligence and its application in dyeing and finishing processes. To ensure accuracy, we have limited our investigation period from 2000 to 2024. Furthermore, this study exclusively focuses on exploring how artificial intelligence can be applied in different dyeing and finishing processes, narrowing down our research scope accordingly. Only complete articles and review articles were chosen, and the research papers were restricted to the English language. Notably, a total of 1810 documents were excluded during the selection phase, while 267 research documents were extracted and proceeded to the next stage. The selection process, following the Prisma framework, is elucidated in figure 3.

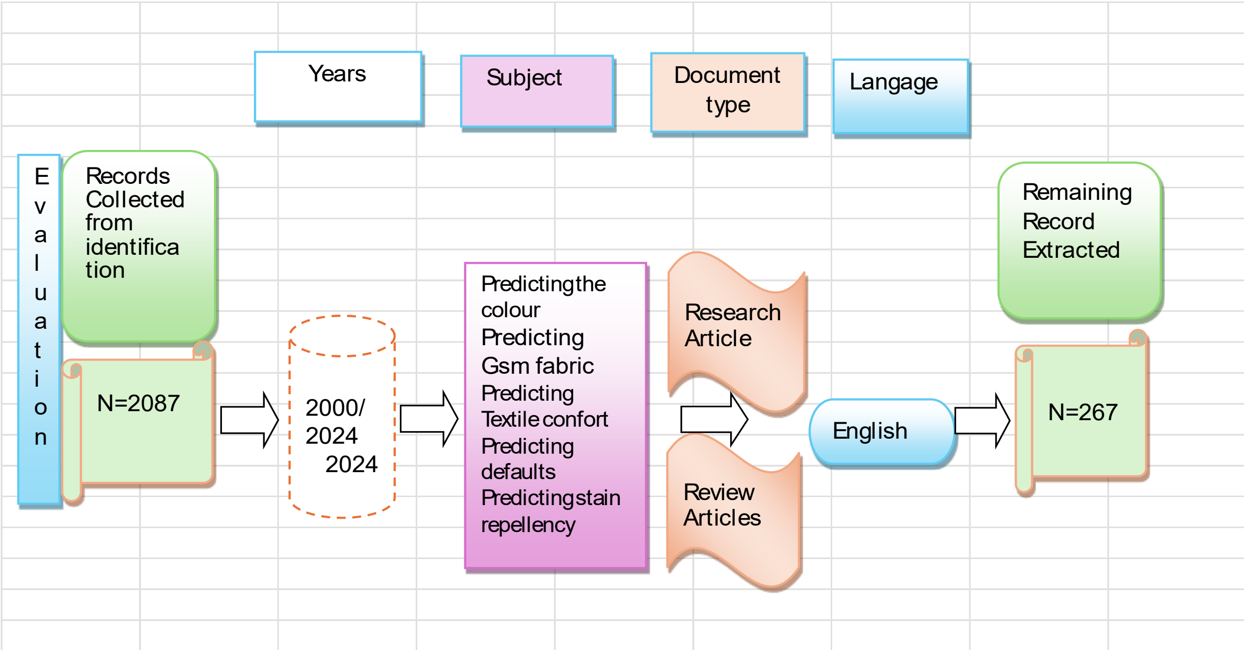

Figure 3. Screening phase of the Prisma Framework

Step 3. Meeting the requirement

This research primarily focuses on full-length research articles and review articles. To maintain accuracy, we conducted a meticulous screening process to eliminate any duplicate material. The abstract of each article was carefully evaluated to ensure its alignment with our objectives, and all the selected articles underwent a thorough review. Furthermore, we identified that 124 articles did not meet our specific requirements. After the screening process, 143 articles successfully passed this milestone and were deemed eligible for further analysis regarding their inclusion or exclusion. A visual depiction of the quality assessment process can be found in figure 4.

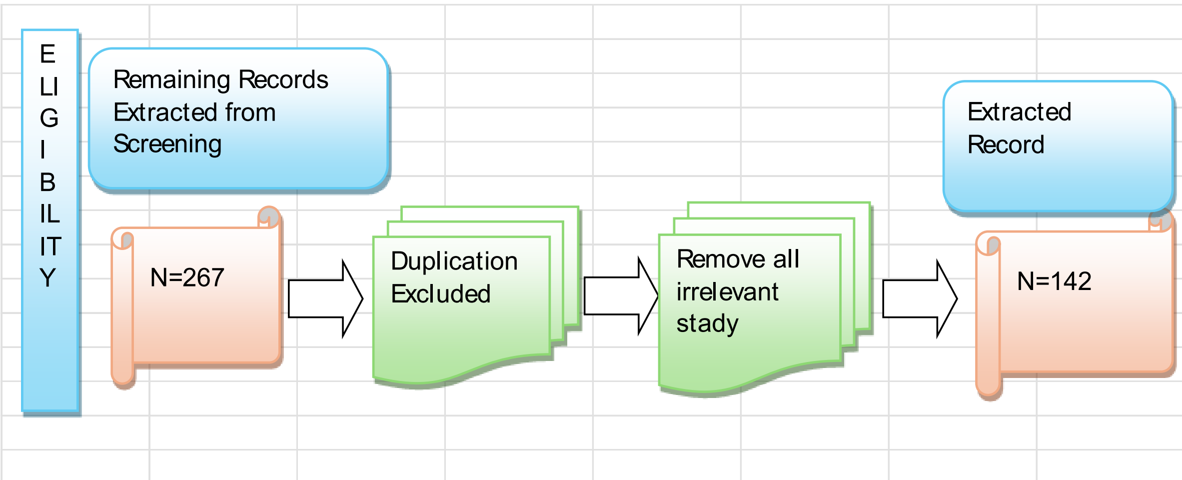

Figure 4. Eligibility phase of Prisma Framework

Step 4. Inclusion et exclusion

The inclusion and exclusion criteria were explicitly defined, and after a comprehensive examination and evaluation of all the extracted documents, 95 documents were excluded from the study. In the end, a total of 47 articles were chosen for the literature review. The incorporation phase of the Prisma guidelines is depicted in figure 5.

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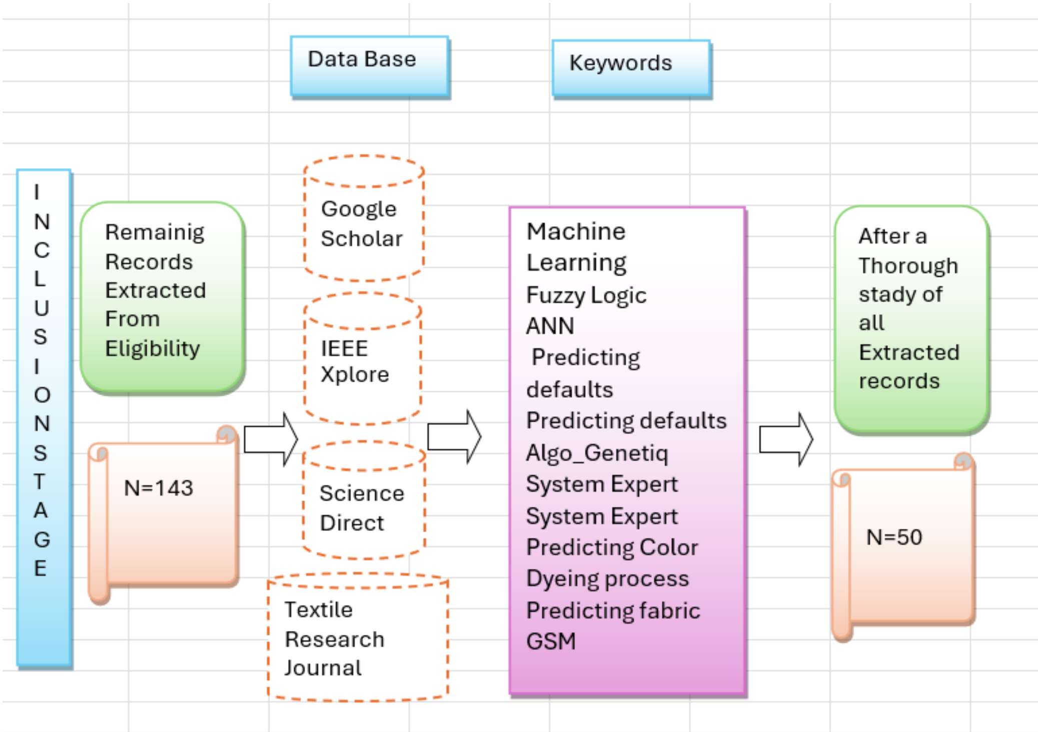

Figure 5. Inclusion stage of Prima Framework

RESULTS

Demographics

Contribution by Publishers

At this stage, the contributions of different publishers have been identified, as depicted in figure 6. Elsevier is at the top, with a maximum number of publications of 8 articles. Taylor and Francis ranked second with 7 articles then we have NISCAIR in a third place with 5 articles, and other articles published by different publishers like Emerald gp, Coreen company of Fibers and Wiley-Blackwell.

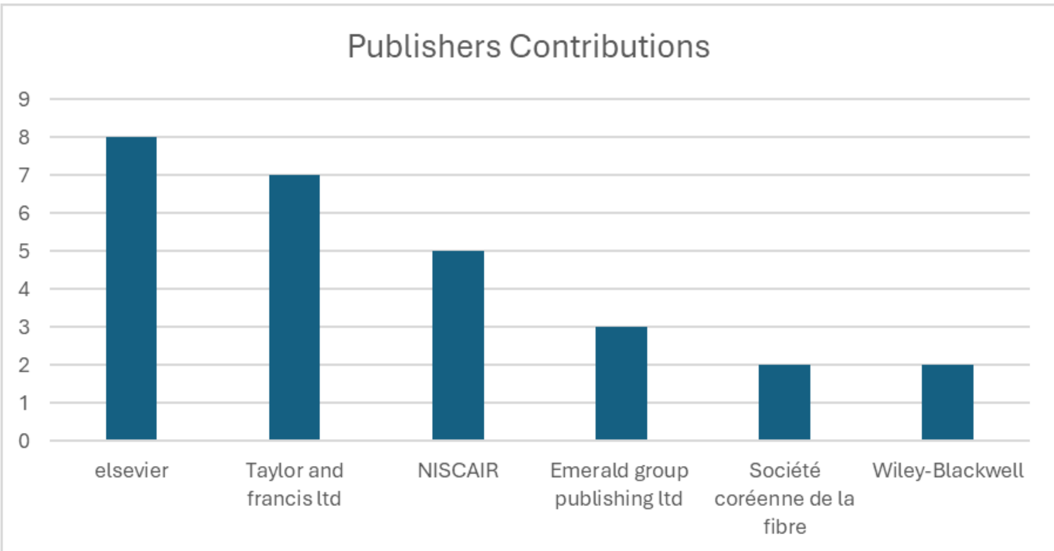

Figure 6. Publishers Contributions

Contribution by Journal

The data is collected from various sources. The sources used to search and select articles on dyeing and finishing technology and the use of artificial intelligence are listed in table 1.

Table 1. Contribution by journals

Year	Journal	Abbreviation	Impact Fact
2001	Textile Research Journal	Text. Res. J	2,3
2002	Textile Research Journal	Text. Res. J	2,3
2022	Research Journal of Textile and Apparel	RJTA	1,5
20O2	spiedigitallibrary	spie	0,37
2005	Design and development Coloration Technology	S.D.C	0,342
2004	Elsevier Dye. Pigment	Elsevier Dye. Pigment	4,71
2007	ElsevierDye.pigment	ElsevierDye.pigment	4,71
2008	Fibres Text. East. Eur.	Fibres Text. East. Eur.	0,9
2009	Environ. Technol	Environ. Technol	2,8
Year	Journal	Abbreviation	Impact Fact
2010	Indian J. Fibre Text. Res	Indian J. Fibre Text. Res	0,82
2010	Oriental Journal of Chemistry	O J C	0,5
2013	Proc. 2013 Jt. IFSA World Congr. NAFIPS Annu. Meet. IFSA/NAFIPS 2013	NAFIPS 2013	0
2013	Color. Technol	Color. Technol	1,8
2013	researchgate	researchgate	4,3
2013	ICMIME2013	ICMIME2013	2,9
2015	Journal of Engineered Fibers and Fabrics	J. Eng. Fiber. Fabr	2,347
2015	The Journal of The Textile Institute	J. Text. Inst	1,77
2016	The Journal of The Textile Institute	J. Text. Inst	1,77
2017	The Journal of The Textile Institute	J. Text. Inst	1,77
2018	Computers & Industrial Engineering	Comput. Ind. Eng	7,9
2018	Fashion and Textiles	Fash. Text	2,79
2019	Textile Research Journal	Text.Res.J.	2,3
2018	AATCC Journal of Research	AATCC J. Res	0,778
2020	Textile Research Journal	Text. Res. J	2,3
2019	Pigment Resin Technology.	Pigment Resin Technol.	1,66
2021	IOSR Journal of Electronics and communication	IOSR J. Electron	3,26
2020	Journal of Engineering and Applied Science	JEAS	1,3
2021	Journal of Water Chemistry and Technology	J. Water Chem. Technol	0,484
2021	The Journal of The Textile Institute	J. Text. Inst	1,77
2021	Production Planning & Control	PPC	7,9
2021	Elsevier Science direct	Elsevier Science direct	4,5
2021	Fibers and Polymers	Fibers Polym	2,5
2021	AUTEX Research Journal	AUTEX Res J	1,4
2022	Chemical Engineering Journal	Chem. Eng. J.	15,1
2022	Research Journal of Textile and Apparel	Res.J. Text. Appar	2,08
2022	Heliyon	Heliyon	4
2022	Coatings	Coatings	3,4
2022	Fibers and Polymers	Fibers Polym	2,5
2023	Membranes (Basel)	Membranes (Basel)	4,3
2023	Scientific Reports	Sci. Rep.	4,6
2023	SpringerLink	SpringerLink	7,4
2023	Journal Of Natural Fibers	J. Nat. Fibers	3,5

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Contribution by Authors

The table below lists the top writers who made the most contributions to the fields of Artificial intelligence and dyeing process (Table 2).

Table 2. Author's contributions

Authors	Author's Affiliation	Number of Citation (2024)
B. L. Iverson	Department of Chemical Engineering, University of Texas, Austin, TX 78712	21306
A. R. Khataee	Faculté de chimie, Département de chimie appliquée, Université de Tabriz, Tabriz, Iran	35170
S. Westland	Université de Leeds	5408
T. Hussain	National Textile University, Faisalabad	4618
Chung FengJeffrey Kuo	Université nationale des sciences et technologies de Taiwan	4110
Aminoddin Haji	Département d'ingénierie textile, Université de Yazd	3036
M. Banchero	Professeur associé, Politecnico di Torino	1978
M. Sentilkumar	University, Chennai, Inde	1816
Pervez, Md Nahid	Université d'État de New York AlbanyCe lien est désactivé., Albany, États-Unis	1679
A. N. M. A. Haque	Chercheur associé	848
Authors	Author's Affiliation	Number of Citation (2024)
J. Lassègue	CNRS, Paris	841
M. G. Tadesse	Université de Boras (Suède), Université technique Gheorghe Asachi (Roumanie)	623
B. xu	The University of Texas at Austin	607
Kubra ULUCAN-ALTUNTAS	Université des études de Padoue	563
Morteza Vadood	Département d'ingénierie textile, Université de Yazd	477
C. C. Huang	Département de science et d'ingénierie des matériaux, Université nationale des sciences et technologies de Taiwan, Taipei	484
Gulzar Alam	Chercheur doctorant, Université d'Ulster	378
Nhat-To Huynh	Université de Danang - Université des Sciences et Technologies	315
Joy Sarkar	Université d'ingénierie et de technologie de Khulna | KUET · Département d'ingénierie textile	274
I. Hossain	Université d'ingénierie et de technologie de Khulna	268
Hanen Ghanmi	Ecole Nationale d'Ingénieurs de Monastir, Université de Monastir	154
R. Guruprasad	Laboratoires de recherche IBM Inde	153
S. Radhakrishnan	Textiles and clothing sustainability	143
Luo, Yan	Institut de la mode, Université Donghua, Shanghai 200051, Chine	140
M. Nasiri	Université iranienne des sciences médicales	78
Chengbing Yu	School of Materials Science and Engineering, Shanghai University, Shanghai, China	72
Farida Irshad	Département de technologie des fibres et des textiles, Université d'agriculture, Faisalabad, Pakistan	28
Shakiru Olajide Kassim	Université d'Aberdeen	11
M. Kabbari	Fibres et polymers	6

Contribution by countrys

According to the figure 7 the United state, Iran, UK, and Pakistan are the countries that provide the most citations to this field.

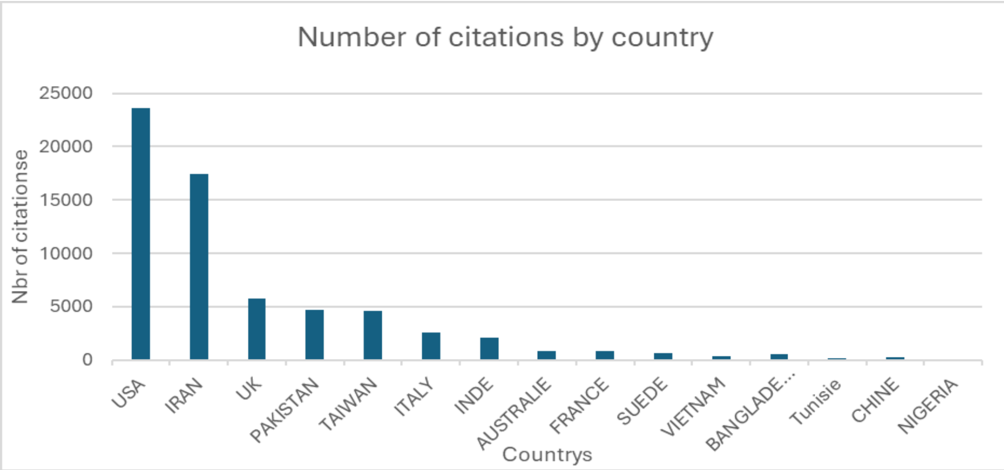

Figure 7. Details of a country-specific citation

According to the figure 8, Bangladesh, Iran, USA, and India are the countries that provide the most publications to this field.

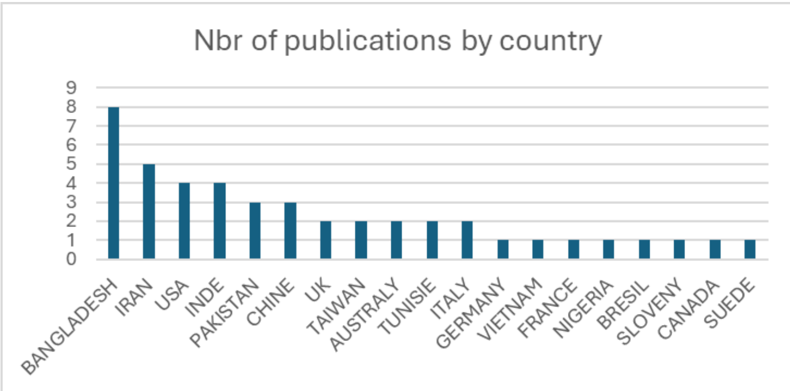

Figure 8. Details of a country- specific publication

Year-Wise Publications

In this segment, we will provide an overview of various articles categorized by their publication years. Figure 8 illustrates a significant increase in the number of articles published recently, which can be attributed to the growing recognition of Artificial Intelligence as an incredibly powerful tool for streamlining the dyeing process and aiding decision-making.

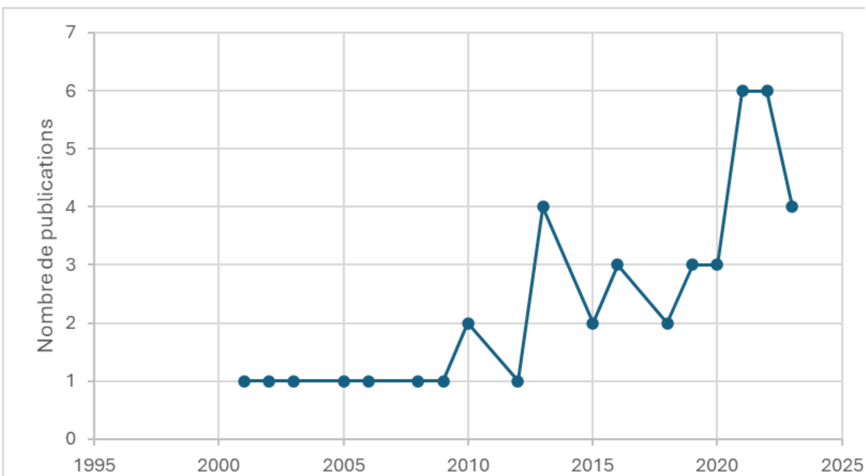

Figure 9. Data on publications by year

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Classify

This study examines two terms: artificial intelligence and the enhancement process. Regarding the enhancement process, we have divided artificial intelligence into several main axes:

1. Artificial intelligence and dyeing defects (DD).
2. Artificial intelligence and cotton color grading (CG).
3. Artificial intelligence and spectral reflectance (SR).
4. Artificial intelligence and deep shade of coloration (PSC).
5. Artificial intelligence and water treatment (WT).
6. Artificial intelligence and troubleshooting ink jet printing (PR).
7. Artificial intelligence and color strength of fabric (PCS).
8. Artificial intelligence and mechanical properties of fabric (PM).
9. Artificial intelligence and shade change in finishing process (PSC)

In table 3, a detailed explanation of each study is provided following the structure of the article, according to the research objectives, the methodology used, and the results obtained.

Table 3. Detailed comparison of research article

Reference 3	Hybrid Fuzzy, NN		X	Objective	The present study focuses on investigate recognition of seven kinds of dyeing defects: filling band in shade, dye and carrier spots, mist, oil stain, tailing, listing, and uneven dyeing on selvage.
	Dyeing process	DD DM	X	Method	The fuzzy neural classification system is constructed by a fuzzy expert system with the neural network as a fuzzy inference engine. The neural network is trained to become the inference engine using sample data.
		PS WT		Results	The results demonstrate that the fuzzy neural network approach can precisely classify these samples by the features selected. results demonstrate that the fuzzy neural net- work can precisely classify the testing samples with an RMS error of 0,001103
Reference 4	Fuzzy Infere system		X	Objective	This paper describes the application of fuzzy logic to cotton color grading to improve the acceptance of machine grading for cotton colors.
	Dyeing process	DD CG	 X	Methode	In this paper, we present the procedures for constructing a Fuzzy inference system (FIS) using fuzzy logic to classify major classes of cotton colors, and the preliminary results to demonstrate FIS effectiveness in reducing machine-classer disagreements in color grading.
		PS WT		Results	The results from the Fis show great consistency for multiple year of cotton color data. the preliminary results have shown great potential as a more reliable way of grading cotton colors.
Reference 5	Artificial Neural Network		X	Objective	This study investigates the ability of ANNs to predict spectral reflectance from colorant concentrations using a set of data measured from known mixtures of lithographic printing inks.
	Dyeing process	DD CG SR	 X	Method	The network reached the best performance with 10 units in the hidden layer. A modified version of the algorithm was then used whereby the learning rate linearly reduced during training from 0,2 to 0,05 (algorithm implemented by the training function trained).
		WT		Results	RMS error of 0,05. DE between actual and predicted reflectance for the test set is 8,23 units which is much greater than the value of 2,9 that can be obtained using the K-M model

Reference 6	Expert system D'expert		X	Objective	The aim of this research was to develop a knowledge-based expert system in the knowledge domain of troubleshooting problems in the dyeing of cotton
	Dyeing process	DD CG	X	Method	Sources of knowledge included books, journals, manuals, case studies, the internet, dye manufacturers, machinery manufacturers and expert dyers
		PS WT		Results	Was demonstrated the design and explained the methodology employed for the development of 'Dexpert'
Reference 7	Artificial Neural Network		X	Objective	An attempt made on the prediction of dyeing time. required to achieve expected depth of shade in the application of reactive HE dyes on cotton fabric using ANN is reported in this paper
	Dyeing process	DD CG		Method	The software used in this study was a feed forward. back propagation network. To carry out prediction, the network was trained with training patterns namely input and output parameters
		PS TW	X	Results	The results obtained from the network gives an average training error of around 1 % in the prediction of the time duration for achieving the correct depth of shade.
Reference 8	Artificial Neural Network		X	Objective	the use of neural networks to model CIELAB values for predicting
	Dyeing process	DD CG		Method	the neural network constructed using the input and output parameters are less than 2,0 % for vinyl sulfone dyes
		PS	X	Results	the difference between the calculated values and the predicted values, was obtained. Most samples have a brightness difference between 0,7 and 0,4, which is acceptable
Reference 9	Artificial Neural Network		X	Objective	This paper demonstrates the possibility of using counter-propagation neural networks to identify the combinations of dyes in textile printing paste formulations.
	Dyeing process	CG MD		Method	An existing collection of 1430 printed samples produced with 10 dyes was used for neural network training. The reflectance values served as input data and the known concentrations of single dye, or two dyes were used for printing each sample
		PS		Results	The best predictions for the modified data were achieved using K/S + min - max modification, yielding 83,8 % of predictions
Reference 10	ANN		X	Objective	The aim of this article it's the investigation of biosorption of triphenylmethane dye, C.I. Basic Green 4 (BG4), by Chlamydomonas species. Using an ANN
	Dyeing process	CG MD		Method	An artificial neural network model was developed to predict the bio-sportive decolorization of BG4 solution.
		PS		Results	The findings indicated that ANN provided reasonable predictive performance (R2 = 0,979).
Reference 11	Review		X	Objective	This paper reviews the application of principal soft computing techniques for the study of textile processes and products.
	Dyeing process	DD CG		Method	fuzzy logic, neural networks, and genetic algorithms, are discussed in detail with respect to their applications in solving variety of textile problems ranging from fibre classification, color grading, yarn, and fabric property prediction.

		PS		Results	Hybrid models based on neuro-fuzzy, neuro-genetic, fuzzy-genetic, and neuro- fuzzy-genetic methodologies can provide solutions to various problems in engineering of textile products and processes.
Reference 12	Fuzzy Logic		X	Objective	the application of fuzzy logic in the textile industry was investigated
	Dyeing process	DD CG		Method	The study presented two examples that focused on utilizing fuzzy logic for process control in the sizing process
		PS		Results	The implementation of improved process control methods saves energy and chemicals
Reference 13	Expert system		X	Objective	Ink jet expert system was developed using an expert system shell CLIPS (C Language Integrated Production System) .IT has been designed to find the causes of main possible faults of ink jet printed cotton substrates
	Dyeing Process	DD MD		Methods	The parameters influencing the ink jet printing were organized in a fish bone diagram. In addition, the symptoms and the possible causes were discussed with human expert by means of interviews
		PS WT	X	Results	The results of the evaluation showed that the system was highly accepted by the contributors who were expert in ink jet printing. In addition, it was suggested that the system might be useful in not only industrial applications but also educational purposes.
Reference 14	Fuzzy system		X	Objective	The present study aims to develop a model of color yield in polyester high temperature dyeing
	Dyeing Process	DD MD		Method	we compare three possibilities for model construction: purely knowledge-driven, purely data-driven and a hybrid approach combining these two.
		PS WT		Results	hybrid modeling approach can outperform a purely data-driven and a purely knowledge-driven approach if expert knowledge and model calibration are combined in a suitable way
Reference 15	Review		X	Objective	This Feature article provides an excellent summary of recent developments in a coloration technology that could transform the business of exhaustion dyeing
	Dyeing Process	DD MD		Method	The aim of the paper is to provide the reader with an up-to-date overview of this subject, covering various aspects, such as the solubility and equilibrium partitioning of the dyes, mass transfer phenomena and solvent–polymer interactions occurring during coloration, up to the most recent reports on the technology of the dyeing process.
		PS WT		Results	the best results have been obtained in the coloration of synthetic textiles, particular attention is given to the dyeing of natural textiles, which is, now, the limiting step of this technology.
Reference16	Response surface equation		X	Objective	The aim of the study was to discover the effect of experimental parameters like pH, enzyme dosage and temperature, on the removal of natural and accidental impurities from cotton and Lycra cotton weft knitted fabrics, to make them suitable for further processing like dyeing and finishing
	Dyeing Process	DD MD		Methods	The optimal experimental conditions and their effects have been ascertained by response surface methodology using the Box–Behnken model. The optimum values were found to be pH 8,5, enzyme dosage 0,4 % on weight of fabric and temperature 55 ◦C

		PS WT	X	Results	The developed fuzzy expert system was flexible, allowing easy modifications in response to changes in dyeing process parameters
Reference 17	Fuzzy expert system		X	Objective	The aim of this study was to model the color strength of viscose/Lycra (95:5) blended knitted fabrics.
	Dyeing Process	DD MD		Method	The approach to deal with such a complex process is by using a fuzzy logic expert system (FLES), which perform remarkably well in non- linear and complex systems with minimum experimental data
		CS WT	X	Results	The model was assessed by analysing various numerical error criteria. The mean relative error was found to be 3,80 %, the correlation coefficient was 0,992, and goodness of fit was 0,986
Reference 18	Taguchi method		X	Objective	The main purpose of this study was to find the optimal dyeing conditions as well as predict the colour strength (CS) of viscose/Lycra blended knitted fabrics using Taguchi method
	Dyeing Process	DD MD		Method	An L25 orthogonal array design has been chosen and conducted 25 experiments with three runs for each experiment
		CS WT		Results	The mean absolute error and coefficient of determination (R2) were found to be 3,48 % and 0,88, respectively, from the actual and predicted CS. It is concluded that Taguchi method is efficient on the optimisation and prediction of fabric CS in non-linear complex dyeing.
Reference 19	Fuzzy logic		X	Objective	The present study is intended to develop an intelligent model for the prediction of color strength of cotton knitted fabrics using fuzzy knowledge based expert system (FKBES)
	Dyeing Process	DD MD		Methods	three dyeing process parameters namely dye concentration (DC), dyeing time (DT) and process temperature (PT) have been used as input variables and color strength (CS) of the dyed fabrics as the output variable.
		CS WT	X	Results	It was found that actual and predicted values of color strength of the knitted fabrics were in good agreement with each other with less than 5 % absolute error.
Reference 20	Fuzzy logic		X	Objective	The main objective of this research is to predict the mechanical properties of viscose/Lycra plain knitted fabrics by using fuzzy expert system
	Dyeing Process	DD MD		Method	fuzzy prediction model has been built based on knitting stitch length, yarn count, and yarn tenacity as input variables and fabric mechanical properties specially bursting strength as an output variable
		CS PM	 X	Results	The mean absolute error and coefficient of determination between the actual bursting strength and that predicted by the fuzzy model were found to be 2,60 % and 0,961, respectively
Reference 21	Fuzzy logic, RSM		X	Objective	Investigate the effect of a stain repellent treatment on the water-oil repellency characteristics of plush knitted fabrics
	Dyeing Process	DD		Method	Two methods of modeling; a Multicriteria analysis was employed by means of surface response method and an artificial intelligence-based system approach is presented by fuzzy logic modeling in which the effects of the operating parameters and intrinsic features of fabrics are studied
		MD			

		SR WT	X	Results	it is believed that artificial intelligence system could efficiently be applied to the knit industry to understand, evaluate, and predict water-oil repellency parameters of plush knitted fabrics more than Multicriteria analysis.
Reference 22	Genetic Algorithm		X	Objective	This study aims to develop a multi-subpopulation genetic algorithm with heuristics embedded (MSGA-H) to minimize the make span to improve the textile batch dyeing scheduling that is the bottleneck
	Dyeing Process	DD MD		Methods	A multi-subpopulation genetic algorithm with heuristics embedded (MSGA-H) was developed to solve the large cases effectively
		CS WT	X	Results	The results have showed the efficiency of the proposed batching and extreme heuristics that embedded into MSGA Multiple subpopulation technique can reduce the drawbacks of the sensitivity of mutation rate and crossover rate.
Reference 23	Fuzzy logic ANN		X	Objective	This paper aims to predict the hand values (HVs) and total hand values (THVs) of functional fabrics by applying the fuzzy logic model (FLM) and artificial neural network (ANN) model
	Dyeing Process	DD MD		Method	The FLM was applied to predict the HV from finishing parameters; then, the FLM and ANN model were applied to predict the THV from the HV.
		SR PP	X	Results	the prediction performance of the FLM and ANN model on THV was effective, where RMSE values of 0,21 and 0,13 were obtained, respectively; both values were within the variations of the experiment. The RMPE values for both models were less than 10 %,
Reference 24	Fuzzy logic, FIS		X	Objective	The article investigates on Prediction of whiteness index of cotton using bleaching process variables by fuzzy inference system
	Dyeing Process	DD MD		Method	Fuzzy inference system is a prospective modeling tool,Triangular-shaped membership functions were considered for the variables and total 48 rules were created in this study
		SR WT	X	Results	The root-mean squared (RMS), mean absolute error percentage (MAEP) and coefficient of determination (R2) between the predicted and experimental values of whiteness index were found to be 0,536, 0,798 and 0,959 respectively.
Reference 25	Fuzzy logic		X	Objective	The utilisation of Fuzzy Modelling for Prediction of Bursting Strength of Knitted Cotton Fabric using Bleaching Process Variables
	Dyeing Process	DD MD		Method	A fuzzy prediction model has been built based on parameters of bleaching as the input variables and knitted cotton fabric bursting strength as the output variable
		CS PB	X	Results	The root mean square, mean absolute error percentage, and coefficient of determination (R2) between the predicted and experimental values were found to be 4,89, 0,707, and 0,965 respectively.
Reference 26	LSSVM, PSO		X	Objective	The aim of this article to predict the K/S value of dyed cotton fabrics
	Dyeing Process	DD MD		Method	three models were developed incorporating least squares support vector machine (LSSVM) to predict the K/S values of dyed cotton fabrics,
		SR PK/S	X		Results of this work indicate that a PSO-LSSVM model is a powerful tool for predicting the K/S value in cotton fabric dyed with reactive dye

Reference 27	ANN, ANFIS		X	Objective	The purpose of this study is to investigate the effects of plasma treatment parameters on the color strength of the dyed samples
	Dyeing Process	DD MD		Method	Fuzzy inference system is a prospective modeling tool, Triangular-shaped membership functions were considered for the variables and total 48 rules were created in this study
		SR CS	X	Results	(RMS), (MAEP) and coefficient of determination (R2) between the predicted and experimental values of whiteness index were found to be 0,536, 0,798 and 0,959 respectively.
Reference 28	Fuzzy logic		X	Objective	This study intends to develop and validate a fuzzy logic-based model to predict the GSM and crease recovery angle of laser engraved denim
	Dyeing Process	DD MD		Methods	A fuzzy logic-based model has been developed to explain the complex relationship among the input variables namely pixel time and Dots Per Inch (DPI) and output variables GSM and crease recovery angle.
		CS PGSM	X	Results	The Mean Relative Error was found 1,68, 2,18, and 2,25 for GSM, warp way crease recovery angle, and weft way crease recovery angle respectively. On the other hand, the coefficient of determination (R2) was found to be 0,966, 0,952, and 0,958 for
Reference 29	Fuzzy logic		X	Objective	In this work, a fuzzy logic based simple water level indicator and controller was designed and implemented
	Dyeing Process	DD MD		Method	The fuzzy logic controller (FLC) was based on Mamdani type Fuzzy Inference System which has two inputs; error in level and rate of change of error with one output; valve position
		SR PK/S	X	Results	The results obtained shows that Fuzzy logic has little overshoot and steady state error and stabilizes quickly providing accurate level control, hence can be used for rapid control with coarse adjustment.
Reference 30	Fuzzy logic		X	Objectiv	In this study the objective was to predict the efficiency of COD, total organic carbon (TOC), and color removal from the wastewater
	Dyeing Process	DD MD		Method	textile wastewater obtained from industry was treated by electrocoagulation process and the results were evaluated with fuzzy logic, an artificial intelligence-based modelling, surface maps were prepared for COD, TOC and colour removal
		SR WT	X	Results	The results were evaluated with the multiple regression model, The optimum conditions are: 60 mA/cm2 of current density, pH 5 and 20 min of reaction time. When these parameters were examined, colour, TOC and COD removal efficiencies were attained as 89, 86 and 61 %, respectively.
Reference 31	ANN		X	Objective	This article presents a development of shade prediction system to quantify the shade change after crease recovery finish application using artificial neural networks
	Dyeing Process	DD MD		Method	The individual neural networks were trained for the prediction of color of the finished samples, which are delta color coordinates values dl,da,db, dc,dh.
		CS PSC	X	Results	The dL, da, db, dc and dh models have been generalized on unseen data with MAE 0,6542, 0,5872, 0,5318, 0,4839 and 0,4707, respectively. The MAE values confirmed that developed model predictions are in close co- relation with the targeted values and the models can be successfully utilized to predict shade change.

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Reference 32	ANN		X	Objective	The aim of this study it's the use of a Neural Network Model to Predict the Color of Dry Cotton Fabric from a Wet State
	Dyeing Process	DD MD		Method	A three-layer neural network model was constructed, which. predicted the color of dry cotton fabric from its wet state. Different models were developed based on squeeze pressure, with inputs to the models consisting of the L*a*b* reflectance values in the wet state and the outputs of the model consisting of the predicted L*a*b* values in the dry state.
		SR PCWS	X	Results	Using a neural net, the model correctly predicted the color of the dry fabric when measured in the wet state to under one-color difference unit (using the DE2000 equation) over 90 % of the time.
Reference 33	Systematic literature review		X	Objective	In this study, was examined the scientific research focussing on the relationship between PPC and eco-efficient practices to determine how PPC tools/activities improve eco-efficiency using bibliometrics and a systematic literature review
	Dyeing Process	DD MD		Method	Method used: bibliometrics and a systematic literature review
		SR WT	X	Results	We conclude that PPC improves operational eco-efficiency because it contributes to remanufacture, recycle, and reuse of materials, utilisation of renewable materials, reduction in wastes, and minimisation of energy and water consumption.
Reference 34	A review of evaluation methods		X	Objective	paper provides a review of the methods that can be potentially used for measurement of environmental sustainability.
	Dyeing Process	DD MD		Method	The method includes the life cycle assessment, environmental footprint, eco-efficiency and Higg index. This paper reviewed the methodologies of these approaches and discussed about their limitations against the unique context of the textiles and apparel industry
		CS PSC	X	Results	This paper reviewed the methodologies of these approaches and discussed about their limitations against the unique context of the textiles and apparel industry
Reference 35	ANN Fuzzy Logic GA		X	Objective	The aim of this article is, to evaluate the effect of each parameter on the color strength,
	Dyeing Process	DD MD		Method	the data was evaluated using multiple analysis of variance. Then, the artificial neural network (ANN) and fuzzy logic models were used to predict the measured K/S values. the genetic algorithm was implemented to optimize the model accuracy
		SR P/KS	X	Results	It was observed that the best obtained ANN and fuzzy models can predict the K/S values with mean absolute percentage error of 2,52 and 3,01, respectively
Reference 36	ANN		X	Objective	This article presents the method of intelligent prediction of the shade change of dyed knitted fabrics after Finishing application by using artificial neural networks (ANNs).
	Dyeing Process	DD MD		Method	Individual neural networks are trained for the prediction of delta values (ΔL, Δa, Δb, Δc, and Δh) of finished samples with the help of reflectance values of the knitted dyed samples along with color, shade percentage, and finishing concentrations, which were selected as input parameters

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			SR PCS	X	Results	The developed system can predict the shade change with >90 % accuracy and help to decrease the rework and reprocessing in the wet processing industries
Reference 37	ANN ANN-DE			X	Object	This review summarizes various AI techniques and their applications in water treatment with a focus on the adsorption of pollutants
		Dyeing process			Method	The proposed ANN model for the adsorption of metals and phenol while the hybrid architecture (ANN-DE) topology employed to assess zinc removal by activated carbon. The significant parameters that affect the removal process were used as input variables, while the removal efficiency was the output.
				X	Results	ANN is a more efficient model and accurately estimated the experimental values
Reference 38	Fuzzy Logic			X	Object	The prime intention of this study is to develop and validate the efficiency of a fuzzy logic model to predict the tensile strength of bleach washed denim garments
		Dyeing process	MP MD SR		Methods	a fuzzy expert-based system has been constructed to model and illustrate the complex relationship among bleach concentration, time, and temperature in the input side, whereas tensile strength is the output.
			PTES	X	Results	the mean relative error was 2,82 and 3,92 for warp and weft direction tensile strength, respectively. On the other hand, the comparison exhibited a coefficient of determination (R2) of 0,99 for both warp and weft direction tensile strengths.
Reference 39	Fuzzy Logic			X	Object	This research aims to develop a fuzzy logic-based model for predicting the warp way and weft way Tearing Strength (TS) of laser engraved denim garments
		Dyeing process			Methods	In this research, two variables such as Dots Per Inch (DPI) and Pixel Time (PT) were used as input variables and Tearing Strength (TS) as the output variable. The proposed model was then developed using a fuzzy toolbox of MATLAB (Version 9,6)
				X	Results	the Mean Relative Errors (%) for warp and weft way Tearing Strength was found to be 3,34 and 3,53, respectively, which are within the acceptable limits. The coefficient of determination (R2) was found 0,98 (R ¼ 0,99)
Reference 40	ANN PSO, FMIN, GA			X	Object	The application of ANN Weighted by Optimization Algorithms to Predict the Color Coordinates of Cellulosic Fabric in Dyeing with Binary Mix of Natural Dyes
		Dyeing process			Method	To determine the best model to predict the color coordinates of cotton fabrics, the regression method and ANN models weighted with back-propagation (BP) and the genetic algorithm, PSO, Gray wolf optimization, FMINCON (a built-in function of MATLAB software) and a combination of PSO and FMINCON (PSO-FMIN), were employed and compared based on the mean squared error (MSE
				X	Results	The MSEs obtained for ANN outputs and the corresponding actual values reached 2,02, 1,68 and 1,39 for the l*, a* and b* coordinates, which were 44 %, 23 % and 26 % better than the result obtained with BP, respectively.

Reference 41	Fuzzy Logic RS	X	Object	In This article used Fuzzy Logic and Response Surface Methodologies for Predicting Wool and Polyamide Dyeing Behaviors with a Biological Extract of Juglans Regia
	Dyeing process		Method	in the present investigation, fuzzy logic and response surface methodologies were compared and used to predict the dyeing behavior of wool and polyamide Fibers with Juglans R. extract to achieve the best-fit model, root mean square error (RMSE), (RMAE), (MRPE) were used as performance criteria.
		X	Results	The results indicated that the MRPE values were between 0,25 % and 0,6 %, which could be considered low and significant, according to the literature. RMSE values were less than the K/S standard deviation
Reference 42	A Review	X	Object	This review presents the most recent valorisation opportunities among different industrial sectors (water, food, mining, chemistry, etc.)
	Dyeing process		Method	The review shows the high potential of the different types of electrodialysis processes to treat wastewaters and liquid by-products to add value or to generate new raw materials
		X	Results	The ideal scenario for sustainable development would be to make a transition toward an eco-circular economy
Reference 43	Tagauchi _ML	X	Object	The aim of this study it's the Optimization and prediction of the cotton fabric dyeing process using Taguchi design-integrated machine learning approach
	Dyeing process		Method	this research used a combined design of experiments and machine learning prediction models' method to offer a sustainable and beneficial reactive cotton fabric dyeing process.
		X	Results	The findings reveal that the LSSVR model greatly outperformed competing models in predicting the E%, F%, T%, and K/S. This is shown by the LSSVR model's much smaller RMSE and MAE values. Overall, it provided the highest possible R2 values, which reached 0,9819.
Reference 44	ANN Fuzzy SVM	X	Object	This article present a Prediction of color coordinates of cotton fabric dyed with binary mixtures of madder and solder natural dyes using artificial intelligence
	Dyeing process		Method	t was attempted to separately model the relationship between the concentration of the mentioned materials and each color coordinate using regression method, artificial neural network (ANN), fuzzy logic and vector machine support (SVM)
		X	Results	It was found that in predicting L* and b*, the ANN optimized with GWO presents the most accurate model with MAPE of 1,29 % and 2,51 %, respectively. While in the case of a*, the ANNs optimized with PSO have the least MAPE (4,65 %).
Reference 45	ANN	X	Object	Artificial neural network models were developed for the prediction of shade change and developed models are successfully solving the major problem of the dyeing industry
	Dyeing process		Method	an artificial intelligence-based system is developed to foresee the behavior of color before finishing. Color, shade percentage, finish type, finish concentration, and 31 reflectance values in the visible range 400-700 nm were selected as input for the training of artificial neural networks
		X	Results	the predictions of $\triangle L$, $\triangle a$, $\triangle b$, $\triangle C$, and $\triangle h$ with mean absolute errors 0,0765, 0,0869, 0,1528, 0,0829 and 0,1626, respectively. Mean absolute error values are showing a close correlation between actual and predicted values.

Reference 46	Fuzzy logic	X	Object	This research work presented in this paper is the modelling of the prediction of the weavability of a new fabric at the time of its creation
	Dyeing process		Methods	This model is based on fuzzy set theory and uses knowledge and expertise to help designers predict the degree of difficulty in making new fabric
		X	Results	the results of the simulation in different cases: the two diagrams easily show the ranges where weaving is easy and the cases where it becomes difficult or even impossible
Reference 47	Literature Review	X	Object	In this research study, a systematic literature review methodology was employed to examine the application of fuzzy logic within the weaving process.
	Dyeing process		Methods	The Prisma framework was utilized, resulting in the inclusion of solely journal articles for the literature review
		X	Results	The review shows insufficient in the face of the weaving process, which persists as a complex field.

DISCUSSION

This systematic and scholarly literature review thoroughly and critically examined a wide range of primary studies, encompassing a broad scope and depth of research in its overall assessment. According to a report published by Westland et al.[5], the utilization of a neural network for recipe formulation was initially an experimental approach until 1994, lacking established credibility. Westland also emphasized the development of cost-effective colorimetric online equipment based on artificial neural networks (ANNs). By calculating arbitrary mappings between readings from various instruments such as spectrophotometers and colorimeters, ANNs have the potential to enhance inter_instrument reliability.

This article was followed by others dealing with 9 different aspects of the dyeing process.

16 articles on the application of fuzzy logic to model and evaluate dyeing fabric quality characteristics:

Classification of the dyeing defects in 2001: the current study aims to investigate the recognition of seven different types of dyeing defects:[3] filling band in shade, dye and carrier spots, mist, oil stain, tailing, listing, and uneven dyeing on the selvage, using fuzzy expert system with the neural network as a fuzzy inference engine. The neural network is trained to become the inference engine using sample data.

Classification of cotton color 2002: this paper outlines the methodology employed in constructing a Fuzzy Inference System (FIS) utilizing fuzzy logic for the classification of primary categories of cotton colors.[4] Additionally, it presents initial findings that demonstrate the effectiveness of the FIS in minimizing discrepancies between machine-classed results in color grading.

Modeling of color yield in polyester dyeing 2013: this new model class was evaluated in the context of a concrete case study, namely the modeling of color yield in polyester high temperature dyeing as a function of disperse dyes concentration, temperature and time.[14] It showed that a hybrid modeling approach can outperform a purely data-driven and a purely knowledge-driven approach if expert knowledge and model calibration are combined in a suitable way.

Modeling color strength of knitted fabric 2013: the primary aim of this research is to establish a model for predicting the color strength of cotton knitted fabric.[17] This is achieved by employing a fuzzy expert system that considers factors such as dye concentration, temperature, and time. The developed fuzzy expert system is designed to be user-friendly and can be easily adjusted to accommodate changes in dyeing process parameters. The same model used in 2015 for modeling color strength of Viscose /Lycra.[19] To tackle the intricacies of such a complex process, a viable approach is to employ a fuzzy logic expert system (FLES). FLES demonstrates exceptional performance in handling non-linear and complex systems, even when limited experimental data is available.

Predicting of color strength of cotton 2016: the objective of this study is to create an intelligent model that can predict the color strength of cotton knitted fabrics. This is accomplished by employing a fuzzy knowledge-based expert system (FKBES).[20] The results demonstrated a strong agreement between the actual and predicted values of color strength for the knitted fabrics, with an absolute error of less than 5 %.

Predicting the mechanical properties of viscose /Lycra 2016: this research aims to predict the bursting strength of viscose/Lycra plain knitted fabrics using a fuzzy expert system.[18] The model considers knitting stitch length, yarn count, and yarn tenacity as input variables. The evaluation shows a mean absolute error of 2,60 % and a coefficient of determination of 0,961, indicating accurate predictions and strong agreement with

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actual measurements. In summary, the fuzzy prediction model effectively forecasts the mechanical properties of these fabrics, specifically bursting strength.

Predicting stain repellency characteristics of knitted fabric in 2017: this study utilizes two modeling methods to analyse plush knitted fabrics: multicriteria analysis using surface response methodology and fuzzy logic modeling based on artificial intelligence.[22] The aim is to investigate the impact of operational parameters and intrinsic fabric characteristics on the water-oil repellency properties; The results suggest that the application of artificial intelligence systems, specifically fuzzy logic modeling, is more effective in understanding, evaluating, and predicting water-oil repellency parameters of plush knitted fabrics compared to Multicriteria analysis. This indicates that artificial intelligence systems have greater potential for practical implementation in the knit industry.

Predicting whiteness index of cotton in 2018: this article investigates the prediction of cotton whiteness index using a fuzzy inference system.[25] Triangular-shaped membership functions were used for variables, resulting in 48 rules. The system's performance was assessed by comparing predicted and experimental values. The root-mean squared (RMS) error was 0,536, mean absolute error percentage (MAEP) was 0,798, and coefficient of determination (R2) was 0,959. Overall, the fuzzy inference system accurately predicted the whiteness index, as indicated by the evaluation metrics.

Predicting the bursting strength of knitted cotton in 2019: a fuzzy modeling approach was employed to predict the bursting strength of a knitted cotton fabric, considering the variables of hydrogen peroxide concentration, bleaching temperature, and bleaching time as inputs.[26] The fuzzy prediction model yielded evaluation measures of 4,89 for the mean square error, 0,707 for the mean absolute percentage error, and 0,965 for the coefficient of determination (R2) compared to experimental values. These results indicate a relatively accurate and strong correlation between the predicted and actual bursting strength values.

Predicting the GSM fabric and crease recovery angle in 2020: this study focuses on developing and validating a fuzzy logic-based model to predict the GSM (Grams per Square Meter) and crease recovery angle of laser-engraved denim.[29] The model aims to capture the intricate relationship between the input variables, specifically pixel time and Dots Per Inch (DPI), and the output variables, GSM, and crease recovery angle. The model's performance was evaluated, resulting in a Mean Relative Error of 1,68, 2,18, and 2,25 for GSM, warp-way crease recovery angle, and weft-way crease recovery angle, respectively. Moreover, the coefficient of determination (R2) was calculated to be 0,966, 0,952, and 0,958 for these respective variables.

Implementation and design water level controller in 2021: the fuzzy logic controller (FLC) utilized in this study employed a Mamdani type Fuzzy Inference System with two inputs: error in level and rate of change of error, and one output: valve position.[30] The obtained results demonstrate that the fuzzy logic approach exhibits minimal overshoot and steady-state error, leading to fast stabilization and precise level control. Therefore, it can be effectively utilized for rapid control with coarse adjustment.

Predicting water treatment efficiency in 2021: the aim of this study was to predict the efficiency of COD (Chemical Oxygen Demand), total organic carbon (TOC), and color removal in textile wastewater. The wastewater obtained from the textile industry was treated using the electrocoagulation process, and the results were analysed using fuzzy logic, an artificial intelligence-based modeling technique. Surface maps were created to visualize the removal of COD, TOC, and color.[31] The results were further assessed using a multiple regression model. The optimal operating conditions were determined to be a current density of 60 mA/cm^2, pH 5, and a reaction time of 20 minutes. Under these conditions, the removal efficiencies for color, TOC, and COD were found to be 89 %, 86 %, and 61 %, respectively.

Predicting the tensile strength of bleach washed denim in 2022: the primary objective of this study was to develop and validate the effectiveness of a fuzzy logic model in predicting the tensile strength of bleach-washed denim garments.[39] A fuzzy expert-based system was constructed to capture and represent the intricate relationship between bleach concentration, time, and temperature as input variables, while tensile strength served as the output variable. The evaluation of the model revealed a mean relative error of 2,82 and 3,92 for the tensile strength in the warp and weft directions, respectively. Furthermore, the comparison demonstrated a coefficient of determination (R2) of 0,99 for both the warp and weft direction tensile strengths.

Predicting the tearing of laser engraved denim in 2022: the objective of this research is to create a fuzzy logic-based model for predicting the Tearing Strength (TS) in both the warp and weft directions of laser-engraved denim garments.[40] The model utilizes two input variables, Dots Per Inch (DPI) and Pixel Time (PT), and the output variable is Tearing Strength (TS). The model development was carried out using the fuzzy toolbox of MATLAB (Version 9,6). The evaluation of the model resulted in Mean Relative Errors (%) of 3,34 and 3,53 for the warp and weft Tearing Strength, respectively, which are considered acceptable within the given limits. The coefficient of determination (R2) was found to be 0,98 (R = 0,99) for both.

The modelling of the prediction of the weavability of a new fabric 2023: the research already carried out shows the importance of applying fuzzy logic in weaving and describes the four different segments addressed by the authors: the properties of a warp and weft fabric, the performance of weaving machines, the performance of the organization of a weaving company, and health and safety in the workplace.[48]

8 articles on the application of ANN model and evaluate dyeing process, fabric quality characteristics:

Expecting deep shade in reactive dye in 2006: this paper presents a study on predicting the dyeing time necessary to achieve the desired depth of shade when applying reactive HE dyes to cotton fabric. The prediction was carried out using an Artificial Neural Network (ANN) with a feed-forward backpropagation network architecture.(7) The network was trained using input and output parameters as training patterns. The results obtained from the trained network demonstrate an average training error of approximately 1 % in predicting the time duration required to achieve the desired depth of shade. Furthermore, when tested with other reactive HE dyes, the trained network maintains the same average error percentage.

Determination of pigments combination for textile printing 2008: this research demonstrates the feasibility of utilizing counter-propagation neural networks to identify dye combinations in textile printing paste formulations.(9) A dataset of 1430 printed samples, produced with 10 different dyes, was employed for training the neural network. The reflectance values of the samples were utilized as input data, while the known concentrations of single or two dyes were used for printing each sample. Some adjustments were made to the input and output data to enhance the learning capabilities of the network. The most accurate predictions, achieved through the modification of the data using K/S + min-max approach, resulted in an 83,8 % success rate. This means that in 83,8 % of the cases, the neural network accurately predicted both dyes employed in the printed sample.

Predicting the bio-sportive decolorization of BG4 solution in 2009: this article focuses on investigating the biosorption of C.I. Basic Green 4 (BG4), a triphenylmethane dye, by Chlamydomonas species.(10) The study utilizes an Artificial Neural Network (ANN) to develop a model for predicting the bio-sportive decolorization of BG4 solution. The effects of various operational parameters, including initial dye concentration, temperature, pH, reaction time, and algal concentration, on the efficiency of bio-sportive decolorization were examined. The findings of the study indicate that the ANN model demonstrates reasonable predictive performance, with an R2 value of 0,979. The influence of each parameter on the response was assessed, revealing that the initial concentration of the dye had the most significant impact, followed by temperature.

Predicting the shade change after finishing in 2021: this article presents the development of a shade prediction system that quantifies the change in shade after the application of a crease recovery finish using artificial neural networks.(32) Individual neural networks were trained to predict the color of finished samples, specifically the delta color coordinate values dl, da, db, dc, and dh. The input variables for training the networks included reflectance values within the visible range (400-700nm) of dyed samples, color information, shade percentage, and finish concentration. The dL, da, db, dc, and dh models were successfully generalized to unseen data, achieving mean absolute error (MAE) values of 0,6542, 0,5872, 0,5318, 0,4839, and 0,4707, respectively. These MAE values indicate that the developed models provide accurate predictions closely aligned with the targeted values. Consequently, these models can be effectively utilized to predict shade changes resulting from crease recovery finish applications.

Predicting color of dry cotton from a wet state in 2022: the objective of this study is to utilize a Neural Network Model to accurately predict the color of dry cotton fabric based on its wet state. A three-layer neural network model was constructed for this purpose. Multiple models were developed, each corresponding to a specific squeeze pressure.(50) The inputs to the models included the Lab* reflectance values of the fabric in its wet state, while the outputs consisted of the predicted Lab* values of the fabric in its dry state. The neural network model achieved impressive results, correctly predicting the color of the dry fabric from its wet state with an accuracy of under one color difference unit (using the DE2000 equation) over 90 % of the time. This indicates the effectiveness of the model in accurately estimating the color transformation between the wet and dry states of the cotton fabric.

Predicting the shade change after softening in 2021: this article focuses on the development of a shade prediction system that utilizes artificial neural networks to quantify the change in shade after applying a crease recovery finish.(37) Individual neural networks were trained to predict the color of finished samples, specifically the delta color coordinate values dl, da, db, dc, and dh. The input variables used to train the networks included reflectance values within the visible range (400-700nm) of dyed samples, color information, shade percentage, and finish concentration. The dL, da, db, dc, and dh models were successfully generalized to unseen data, achieving mean absolute error (MAE) values of 0,6542, 0,5872, 0,5318, 0,4839, and 0,4707, respectively. These MAE values indicate a close correlation between the developed model predictions and the targeted values, demonstrating the effective utilization of the models for predicting shade change.

Optimising adsorption process water treatment in 2022: this review provides an overview of different artificial intelligence (AI) techniques and their applications in water treatment, specifically focusing on the adsorption of pollutants.(38) The study highlights the use of an Artificial Neural Network (ANN) model for the adsorption of metals and phenol, as well as a hybrid architecture (ANN-DE) topology for evaluating zinc removal using activated carbon. The key parameters influencing the removal process were utilized as input variables, while the output was the removal efficiency. The findings clearly demonstrate that the ANN model is more efficient and accurately predicts the experimental values.

Predicting change variation in dyeing fabric in 2023: this article presents a contribution towards the development of a Prediction System for Shade Change Variations in Dyed Cotton Fabric following the application of water repellent finishes.[33] The research work involves the creation of an artificial intelligence-based system that can anticipate color behavior prior to finishing. Input variables used for training the artificial neural networks include color, shade percentage, finish type, finish concentration, and 31 reflectance values within the visible range of 400-700 nm. The developed models were employed to predict the changes (△) in L, a, b, c, and h values, with corresponding mean absolute errors of 0,0765, 0,0869, 0,1528, 0,0829, and 0,1626, respectively. These results indicate the accuracy of the models in estimating the shade change variations, providing valuable insights into the impact of water repellent finishes on dyed cotton fabric.

7 articles on the application of Hybrid (Fuzzy, ANN, GA, RS.) model and evaluate dyeing process, fabric quality characteristics:

Discussing divers applications of soft computing in textiles in 2010: this paper provides a thorough examination of how soft computing techniques are applied in the analysis of textile processes and products.[11] Soft computing offers a flexible and user-friendly computing approach, making it suitable for textile-related applications. The article specifically focuses on fuzzy logic, neural networks, and genetic algorithms, discussing their diverse applications in solving numerous textile challenges. These challenges encompass Fiber classification, color grading, prediction of yarn and fabric properties, optimization of products and processes, and even the exploration of visually appealing garment designs. The paper also highlights the advantages of employing hybrid models that combine different soft computing methodologies. Specifically, it explores the effectiveness of neuro-fuzzy, neuro-genetic, fuzzy-genetic, and neuro-fuzzy-genetic approaches in addressing engineering obstacles related to textile products and processes. These hybrid models have demonstrated their utility in tackling various complexities encountered in the textile industry.

Predicting the dyeing behaviors of wool and polyamide fibers in 2022: this article explores the use of Fuzzy Logic and Response Surface Methodologies in predicting the dyeing behaviors of wool and polyamide fibers using a biological extract derived from Juglans Regia.[42] The study compares and evaluates the performance of these methodologies.

To obtain the best-fit model, performance criteria such as root mean square error (RMSE), relative mean absolute error (RMAE), and mean relative percentage error (MRPE) were employed. The results revealed that the MRPE values ranged from 0,25 % to 0,6 %, which can be considered low and significant based on existing literature. Additionally, the RMSE values were lower than the standard deviation of K/S measurements.

Predicting the tactile comfort of fabric in 2019: the main objective of this study is to predict the hand values (HVs) and total hand values (THVs) of functional fabrics using both a fuzzy logic model (FLM) and an artificial neural network (ANN) model.[24] The research successfully applied the FLM and ANN models to predict the HV and THV of functional fabrics. These models demonstrated effective prediction performance, as evidenced by the RMSE values falling within the range of experimental variations and the RMPE values being below 10 %.

Predicting of color strength of yarn in 2020: the objective of this study was to examine how plasma treatment parameters impact the color strength of dyed samples, utilizing artificial neural network (ANN) and adaptive neuro-fuzzy inference system (ANFIS).[28] The aim was to assess the predictive capabilities of these methods in determining color strength. Both ANN and ANFIS were employed to model and analyse the influence of plasma treatment parameters on the color strength of the dyed samples. The results indicated that both ANN and ANFIS accurately predicted the experimental data, achieving correlation coefficients of 0,986 and 0,997, respectively. Comparing these correlation coefficients with the previous study using response surface methodology (RSM) models (correlation coefficient = 0,902), ANFIS demonstrated higher accuracy in predicting the study's outcomes than both ANN and RSM models.

Investigating the influence of parameters on color strength in 2021: the main goal of this article is to examine the influence of individual parameters on color strength and to forecast the measured K/S values using artificial neural network (ANN) and fuzzy logic models.[28] The data underwent multiple analyses of variance to evaluate its significance. Additionally, a genetic algorithm was employed to enhance the accuracy of the models.

The outcomes revealed that the best-performing ANN model achieved an impressive mean absolute percentage error of 2,52 when predicting the K/S values. Similarly, the top-performing fuzzy logic model yielded a mean absolute percentage error of 3,01. These results clearly indicate the efficacy of both models in providing precise estimations of color.

Predicting color coordinates in 2022: in this study, various models were used to predict the color coordinates of cotton fabrics in dyeing processes using a binary mix of natural dyes.[45] The models compared were the regression method and artificial neural network (ANN) models, with the ANN models weighted by different optimization algorithms such as back-propagation (BP), genetic algorithm, particle swarm optimization (PSO), Gray wolf optimization, FMINCON, and a combination of PSO and FMINCON (PSO-FMIN). The evaluation criterion used to compare the models was the mean squared error (MSE). The results revealed that the ANN models outperformed the regression method. Specifically, the MSEs obtained for the ANN outputs and the actual values were 2,02, 1,68, and 1,39 for the l*, a*, and b* coordinates, respectively. These values were 44 %, 23 %, and 26 % better than the results obtained with the BP model. This indicates that the ANN models weighted by the optimization algorithms yielded more accurate predictions of the color coordinates compared to the BP model.5 Articles review on the application of artificial intelligence to model and evaluate dyeing and finishing process, fabric quality characteristics.

Emerging techniques in textile industries in 2010: this feature article offers a comprehensive summary of recent advancements in coloration technology that has the potential to revolutionize exhaustion dyeing in the business sector.(12) Its primary objective is to provide readers with an up-to-date overview of the subject, encompassing various aspects such as dye solubility, equilibrium partitioning, mass transfer phenomena, and interactions between solvents and polymers during the coloration process. While the most promising outcomes have been achieved in coloring synthetic textiles, the article pays significant attention to the dyeing of natural textiles, which currently represents the main challenge in implementing this technology.

Relationship between PPC and eco-efficiency in 2021: this study utilized bibliometrics and a systematic literature review to investigate the scientific research pertaining to the correlation between PPC (Pollution Prevention and Control) and eco-efficient practices.(34) The objective was to assess how PPC tools and activities enhance eco-efficiency. The findings indicate that PPC plays a crucial role in improving operational eco-efficiency. It achieves this by fostering practices such as material remanufacturing, recycling, and reuse, as well as the utilization of renewable materials. Furthermore, PPC contributes to waste reduction and minimizes energy and water consumption, thereby promoting sustainable environmental practices.

Measuring environmental sustainability in 2021: this article presents an overview of various methods that have the potential for measuring environmental sustainability.(35) Specifically, it focuses on methods such as life cycle assessment, environmental footprint, eco-efficiency, and Higg index. The paper thoroughly examines the methodologies associated with these approaches and thoroughly discusses their limitations within the specific context of the textiles and apparel industry.

Treating wastewaters in 2023: this review highlights the latest opportunities for valorisation in various industrial sectors such as water, food, mining, and chemistry.(43) It emphasizes the significant potential of different electrodialysis processes in treating wastewaters and liquid by-products. These processes not only help in adding value to these resources but also enable the generation of new raw materials. The goal for achieving sustainable development is to transition towards an eco-circular economy, where resources are utilized in a circular and environmentally friendly manner.

A comprehensive framework was developed to elucidate the impact of employing fuzzy logic, the approach presented in this framework provides a comprehensive and highly effective method for tackling the complex challenges associated with ambiguity, modification, and subtlety that are frequently observed in the intricate and intricate process of weaving.

2 articles on the application of Taguchi model and evaluate dyeing process, fabric quality characteristics:

Predicting color strength in 2015: this study aimed to determine optimal dyeing conditions and predict color strength (CS) of viscose/Lycra blended knitted fabrics using the Taguchi method.(19) An L25 orthogonal array design was used with 25 experiments, each consisting of three runs.

The optimal parameters for dyeing were identified as follows: dye concentration (9 %), time (60 minutes), temperature (75˚C), salt concentration (50 g/l), alkali concentration (14 g/l), and liquor ratio (1:8). The prediction of CS yielded a mean absolute error of 3,48 %, indicating a relatively small deviation between actual and predicted values. The coefficient of determination (R2) was 0,88, indicating a strong correlation between predicted and actual CS. In conclusion, the Taguchi method efficiently optimized the dyeing process and accurately predicted the color strength of the fabric, even in non-linear and complex dyeing scenarios.

Optimising the dyeing of cotton fabric in 2023: this study aimed to optimize and predict the dyeing process of cotton fabric using Taguchi design and machine learning techniques.(44) The results showed that the least squares support vector regression (LSSVR) model outperformed other models in predicting variables like E%, F%, T%, and K/S. The LSSVR model had smaller RMSE and MAE values and achieved the highest coefficient of determination (R2) of 0,9819. These findings demonstrate the effectiveness of the combined Taguchi design and LSSVR model in optimizing and accurately predicting parameters in cotton fabric dyeing.

1 article on the application of LSSVM/PSO model and evaluate dyeing and finishing process, fabric quality characteristics:

Predicting the K/S value of dyeing fabric in 2020: this article focuses on predicting the K/S value of dyed cotton fabrics. Three models were created using the least squares support vector machine (LSSVM) to estimate the K/S values.(27) The parameters of the LSSVM model were optimized and fine-tuned using particle swarm optimization (PSO), resulting in a PSO-LSSVM model. The results of this study demonstrate the effectiveness of the PSO-LSSVM model in predicting the K/S value of cotton fabric dyed with reactive dye. This model serves as a valuable tool for improving production processes and reducing costs associated with the dyeing of cotton fabrics.

1 article on the application of expert system model and evaluate dyeing and finishing process, fabric quality characteristics:

Application of an expert system in 2012: an ink jet expert system was developed using the CLIPS expert system shell to identify faults in ink jet printed cotton substrates.[13] Parameters were organized in a fishbone diagram, and human experts were consulted through interviews to determine symptoms and causes. A survey with thirteen symptoms and sixty-one causes received positive feedback from industry and academic experts. The system was deemed useful for both industrial and educational purposes.

1 article on the application of Box and Benken model and evaluate dyeing and finishing process, fabric quality characteristics.[16]

This study investigated the impact of pH, enzyme dosage, and temperature on removing impurities from cotton and Lycra cotton weft knitted fabrics. The goal was to prepare the fabrics for dyeing and finishing. Using response surface methodology, the optimal conditions were determined: pH 8,5, enzyme dosage of 0,4 %, and a temperature of 55°C.

1 article on the application of dynamic stochastic model and evaluate dyeing and finishing process, fabric quality characteristics:

The aim of this study was to investigate the scientific research that explores the correlation between PPC (Production and Process Control) and eco-efficient practices.[34] The study utilized bibliometrics and a systematic literature review as its methods. Based on our findings, we can conclude that PPC tools and activities have a positive impact on operational eco-efficiency. This is primarily due to their ability to facilitate processes such as remanufacturing, recycling, and material reuse. Additionally, PPC promotes the use of renewable materials, reduces waste generation, and minimizes energy and water consumption.

1 article on the application of genetic algorithm model and evaluate dyeing and finishing process, fabric quality characteristics:

Introducing a multi-subpopulation genetic algorithm in 2018: the objective of this study is to enhance the scheduling of textile batch dyeing, which is currently a bottleneck, by introducing a multi-subpopulation genetic algorithm with embedded heuristics (MSGA-H).[23] The developed MSGA-H algorithm effectively solves larger cases and minimizes the make span. The study's findings demonstrate the effectiveness of the proposed batching and extreme heuristics embedded within the MSGA-H framework. These heuristics help alleviate the sensitivity issues associated with mutation rate and crossover rate, resulting in improved efficiency and performance.

Future Research

Literature reviews and research articles serve as in-depth evaluations of the existing knowledge within a particular field of study. The main aim of the authors is to improve comprehension and identify areas that necessitate further investigation, thus facilitating future inquiries. The subsequent table delineates potential research endeavors derived from the reviewed articles, highlighting the need for additional exploration to deepen the understanding. The table provided below presents the future research directions identified in the studied articles.

Table 4. Details of research article

Authors	Year	Future Research
C. C. Huang and W. H. Yu	2001	The approach of this article is limited to the classification of solid colors only, which opens research opportunities for printed fabrics. Additionally, the width of the fabric is much larger than the size of an image, necessitating the merging of multiple images on the same fabric width.
B. xu, D. S. Dale, Y. Huang, and M. D. Watson	2002	The fuzzy system implemented in this article can perform consistent classifications for samples from different years, considering two classes. Future research should focus on expanding the analysis to more than two colors since there can be five types of cotton colors. Additionally, it is recommended to test the system on a larger sample basis to further validate its performance.
S. Westland, L. Iovine, and J. M. Bishop	2002	Future research will focus on a hybrid model that combines an ANN while retaining the key characteristics of the K-M model to outperform both approaches, K-M and ANN, simultaneously.
M. Sentilkumar and N. Selvakumar	2006	The model worked well for vinyl sulfone dyes. However, since there are multiple families of dyes such as monochloro-triazine, Di chlorotriazine, and vinyl-sulfone monoclorotriazine, further research is needed to explore their application with the developed model.

D. Golob, D. P. Osterman, and J. Zupan,	2008	The next step of research in this area will be the determination of the quantity of a dye in printing paste for achieving the required colour. to use the error back-propagation neural network method to interpolate the concentration of each dye to reproduce the target sample.
A. R. Khataee, M. Zarei, and M. Pourhassan	2009	An alkaline solution was identified as the desired pH condition for decolorization. However, the alkalinity ranges from weak alkaline to moderate alkaline and highly alkaline. Therefore, future research in this area should focus on optimizing the process using Fuzzy Logic methods.
R. Guruprasad and B. K. Behera	2010	The article mentioned various types of soft computing, ranging from Fiber classification to cotton color sorting, and from predicting yarn and fabric properties to optimizing products and processes. Future research will be ideal for their use in coloration prediction.
Y. Yadav and R. Singh	2010	It is crucial to continue researching and developing these advanced technologies to make them even more viable, with a particular emphasis on CO2 dyeing, especially for natural materials.
B. Kalav	2012	Future research should focus on the language selection for the expert system, it should be more user-friendly and easily updatable.
M. Nasiri, T. Fober, R. Senge, and E. Hullermeier	2013	The case study presented in this article is still of limited complexity. In future work, it is necessary to evaluate these methods on more complex modeling tasks using other hybrid systems to achieve higher precision.
M. Banchero	2013	Future investigations could involve the use of reactive dyes and swelling solvents to improve lightfastness, or heat-set textiles to enhance mechanical resistance, especially for natural materials.
S. Radhakrishnan	2013	Optimizing the bio-scouring process using fuzzy logic combined with response surface methodology provides new opportunities to enhance the precision and efficiency of this textile Fiber pre-treatment stage.
I. Hossain, A. Hossain, I. A. Choudhury, A. Bakar, and A. Shahid	2013	Further research should incorporate more input variables into the expert system to obtain more reasonable and accurate results. In addition, for better performance, hybrid models of Fuzzy logic and genetic algorithms should be tried
I. Hossain, A. Hossain, and I. A. Choudhury,	2015	By incorporating these research directions, the fuzzy expert system can be further developed as a valuable tool for optimizing the pre-bleaching and finishing processes of viscose and linen.
I. Hossain, A. Hossain, and I. A. Choudhury	2015	While the Taguchi method has proven effective, future research should explore the potenti al of comparing it with fuzzy logic expert systems for optimizing textile processes
I. Hossain, A. Hossain, I. A. Choudhury, and A. Al Mamun	2016	Future research should focus on troubleshooting the discrepancy between laboratory and workshop results, as the model has shown excellent predictive performance in laboratory-to-laboratory settings.
I. Hossain, I. A. Choudhury, A. Bin Mamat, A. Shahid, A. N. Khan, and A. Hossain	2016	A fuzzy model has been developed for predicting the mechanical properties, such as bursting strength, of viscose/Lycra plain knitted fabrics. Future research should focus on applying this model to non-plain knitted fabrics.
M. Kabbari, F. Fayala, A. Ghith, and N. Liouane,	2017	The model used has yielded promising results in explaining the relationship between different water-oil repellent characteristics. However, future research should focus on optimizing the use of these products and the process, while also considering their impact on the color of the articles.
N. T. Huynh and C. F. Chien	2018	Future research could explore the Application to other textile processes: investigating the applicability of MSGA-H to other textile processes, such as weaving, knitting, and finishing.
M. G. Tadesse *et al*	2019	Future Research Directions for ANFIS in Textiles: expanding data sets: by using more data sets, ANFIS models can be trained to handle a wider range of textile processes and materials. Integration with other AI techniques: combining ANFIS with other AI techniques, such as deep learning or reinforcement learning, can further enhance its capabilities.

A. N. M. A. Haque, S. A.	2018	Future research must more bleaching ingredients as Alkali concentration and H2O2 stabiliser
A. N. M. A. Haque, S. A.	2019	Combining fuzzy logic with artificial neural networks (ANNs), and evolutionary algorithms (EAs), to leverage their respective strengths and overcome their limitations.
C. Yu, Z. Xi, Y. Lu, K. Tao, and Z. Yi	2020	Further work should be done to assess the impact of using different colored dyes and incorporate additional environmental factors.
A. Haji and P. Payvandy	2020	Further research and development would be needed to adapt the process for industrial-scale implementation, ensuring its feasibility and cost-effectiveness.
J. Sarkar, M. S. Mondal, and E. Khalil	2020	The long-term effects on other fabric properties, such as strength, durability, and color fastness, should also be investigated
S. O. KASSIM, A. G. Ali, and I. M. Harram	2021	To enhance the accuracy and performance of the fuzzy logic controller (FLC), integrating advanced optimization algorithms, such as genetic algorithms or particle swarm optimization, can be explored.
K. Ulucan-Altuntas, F. Ilhan, C. Kasar, and M. T. Gonullu	2021	In future work, it is necessary to evaluate these methods on more complex modeling tasks using other hybrid systems to achieve higher precision.
A. Farooq, F. Irshad, R. Azeemi, M. Nadeem, and U. Nasir,	2021	Exploring the use of convolutional neural networks (CNNs) or recurrent neural networks (RNNs), to capture complex non-linear relationships between input variables and shade change.
H. Zhu	2022	This method can be used on various substrates and dye classes. For example, direct dyes, acid dyes, and other series of reactive dye
I. de Souza Costa, G. Cardoso de Oliveira Neto, and R. Rodrigues Leite	2021	Investigate how PPC can be aligned with circular economy principles, such as designing for disassembly, product remanufacturing, and closed-loop supply chains.
X. W. Yan Luo, Kun Song, Xuemei Ding	2021	Future research should be focused on creating a multi-dimensional approach and a hybrid evaluation system
A. Haji and M. Vadood,	2021	Optimize the dyeing parameters using advanced optimization techniques like metaheuristic algorithms (e.g., particle swarm optimization, simulated annealing) or machine learning algorithms.
A. Farooq, F. Irshad, R. Azeemi, and N. Iqbal	2021	Future research can be focused on the use of the color change after Thermofixation
M. S. Gulzar Alam, Ihsan, Mu. Naushad	2022	Future research on Hybrid model’s wastewater treatment can leverage the strengths of different AI approaches to achieve more accurate predictions and better overall performance.
J. Sarkar, N. M. Rifat, and A. Al Faruque	2022	Investigating the influence of other process variables like fabric tension, pre-treatment conditions, and post-treatment finishing could further refine the model’s accuracy and predictive power.
J. Sarkar, M. A. Al Faruque, and E. Khalil	2022	future research could explore the inclusion of other important parameters such as fabric thickness, fabric composition, laser power, engraving speed, and laser density.
M. Vadood and A. Haji	2022	Exploring the use-to-use other artificial intelligence methods, such as fuzzy logic and support vector machines, to predict the color coordinates and compare the outcome with the current results.
H. Ghanmi, N. Sebeia, M. Jabli, Y. O. Al-Ghamdi, and A. M. Algohary	2022	Investigating the dyeing behavior of Juglans Regia extract on other types of fabrics, such as cotton, silk, or blended fabrics. This can help determine the versatility of the natural dye and its compatibility with different textile materials.
A. Cournoyer and L. Bazinet	2023	Sustainable development technologies have demonstrated significant achievements in terms of eco-efficiency. Therefore, there is considerable interest in studying them to attempt the development of an eco-circular economy.
M. N. Pervez, W. S. Yeo, L. Lin, X. Xiong, V. Naddeo, and Y.	2023	Further studies are needed to determine whether incorporating another algorithm into the LSSVR model would enhance its prediction capability.
A. H. &Morteza Vadood	2023	Investigate the influence of additional process parameters such as pH, mordanting time, and dye bath ratio on the color strength and fastness properties of dyed cotton fabrics.

CONCLUSIONS

Research on applying artificial intelligence in dyeing and finishing highlights several key segments:

- Defect Detection: detecting various dyeing and finishing defects, including oil stains, dye stains, soiling, unevenness, holes, and snags.
- Quality Control: covering aspects like color, width, GSM (grammage), and uniformity.
- Process Optimization: focusing on precise decisions during production regarding parameters such as temperature, concentration, and time.
- Deep Shade Prediction: extensively studying AI for predicting deep shades, considering different dyes and textile materials.
- Mechanical Properties Prediction: investigating tensile strength and tear resistance using AI.
- Wastewater Treatment Optimization: identifying influential parameters and favorable conditions for dyeing wastewater treatment.
- Natural Dye Behavior Prediction: using AI to predict behavior with natural dyes.
- The combination of fuzzy logic, neural networks, and genetic algorithms enhances modeling, prediction, and optimization, improving enrichment processes.
- The outcomes achieved by applying fuzzy logic, neural networks, genetic algorithms, and their hybrids demonstrate their potential applicability to unexplored domains that have yet to be studied and experimented with, pushing the boundaries of their capabilities.

Here are the results:

- In the realm of inventory management for chemical and dye stores, the integration of fuzzy logic, neural networks, genetic algorithms, and their hybrids can facilitate decision-making regarding product quantity orders, optimal order timing, and determination of safety stock levels.
- In the context of pre-treatments for textile materials in the printing industry.
- When aiming to enhance machine performance, fuzzy logic can be effectively employed.
- Regarding the prediction of fabric characteristics, the ability to forecast or estimate specific fabric properties or performance before dyeing or finishing processes.
- Machine maintenance can benefit from the utilization of fuzzy logic and neural networks for decision-making pertaining to maintenance planning, fault detection, prediction of component lifespan, and more. Fuzzy logic and neural networks can consider difficult-to-quantify parameters such as performance variations, environmental conditions, historical data, and other aspects that have yet to be explored in previous studies.

To summarize, the results obtained from implementing fuzzy logic and neural networks exemplify their adaptability and effectiveness across various sectors. From inventory control to enhancing machine performance, anticipating fabric attributes, technological process, fuzzy logic and neural networks provide solutions that address both uncertainty and variability. Moreover, the potential for applying fuzzy logic and neural networks to unexplored domains paves the way for new research prospects and practical applications across a multitude of fields.

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