Journal of Applied Research and Technology

www.jart.icat.unam.mx

Journal of Applied Research and Technology 24 (2026) 585-597

Original

From Structure to Feel: Statistical Modeling Using SPSS to Perform Some Textile Compositions of Flame Retardant Fabrics

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Received: 26 09 2025; Accepted: 13 11 2025
Available: 31 08 2026

Abstract: Studying the performance of fabric compositions of flame-retardant-treated fabrics is gaining increasing scientific and practical importance, especially in the fields of safety and personal protection. This research focuses on analyzing the mechanical and sensory properties of flame-retardant-treated (2/1, 3/1) and warp-stretch (2/2) fabrics, and correlating these properties using SPSS statistical analysis to understand the relationship between the structural variables of the fabric composition and the functional performance of the treated fabric. The research aims to present a quantitative predictive model that helps improve the design of protective fabrics while evaluating the changes in properties after treatment based on objective sensory analysis.

The results showed that the warp-stretch fabrics (2/2) generally showed greater flame resistance and were the best among the composites in tensile, stiffness, and tear properties (mechanically), while the filbert fabrics showed lower flame resistance, especially the filbert (1/3) with improved crease resistance after treatment (physical), while air permeability was not significantly affected by treatment. The sensory analysis results also showed variations in some sensory properties of the treated samples, especially those measured using fingertips (warmth, thickness, and drape), while the averages of the remaining properties were relatively common to all treated samples. Statistical correlation using SPSS also showed that mechanical properties can be predicted based on sensory analysis, as a strong significant correlation was observed for the test properties: stiffness, wrinkling, tensile strength, and friction resistance, with 14 sensory

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Peer Review under the responsibility of Universidad Nacional Autónoma de México.

properties measured based on human hand sensation, with a (Pearson >0.92) and a statistical significance level of (P≤0.1* ‘P≤0.05**). The study successfully predicted some physical and mechanical properties of fabrics, while also shortening the testing step on measuring devices by determining the corresponding sensory properties according to the fabric texture based on tactile sensation.

Keywords: **Flame resistance, textile structure, sensory analysis, final processing, Pearson coefficient, SPSS.**

1. Introduction

A fabric consists of two sets of threads interlaced at right angles. The first set is called the warp thread, and the other is called the edge thread. The warp thread extends lengthwise to the machine, while the edge thread extends transversely to the fabric. The machine interlocks the warp and edge threads in different ways, causing changes in the warp and edge coverage. This difference in interlacing creates what is called a “fabric structure” (Mamdouh et al., 2022). Plain weave is the most common and widely used fabric, with 80% of woven fabrics made using the plain weave method. This is due to its ease of manufacture, speed of production, and low cost. There are many derivatives of plain, including “extended toward the warp,” “extended toward the edge,” and “extended toward both the warp and edge” (hopscotch fabrics) (Muhyiddin, 2009).

Twill is the second most commonly used type of fabric structure and is generally characterized by the presence of oblique stripes at different angles. Twill fabric is usually more cohesive and durable than plain fabric (Muhyiddin, 2009), (see Figure 1).

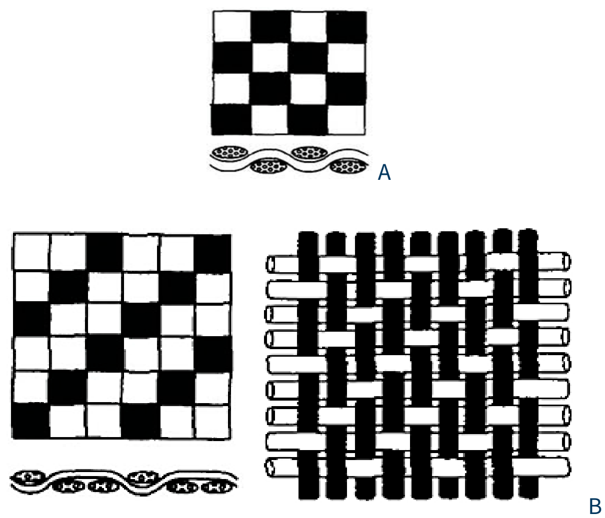


Figure 1. Some fabric structures, (A) plain, (B) quilted (Muhyiddin, 2009).

Final treatments constitute a very broad and important field in textile engineering. The process of finishing a fabric adds value or enhances its functionality and effectiveness. The final treatment of textiles aims to make the fabric more attractive, more comfortable to use, as wrinkle-free as possible, and more resistant to various factors such as washing, wringing, friction, various weather conditions, etc. Treatments are of two types: mechanical and chemical (Lutfor Rahman & Tumpa, 2023).

The final processing of textiles depends on several factors, the most important of which are: the quality of the fibers and their arrangement in the yarns, the quality of the fabric structure, and the physical properties of the fabric (Wiam, 2021). Fabric preparation processes are also carried out before final processing, where waxes and oils on the surfaces of the fibers, especially cellulosic ones, must be removed to ensure good absorbency (Ziad, 2017).

Textiles are an essential part of daily life and must therefore be used as a means of protecting humans from these hazards, such as treating fabrics against fire, moisture, static electricity, and wrinkling (Ahed, 2019).

The final chemical treatment of textiles provides important performance properties in flame resistance, protecting consumers, especially firefighters and emergency personnel who need protection from fires while performing their duties. Combustion is an exothermic reaction and a process that requires three components: heat, oxygen, and the appropriate fuel. When a fire is left unchecked, combustion becomes self-catalyzed and will continue until the oxygen, fuel supply, or excess heat is exhausted, as shown in Figure 2 (Dechant, 1985).

The most important commercial flame retardants can be classified into three categories: primary flame retardants based on phosphorus, halogens (Ehrler & Schmeer-Lioe 1991), synergistic enhancers which have small flame retardant effects on their own, and also significantly enhance primary flame retardants (nitrogen-based flame retardants with phosphorus and antimony-based flame retardants with halogens), and auxiliary flame retardants which exhibit their activity through physical effects (borates, alumina trihydrate, calcium carbonate) (Mahall, 1972).

Inorganic salts can provide excellent flame-retardant properties to cellulose, along with its wash stability. Therefore, treatment should be incorporated into any finishing stage intended for garment use. The most successful permanent flame retardants for cellulose are based on chemical systems containing phosphorus and nitrogen, which can react with the fibers and form cross-linked structures on them. One such finishing treatment consists of tetrahydroxymethylphosphonium chloride (THPC), which is made from phosphine, formaldehyde, and hydrochloric acid. THPC reacts with urea to form an insoluble structure on cellulose during the drying process, (see Figure 3) (Ehrler & Schmeer-Lioe 1991).

The properties of fabrics are greatly influenced by many structural variables, starting with the type of raw material, the number and density of the threads, as well as the weaving structure and operating conditions of each type of woven fabric.

The most important properties of fabrics are: tensile strength and elongation, draping tear strength, wrinkling, air permeability, weight per square meter, thickness, and friction (Collier & Epps, 1999).

The texture of fabrics is defined as the quality of the fabric or threads evaluated through the effect obtained from the sense of touch (Bishop, 1996).

Sensory analysis has evolved from being a mere sensory testing method to a study in itself to reveal people's tendencies and desires for a particular product and to meet all requirements. This helps textile companies build advanced marketing plans that cater to all opinions and tastes (Ragot, 1997). The concept of hand touch is directly related to such qualities that express a fabric sample: brittle, dry, flexible, thin, grainy, rough, smooth, papery, cold, warm, oily surface, thick (Bishop, 1996).

There are three main methods for conducting sensory analysis of products. These methods are sensory tests that can be applied according to the information sought for the product: discriminative, temperamental, and descriptive tests. One of the methods used in descriptive

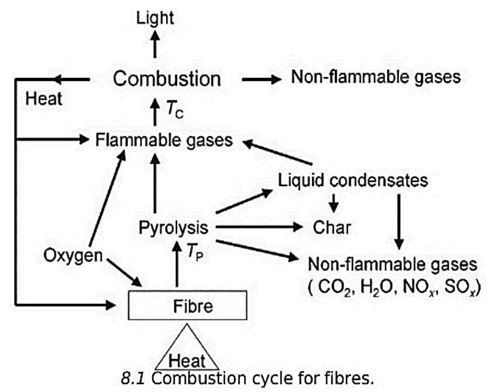


Figure 2. Fiber combustion cycle (Dechant, 1985).

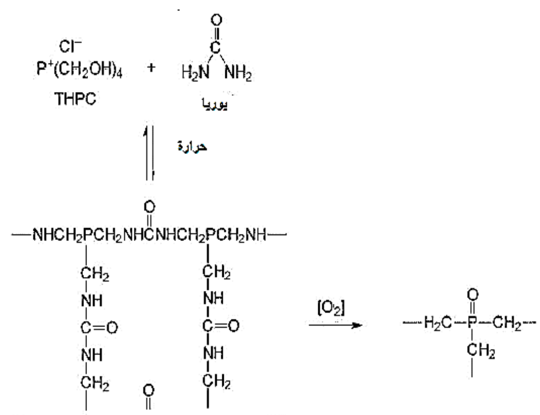


Figure 3. Interaction of THPC with urea (Ehrler & Schmeer-Lioe 1991).

sensory analysis is the quantitative descriptive method, which allows for a complete sensory description of products (such as texture, appearance, consistency, and smell) using expressive descriptive words by a trained jury. According to this method, the sensory difference between products is indicated and the amount of this difference is determined quantitatively, allowing for an accurate, objective sensory evaluation that compares the differences between the sensory specifications of several products (Civille et al., 2024; ISO, N. 1995). The protocol used to apply the quantitative descriptive method in sensory analysis can be implemented through the following steps, as specified in the international standard ISO NF 11035. This includes selecting the evaluation committee, selecting the sensory vocabulary, and training and monitoring the committee (ISO, 2023).

Nawaz et al. (2011) studied the changes in the surface properties of fabrics used in firefighter protective clothing due to flame-retardant treatment. They found that the initial MIU was lower than the wet state, while the SMD was lower than the wet state for samples of 100% wool, 100% cotton, and 100% polyester, and higher for the remaining samples (Nawaz et al., 2011). Tang et al. (2017) studied the flammability, comfort, and mechanical properties of plant-structured fabrics and found that treatment with inhibitors had adverse effects on comfort and mechanical properties (Tang et al., 2017). In 2022, Yu Chen and Ying Liao studied the use of final flame-retardant treatments using phosphorus-based reactions. The results showed good washing stability, thermal stability, and combustion behavior for cotton, evaluated using thermogravimetry (TG), which measures the mass of a sample while it is heated or cooled (Chen et al., 2022).

SPSS

IBM's SPSS statistical analysis software offers advanced statistical analysis, an extensive library of machine learning and text analysis algorithms, open-source scalability, integration with big data, and seamless deployment into applications. SPSS stands for Statistical Package for Social Sciences. SPSS provides many graphs that best illustrate results. These graphs can be used in research papers to present the results of a study.

A set of instructions is followed to arrive at a correlation coefficient between these results, as follows (DeCoster & Claypool, 2004):

correlate → private → Analyze

Despite extensive research, there is still a gap in understanding the relationship between the fabric composition of the treated material and its mechanical and sensory properties. Flame-retardant treatment often leads to undesirable changes in material properties, particularly durability and wear comfort. Hence, the need to develop predictive models that allow fabric designers to predict final fabric performance based on measurable variables. This research presents a methodology for using multiple regression analysis to analyze fabric data using SPSS, which can subsequently be provided to textile manufacturers to enable them to select the optimal composition to achieve a balance between properties and usage.

2. Materials and Methods

2.1. Materials

This research was conducted on raw cotton fabrics using 4% sodium hydroxide and 8% hydrogen peroxide bleaching agents, flame-retardant treatment media. The proportions of these agents are shown in Table 1.

Table 1. proportions of materials used to retard flame.

Phosphorus acid	Urea gr/l	Trichloroacetic acid gr/l	Basin ratio
14 ml/ 100 ml H_2O	50	50	1:124

2.2. Equipment

The laboratory equipment used in the research is listed in Table 2 along with their technical and standard specifications.

Table 2. Technical specifications of laboratory equipment.

Device	Model / manufacturing	Testing standard
Drying oven	SDL International	-
Foulard device	"Local manufacturing"	-
Tear testing device		BS 4303-199
Friction resistance measuring device	Martindale	ASTM D4966-98
Air permeability measuring device	"Local manufacturing"	ASTM D737
Tensile strength measuring device	Tinius Olsen H50KS	ASTM D5034-2001
Crease angle measuring device		AATCC 128
Fabric thickness measuring device	Maesdan	ASTM-D1777

3. Sample Analysis and Processing

The studied cotton fabrics with cooled and plain weave structures were analyzed, and their specifications were determined in Table 3.

The sample preparation process involved bleaching the raw cotton fabric and removing the starch simultaneously to remove impurities and the starch applied during the starching process. The sample was also increased in hydrophilicity and water affinity using sodium hydroxide 4%, hydrogenated water 8%, and a few drops of hydrogenated water stabilizer, at a bath ratio of 1:20. The water bath temperature was raised to 100 °C, and the preparation process continued at a boiling point for an hour. The samples were then rinsed and adjusted with acetic acid, then rinsed with plain water and dried at laboratory temperature.

Table 3. Specifications of the fabric samples used.

Sample number	1	2	3
Fabric composition	refrigerant 1/3	Warp-stretch 2/2	refrigerant 1/2
Nature of raw material		Cotton 100%	
Square meter weight	269	358	258
Warp density	30	28	36
Weft density	16	13	18
Warp number	12	7	16
Weft number	12	7	12
Yarn type		Rotary	

Flame-resistant treatment

The treatment medium was prepared by taking 100 ml of distilled water, adding 5 g of trichloroanthomone, adding 5 g of urea, and then 14 ml of phosphoric acid, while heating until completely dissolved, making sure to cover the sample. After removing the samples from the basin, they were squeezed using a Volar device to remove the excess solution, then dried in a drying oven at a temperature of 80 °C and aged at 100 °C degrees for five minutes.

Flame resistance properties were determined according to the Sanders test. The test was carried out by bringing a flame close to a test sample measuring (103.5) inches, suspended vertically, for three seconds. The sample was considered to have passed the test if the average combustion length, when melting or burning, did not exceed 17.5 cm, no sample burned along its entire length, and the secondary combustion time (RFT) for each individual sample did not exceed 10 seconds (Mamdouh et al., 2022; Muhyiddin, 2009).

The treated samples were subjected to air permeability, thickness, tensile tear hardness, wrinkling, friction, and weight per square meter tests, according to the standard specifications mentioned in Table 2.

4. Results

4.1. Physical and Mechanical Tests

Figure 4 clearly shows the superiority of the warp-stretch (2/2) construction in flame resistance compared to twill fabrics. The nature of the warp construction contributes to the improved flame resistance property of the fabrics.

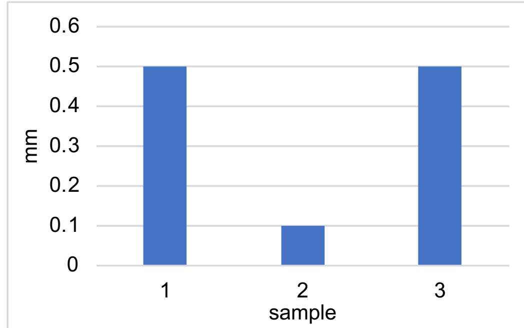


Figure 4. Flame test results.

It is noted from Figure 5-A that the air permeability decreased in the flame-resistant treated samples compared to the reference samples. This is due to the placement of the particles of the materials that make up the solution within the spaces between the fabric and on the surface of the fibers, which led to a decrease in air permeability. The air permeability varied according to the density of the fabric, and was lower for the denser fabric. The first sample was more permeable than the third sample. The permeability of the plain fabric, the second sample, was less compared to the rest of the samples, due to its high absorbency.

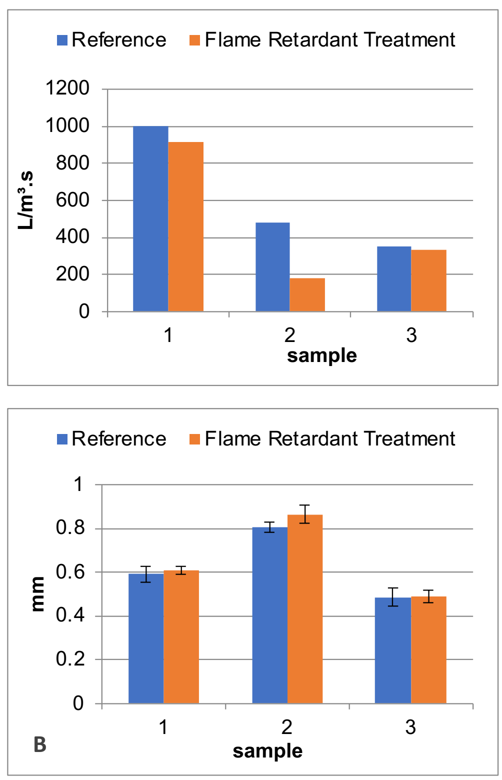


Figure 5. Results of tests: A) air permeability; B) thickness.

It is noted from Figure 5-B that the thickness of the flame-retardant-treated samples increased compared to the reference samples. This is due to the deposition of the flame-retardant treatment solution components on the surface, which then slightly increased the thickness of the fabric. The thickness of the samples also varied according to the thread number, weight per square meter, and type of threads used. The second sample, with a plain weave construction, was thicker than the samples with a cooled weave construction. This increase remains insignificant given the standard deviation.

Figure 6-A shows an increase in the stiffness of the flame-retardant-treated fabrics compared to the reference fabric. This is due to the increased weight of the flame-retardant-treated samples, as the weight of the samples increased with the increase in their absorption rate and density. The weight of the first sample increased more than the third sample, and thus its stiffness increased significantly, while the second sample was stiffer than the rest of the samples.

It is noted from Figure 6-B that the tear strength of the flame-resistant treated fabric decreased compared to the reference fabric. This is due to the decreased durability of the fabric and the weakening of the fiber structure due to the use of phosphoric acid as one of the components of the flame-resistant treated solution. The fabrics varied in tear strength value according to the density and number of threads. The third sample required a greater tear strength than the first sample due to its higher density, while the second sample required a greater tear strength than the rest of the treated samples due to the thicker number of threads.

It is noted from Figure 7-A that the tensile strength of the flame-treated fabric decreased compared to the reference fabric. This is due to the weakening of the fabric structure for the same reasons as the low tear strength, namely the presence of phosphoric acid, and thus the reduced tear strength resulting from tension.

It is also noted from Figure 7-B that the crease recovery angle of the flame-treated fabric increased compared to the reference samples. This is due to the flame solution treatment process improving the crease-resistant properties due to the bonding of the solution components, such as urea, with the hydroxyl groups in cellulose and reducing the hydrogen bonds that cause creases. The third, denser sample had less crease compared to the first sample, and the second sample had more creases compared to the rest of the samples due to the thickness of its threads and the increased weight.

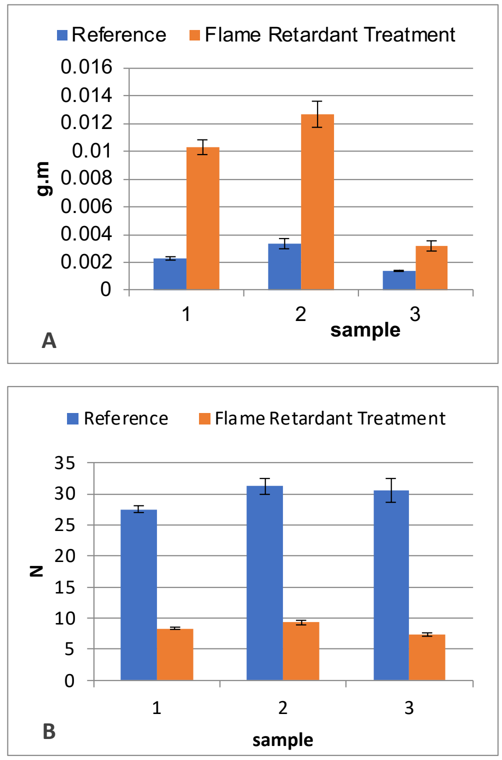


Figure 6. Results of tests: A) hardness; B) tear strength.

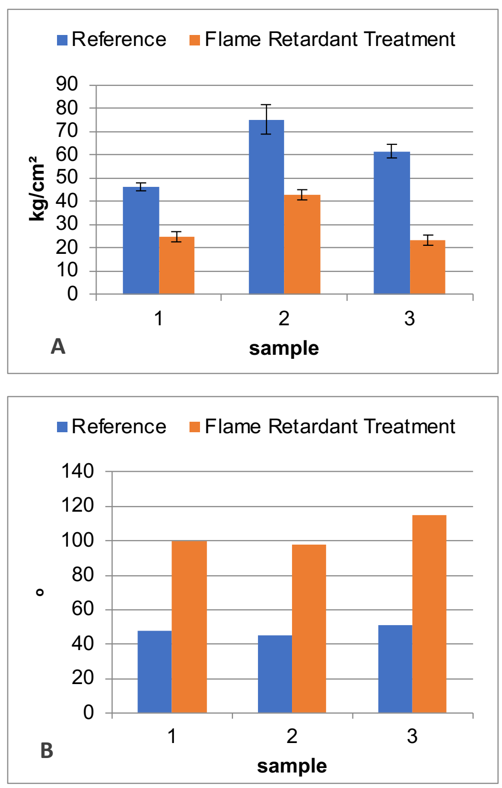
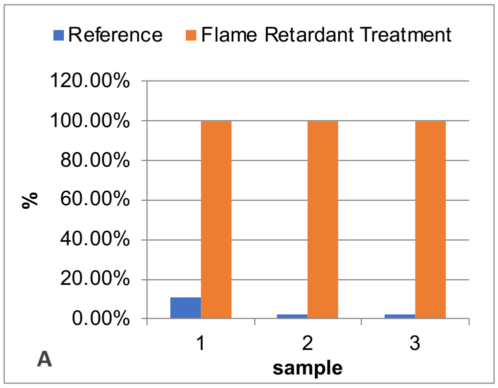


Figure 7. Results of tests: A) tensile strength; B) wrinkle.

Regarding friction Figure 8-A, it was observed that most of the flame-treated samples were worn compared to the reference samples due to damage to the cotton fibers using phosphoric acid, so they were easily worn as a result of friction. Most of the samples did not wear out at a number of (100) cycles, and most of them wore out at a number of (200) cycles, with the exception of sample (2), which began to wear out at (300) cycles due to the thickness of its threads and its high density.

It was also noted that the weight of the flame-treated samples increased compared to the reference samples (ASTM D3776-96), as the weights of the samples increased after treatment. This is because the treatment principle is based on loading the treatment solution onto the fabric, as shown in Figure 8-B.



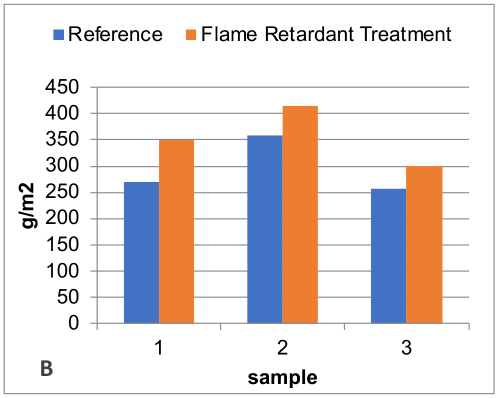


Figure 8. Results of tests: A) friction (loss by weight), B) weight per square meter.

4.2. Sensory Analysis

Selecting the Sensory Evaluation Committee and Determining the Vocabulary

A descriptive quantitative analysis protocol was adopted by selecting a committee of 10 to 12 people. A tactile sensory evaluation committee was selected from a group of trainee engineers in the Textile Engineering Department.

In this study, the evaluation committee was selected, consisting of 10 engineers from the Textile Engineering Department at the University of Homs. They have extensive experience in evaluating fabrics, having participated in numerous research projects in this field.

Based on the selection of objective descriptive words that reflect the true quality of the fabric, a list of (15) sensory vocabulary specifications was used in previous studies and previously used by the evaluation team in the Textile Engineering Department at the University of Homs to characterize textiles. The list of sensory vocabulary is explained as follows:

General vocabulary for describing fabric using fingertips:

- Cold-warm
- Thin-thick
- Light-heavy
- Supple-rigid
- Falling-nonfalling

Specifications for the surface structure of the fabric to characterize the fabric using the thumb and index finger:

- Sticky-nonsticky
- Slippery-nonslippery
- Soft-nonsoft
- Granules-nongranules
- Greasy-nongreasy
- Hairiness-nonhairiness
- Raised-nonraised

Full hand specification:

- Elastic-nonelastic
- Responsive-nonresponsive
- Crumple-like

The committee used an ungraded evaluation scale (0-10).

Sensory evaluation and results

The samples were presented to the selected committee, and each participant was asked to run their fingers over the fabric or feel it with their entire hand, based on the sensory specifications to be evaluated, as mentioned above. They held the edge of the fabric between their forefinger and thumb and rubbed it first widthwise, then lengthwise, then in a circular motion. Each time they touched the fabric, they asked themselves about its drapeability, flexibility, warmth, softness, smoothness, and other previously selected characteristics.

Fabric samples were prepared, measuring 20 x 20 cm, and given to the team members one by one in random order. Prior to testing, the samples were kept under standard conditions of temperature 20 and humidity 65 for at least 24 hours. The tests were conducted in a room where the temperature and humidity were constant. Before evaluation, the team members' hands were washed and dried to avoid deviations that may occur as a result of using cosmetics and other products on their hands.

Each evaluation session (two sessions) lasted 30 minutes, because the hands become less sensitive if the test is too long. The evaluation was conducted in a box prepared for sensory analysis, as shown in Figure 9, so that members of the evaluation committee could not see the samples.

The committee members were trained to measure the quantification of each item to ensure consistency in evaluation. The arithmetic mean value was then calculated for each sensory item. After verifying the repeatability test and ensuring the committee members' readiness to conduct the test, the sensory evaluations of the different samples were compared. Figure 10 shows the results of the sensory analysis of the samples.

It is noted from Figure 10-A that the flame-treated sample was thicker, heavier, and rigider.

It was more non-falling than the reference sample. The flame-resistant treatment did not affect the slipperiness, sticky, softness, and non-greasy texture properties, which were similar to those of the reference samples. The treated and untreated samples also exhibited a non-hairiness and non-raised surface. The treated samples were also less elastic, more responsive, and crumble.

It is noted from Figure 10-B that the second sample exhibited similar properties between the treated and untreated samples in terms of thickness, heaviness, rigidity, sticky, slipperiness, elastic, responsive, and like. The treated sample was also colder, non-falling, and more non-hairiness than the reference samples, and had a softer, non-raised surface While the treated and untreated samples exhibited the same properties in Figure 10-C, they were cold, thin, light, supple, non-sticky, non-hairiness, non-elastic, and non-responsive. The treated samples were more falling, non-slippery, less soft, non-granules, had a non-raised surface, and like more quickly compared to the untreated samples.

The results of the sensory analysis also showed that some sensory properties differed according to the tissue composition of the treated samples, especially those measured using fingertips, while the averages of the remaining properties were relatively similar for all treated samples compared to the reference samples, as in Table 4.

Figure 9. Touch sample analysis procedure box.

Table 4. Sensory properties with values common to treated samples.

Reference	Flame Retardant Treatment
Sticky-Nonsticky	√
Slippery-Nonslippery	√
Soft-Nonsoft	√
Granules-Nongranules	√
Greasy-Nongreasy	√
Hairiness-Nonhairiness	√
Raised-Nonraised	√
Elastic-Nonelastic	√

4.3. Statistical Analysis Using SPSS: Function Correlation Coefficient

By conducting a careful statistical analysis of the results of the physical and mechanical tests with the results of the sensory analysis using SPSS, and including the correlation coefficient values between the sensory properties and the previous physical and mechanical properties of the first sample (reference), it was found that the hardness value is related to the sensory properties (Light-Heavy, Supple-Rigid, Falling-Nonfalling, Raised-Nonraised), the wrinkle recovery angle values are related to the following sensory properties (Light-Heavy, Falling-Nonfalling), the tensile strength value is related to the following sensory properties (Cold-Warm, Light-Heavy, Supple-Rigid, Falling-Nonfalling, Sticky-Nonsticky, Granules-Nongranules, Hairiness-Nonhairiness, Raised-Nonraised), and the weight loss value due to friction is related to the following sensory properties (Light-Heavy, Falling-Nonfalling, Granules-Nongranules, Raised-Nonraised, Elastic-Nonelastic). This is according to the Pearson correlation coefficients shown in Table 5. Similarly, the results of the remaining samples were analyzed, and the correlation coefficients between the physical and mechanical properties and the sensory properties that gave the best correlation were included, and they were listed in Tables 6-10.

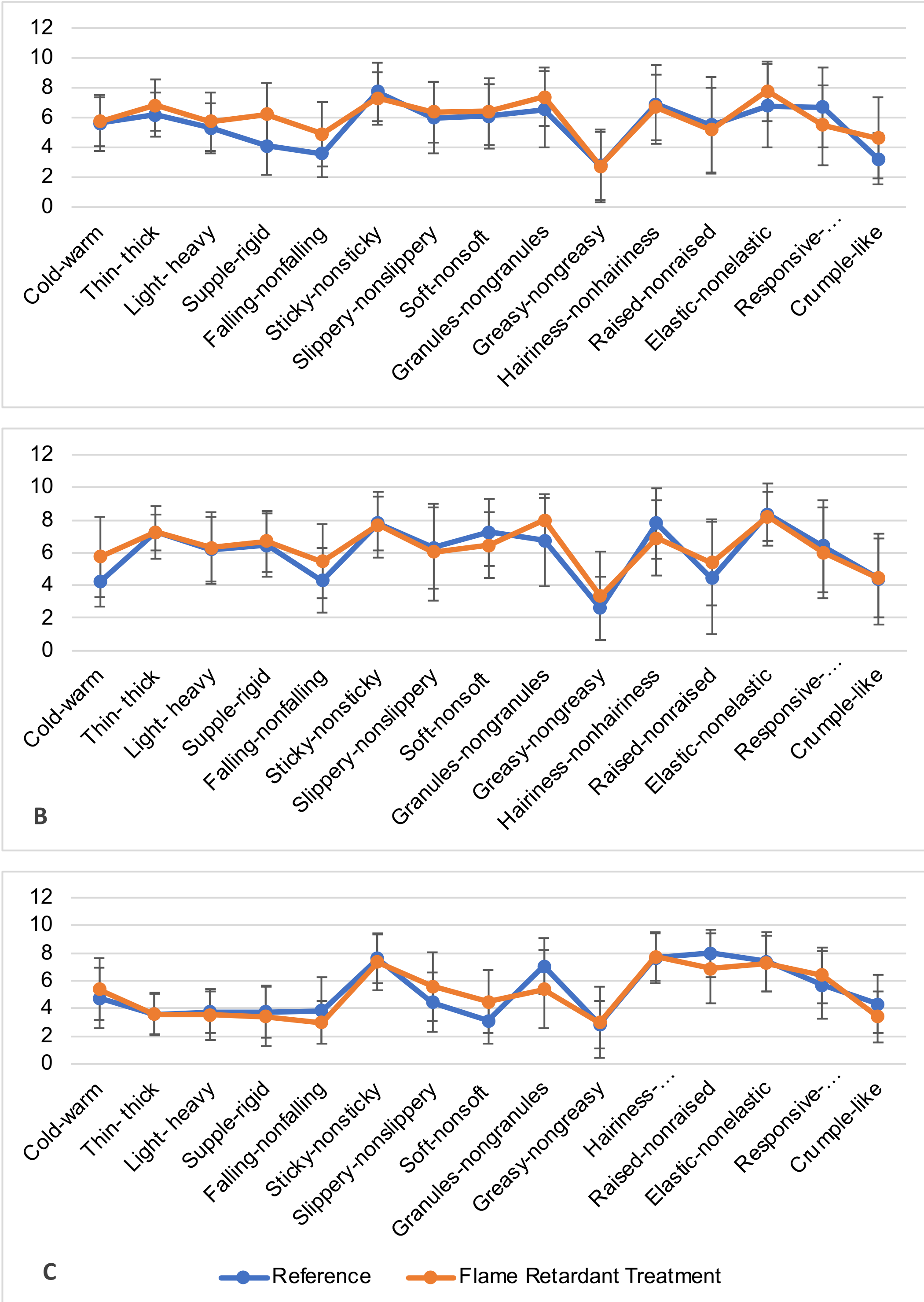


Figure 10. Sensory analysis results for the reference and treated sample:
A) refrigerant 1/3, B) Warp-stretch 2/2, C) refrigerant 1/2.

Table 5. Results of the correlation between sensory analysis and physical and mechanical properties of the first reference sample (refrigerant 1/3).

Sensory properties	Mechanical properties				Physical properties			
	Weight loss (friction)		Tensile strength		Crease recovery angle		Hardness	
	Sig	Pearson correlation	Sig	Pearson correlation	Sig	Pearson correlation	Sig	Pearson correlation
Cold-Warm			0.045	0.990				
Light-Heavy	0.062	0.877	0.061	0.982	0.076	0.849	0.106	0.945
Supple-Rigid			0.045	0.990			0.002	0.999
Falling-Nonfalling	0.023	0.954	0.032	0.995	0.097	0.805	0.077	0.971
Sticky-Nonsticky			0.061	0.982				
Granules-Nongranules	0.002	0.996	0.045	0.990				
Hairiness-Nonhairiness			0.095	0.956				
Raised-Nonraised	0.020	0.960	0.022	0.998			0.068	0.977
Elastic-Nonelastic	0.081	0.837						

Table 6. Results of the correlation between sensory analysis and physical and mechanical properties of the first flame-treated sample (refrigerant 1/3).

Sensory properties	Mechanical properties				Physical properties			
	Weight loss (friction)		Tensile strength		Crease recovery angle		Hardness	
	Sig	Pearson correlation	Sig	Pearson correlation	Sig	Pearson correlation	Sig	Pearson correlation
Cold-Warm			0.075	0.972				
Thin-Thick							0.003	1
Falling-Nonfalling	0.082	0.837			0.05	0.90	0.003	0.998
Slippery-Nonslippery	0.02	0.996						
Raised-Nonraised					0.072	0.857		
Elastic-Nonelastic			0.091	0.959				
Responsive-Nonresponsive					0.08	0.84	0.003	0.997
Crumple-Like					0.022	0.957	0.109	0.942

Table 7. Results of the correlation between sensory analysis and physical and mechanical properties of the second reference sample (Warp-stretch 2/2).

Sensory properties	Mechanical properties				Physical properties			
	Weight loss (friction)		Tensile strength		Crease recovery angle		Hardness	
	Sig	Pearson correlation	Sig	Pearson correlation	Sig	Pearson correlation	Sig	Pearson correlation
Light-Heavy			0.09	0.99	0.053	0.947	0.011	0.990
Sticky-Nonsticky					0.1	0.9		
Slippery-Nonslippery							0.057	0.996
Soft-Nonsoft			0.033	0.999			0.057	0.966
Raised-Nonraised			0.049	0.997	0.003	0.997		
Crumple-Like	0.078	0.922						

Table 8. Results of the correlation between sensory analysis and physical and mechanical properties of the second flame-treated sample (Warp-stretch 2/2).

Sensory properties	Mechanical properties				Physical properties			
	Weight loss (friction)		Tensile strength		Crease recovery angle		Hardness	
	Sig	Pearson correlation	Sig	Pearson correlation	Sig	Pearson correlation	Sig	Pearson correlation
Thin-Thick	0.066	0.867			0.027	0.947	0.057	0.984
Supple-Rigid	0.035	0.929						
Falling-Nonfalling			0.028	0.996	0.014	0.973		
Slippery-Nonslippery			0.049	0.988				
Soft-Nonsoft			0.028	0.996	0.005	0.990		
Greasy-Nongreasy							0.03	0.995
Responsive-Nonresponsive	0.044	0.911						
Crumple-Like	0.064	0.873						

Table 9. Results of the correlation between sensory analysis and physical and mechanical properties of the third reference sample (refrigerant 1/2).

Sensory properties	Mechanical properties				Physical properties			
	Weight loss (friction)		Tensile strength		Crease recovery angle		Hardness	
	Sig	Pearson correlation	Sig	Pearson correlation	Sig	Pearson correlation	Sig	Pearson correlation
Supple-Rigid	0.03	0.987	0.007	0.995	0.02	0.993	0.01	0.990
Sticky-Nonsticky	0.092	0.817						
Granules-Nongranules	0.04	0.986						
Hairiness-Nonhairiness	0.036	0.927						
Raised-Nonraised	0.092	0.817						
Responsive-Nonresponsive	0.029	0.943						
Crumple-Like	0.037	0.926			0.064	0.871		

Table 10. Results of the correlation between sensory analysis and physical and mechanical properties of the third flame-treated sample (refrigerant 1/2).

Sensory properties	Mechanical properties				Physical properties			
	Weight loss (friction)		Tensile strength		Crease recovery angle		Hardness	
	Sig	Pearson correlation	Sig	Pearson correlation	Sig	Pearson correlation	Sig	Pearson correlation
Cold-Warm							0.1	0.95
Thin-Thick			0.089	0.961				
Light-Heavy			0.061	0.982				
Supple-Rigid			0.061	0.982	0.039	0.921		
Falling-Nonfalling			0.003	0.996			0.02	0.990
Slippery-Nonslippery	0.087	0.827						
Granules-Nongranules							0.1	0.95
Raised-Nonraised	0.071	0.857			0.073	0.854	0.066	0.979
Responsive-Nonresponsive	0.036	0.927						

Based on the previous tables, it was noted that (hardness, wrinkle resistance, tensile strength, and friction) resistance were clearly related in most samples to a group of studied sensory properties that were listed in Table 11.

Table 11. Results of statistical analysis according to SPSS, (P≤0.1* ʻP≤0.05**).

Physical and Mechanical Properties	Common Properties	Evaluation
Hardness	Falling-Nonfalling	**
	Thin-Thick	**
	Supple-Rigid	**
	Light-Heavy	**
Crease recovery angle	Light-Heavy	*
	Falling-Nonfalling	**
	Raised-Nonraised	*
	Supple-Rigid	**
	Crumple-Like	**
Tensile strength	Light-Heavy	*
	Cold-Warm	**
	Falling-Nonfalling	**
	Supple-Rigid	**
	Raised-Nonraised	**
	Soft-Nonsoft	**
Weight loss (friction)	Slippery-Nonslippery	**
	Falling-Nonfalling	**
	Raised-Nonraised	**
	Responsive-Nonresponsive	**
	Crumple-Like	*

Conclusion

Final flame-retardant treatments were successfully performed on a group of fabrics with different textures. Their mechanical and sensory properties after treatment were studied, compared to reference samples, and statistically evaluated. All treated samples demonstrated flame resistance, with the lowest burning length being observed for sample 2 (plain warp-stretched 2/2). Regarding the physical and mechanical properties, a decrease in air permeability was observed, with the lowest value being found in the samples with warp-stretched 2/2. This was due to the penetration of the solution into the voids of the plain weave due to its high absorbency compared to the coolant. However, this decrease was not significant. The thickness and weight per square meter increased slightly, and a significant increase in the stiffness of the fabrics was observed as a result of the treatment, along with a substantial improvement in wrinkle resistance. Nevertheless, the tear strength, tensile strength, and abrasion resistance decreased significantly due to the use of phosphoric acid in the treatment, which negatively affected the fabric properties. Therefore, it can be said that the flame-retardant treatment process was successful in improving the flame-retardant and physical properties of the fabrics, while it significantly affected the mechanical properties.

The concept of comfort was studied by examining the sensory properties of treated fabrics and evaluating the fabric's texture. This was achieved by applying sensory analysis (quantitative and descriptive analysis) by a committee of 10 textile engineers. The results showed differences in some sensory properties of the treated samples, especially those measured using fingertips, while the averages of the remaining properties were relatively common for all treated samples.

A statistical analysis study was conducted using SPSS to link the results of the physical and mechanical tests of the treated fabrics with the results of the sensory analysis of the sensory properties. Accordingly, it was observed that (stiffness - resistance to wrinkling - tensile strength - friction resistance) in most samples clearly correlated with a group of the studied sensory properties. Therefore, it can be said that some of the physical and mechanical properties of fabrics can be determined without testing them on devices by determining their sensory properties according to the texture of the fabric, relying on the senses.

Acknowledgment

The authors would like to express their gratitude to the Department of Textile Engineering, Petroleum and Chemical Engineering Faculty of Homs University for their valuable assistance.

Funding

The authors received no specific funding for this work.

Conflict of Interest

The authors declare that they have no conflicts of interest to disclose.

References

Ahed A., A Study of Adding a Water-Resistant Property to Fabrics and Its Effect on Fabric Properties with the Possibility of Integrating It with Other Finishing Treatments, PhD Thesis, Al-Baath University, Homs, Syria, (2019).

Bishop, D. P. (1996). Fabrics: sensory and mechanical properties. *Textile Progress*, *26*(3), 1-62.
https://doi.org/10.1080/00405169608688866

Chen, Y., Liao, Y., Zhang, G., & Zhang, F. (2022). Durable flame-retardant finishing of cotton with a reactive phosphorus-based environmental flame retardant. *Journal of Natural Fibers*, *19*(16), 15128-15138.
https://doi.org/10.1080/15440478.2022.2070327

Civille, G. V., Carr, B. T., & Osdoba, K. E. (2024). *Sensory Evaluation Techniques, CRC Press*.

Collier, B. J., & Epps, H. H. (1999). Textile testing and analysis. *(No Title)*.
https://cir.nii.ac.jp/crid/1970023484972677153

Dechant, J. (1985). Handbook of fiber science and technology. Vol. II. Chemical processing of fibers and fabrics. Functional finishes: Part B. Hg. von Menachem Lewin und Stephen B. Sello. New York/Basel: Marcel Dekker, Inc. 1984. ISBN 0-8247-7118-4. XX, 515 S., geb. SFr. 283.–. *Acta Polymerica*, *36*(4), 242-242.
https://doi.org/10.1002/actp.1985.010360419

DeCoster, J., & Claypool, H. (2004). Data analysis in SPSS.
https://d1wqtxts1xzle7.cloudfront.net/46681601/Data_Analysis_in_SPSS_2005_09-21-libre.pdf?1466530026=&response-content-disposition=inline%3B+filename%3DData_analysis_in_SPSS.pdf&Expires=1786485923&Signature=M5ac0eNf7OBBRJZb9LGDv2EtAeYqtpVjgwssJMnoK-bOQzTUMUcVeo03BUhDicKHWPDgbK9AYmIv0j3P5y-geFMMof72ff8gSXJVxZojJgRZ4KKOBl7pC6fWqeGtYHohp-WMIug8LSw-xV3FxcAeqIf26QTuV5d1tNo0UW4zXpIBx-n4loqIhaLsa4Eh-mpRkg6XTaWnqB3h1z-6whjGzmtWx-Uxd1AqAbt28q8FKM0I1E9nKCzeYVZh~JSukr8KA1-6cU-w46WCuyf80m6MZYmEFTlUWj0Pp99jHnjq9B-KpI-Wd-h~HJh1fY~cKA~8B4RmIpjYXCLYHVYEC5MIY0Jt3fo-6Q__&Key-Pair-Id=APKAJLOHF5GGSLRBV4ZA

Ehrler, P., & Schmeer-Lioe, G. (1991). Das elektrostatische Verhalten als funktionale Eigenschaft und als Qualitätsmerkmal textiler Flächengebilde. *Textile Praxis International*, *46*(10), 1100-1109.

ISO, N. (1995). 11035; Analyse Sensorielle, Recherche et Sélection de Descripteurs Pour L'élaboration d'un Profil Sensoriel par Approche Multidimensionnelle. *AFNOR, juill-1995*.

ISO, N. (2023). 8586 Sensory analysis- Selection and training of sensory assessors.

Lutfor Rahman, M., & Tumpa, T. R. (2023). Advanced Technology in Fabric Finishing. In *Advanced Technology in Textiles: Fibre to Apparel* (pp. 161-176). Singapore: Springer Nature Singapore.
https://doi.org/10.1007/978-981-99-2142-3_6

Mahall, K., (1972), Die permanent antistatische Ausrustung heute, DeutscherFarberkalender, ,76, 332-351.

Mamdouh, F., Reda, M., Abd El-Aziz, H. A., & Othman, H. A. (2022). Overview of different fabric structures. *Journal of Textiles, Coloration and Polymer Science*, *19*(2), 291-306.
https://doi.org/10.21608/jtcps.2022.152641.1131

Muhyiddin, H., Textile Design -1- Theoretical Part, First Edition, Al-Baath University Publications, Homs, Syria (2009).

Nawaz, N., Troynikov, O., & Watson, C. (2011). Evaluation of surface characteristics of fabrics suitable for skin layer of firefighters' protective clothing. *Physics procedia*, *22*, 478-486.
https://doi.org/10.1016/j.phpro.2011.11.074

Ragot, Y. (1997). La conception et la mise en place d'un outil d'aide à la communication et à la conception des finitions de surfaces. *Mémoire DEA, ENSAM Paris*.

Tang, K. P. M., Kan, C. W., Fan, J. T., Sarkar, M. K., & Tso, S. L. (2017). Flammability, comfort and mechanical properties of a novel fabric structure: plant-structured fabric. *Cellulose*, *24*(9), 4017-4031.
https://doi.org/10.1007/s10570-017-1372-0

Wiam, A., Finishing Treatments for Fabrics Using Microcapsules, Master's Thesis, Al-Baath University, Homs, Syria, (2021).

Ziad S., Printing Technology, Theoretical Part, First Edition, Al-Baath University Publications, Homs, Syria, (2017).