Süleyman Demirel Üniversitesi Fen Edebiyat Fakültesi Fen Dergisi https://dergipark.org.tr/sdufeffd
Süleyman Demirel University Faculty of Arts and Sciences Journal of Science e-ISSN: 1306-7575
Research Article, 2024, 19(1): 40-52, DOI: 10.29233/sdufeffd.1383363

Prediction of The Ultraviolet Protection Provided by Woven Fabric Construction Using Fuzzy Logic

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(Received: 30.10.2023, Accepted: 06.03.2024, Published: 27.05.2024)

Abstract: The negative impact of UltraViolet (UV) radiation on human health is an issue that is gaining importance gradually, and the demand for the production of fabrics with UV protective properties is increasing progressively. Textile materials provide simple and useful protection against UV radiation. The degree of this protection is determined by the Ultraviolet Protection Factor (UPF).

The effects of the yarn fineness and the woven fabric tightness, both used in the main representative woven fabric weave-types/constructions (plain, satin, twill), on UPF and bifunctional UV protection were examined and are presented in this article.

A prediction model determined by fuzzy logic programming was derived to describe these effects of the aforementioned parameters. The results show very good agreement between experimental and predicted values.

Keywords: Human health, Ultraviolet protection, Satin, Twill, Plain, Fuzzy logic

1. Introduction

Due to the climate change that is experienced today and is felt very closely, taking precautions against the negative effects of the sun has become a necessity. To ensure this, exposure to too much sunlight should be avoided, protective equipment should be used or clothing that will protect against the harmful effects of sunlight should be preferred.

Dubrovski *et al* observed that the UPF value of woven fabrics heavily relies on various construction parameters [1-2]. Stankovic *et al* in their research, delved into the impact of yarn twist on UPF in cotton woven fabric, alongside the influence of fabric surface properties [3]. Gies *et al* noted that UV light penetrates through the fabric's open areas, and numerous studies on different construction parameters have highlighted their significant effect on UV protection [4]. Among these parameters, Dimitrovski *et al* focused on fabric cover factor [6-7], while Gabrijelčič *et al* investigated fabric open porosity, mass, and thickness, among others. Dubrovski and Golob found that varying weave types (such as twill and satin) exhibit higher UPF in gray-colored 100% cotton woven fabrics of the same yarn fineness, with plain weave showing a lower UPF due to its increased thread passes. In their analysis, satin ranked highest in UPF, followed by twill, and then plain weave [8].

1.2. Ultraviolet

1.2.1. Electromagnetic waves

In modern physics, light or electromagnetic wave is theoretically defined in two complementary forms: a wave in an electromagnetic field and a flow of massless particles called photons [9-10].

Electromagnetic waves are a type of energy that propagates very quickly in space (vacuum) [11]. Numerous physical events we experience on a daily basis, such as sunlight rising, microwaves cooking our meals, and also operating radios and televisions due to the creation of an electromagnetic field, are situations that make us feel the presence of electromagnetic waves [12]. X-rays, ultraviolet rays, microwaves and radio waves can be counted among the main electromagnetic waves [13].

Radio waves, television waves and microwaves are types of electromagnetic waves. They are separated from each other only by their wavelengths. In the electromagnetic spectrum, waves range from very long radio waves the size of buildings to shorter gamma waves the size of the nucleus of an atom.

1.2.3. Ultraviolet light

Ultraviolet (UV) waves have shorter wavelengths than visible light. These wavelengths cannot be seen by the human eye. However, it has been noticed that some species of wasps can see these waves. Scientists have divided the ultraviolet part of the spectrum into three; near UV, far UV and very far UV.

This distinction is made according to the energy of UV radiation. It is expressed in terms of wavelength energy of UV light. Near UV light is close to visible light, very far UV light is close to X-rays, and far UV is in between. The sun emits rays of all wavelengths in the electromagnetic spectrum. Some UV waves coming from the sun pass through the earth's atmosphere, but they are retained by some gases such as the ozone layer. Some days more UV radiation reaches the earth. Scientists have developed the UV index to help protect people from the harmful effects of UV radiation [14].

Ultraviolet rays also consist of groups with different wavelengths. This classification can also be applied by physicists as near UV (320-380 nm), mid-UV (200-320 nm) and vacuum UV (10-200 nm) [14]. UV-A Ray wavelength is between 320-400 nm.

Among UV rays, which rays have the longest wavelength and least energy. Sun-derived UV-A rays are not retained by the atmosphere and can pass through glass. It can penetrate into the human inner skin known as the dermis. Therefore, it causes premature aging, wrinkles on the skin, and the progression of skin cancer. It is generally used in lighting systems in industry [15].

UV-B rays have a wavelength between 280-320 nm and located in the middle of the UV band in terms of both energy and wavelength. It is approximately 1000 times stronger than UV-A [15]. Biologically harmful UV-B radiation reaches the earth's surface depending on the concentration of stratospheric ozone. It is not just stratospheric ozone that absorbs UV-B and prevents it from reaching the earth's surface. Most of the UV rays are absorbed by clouds. Atmospheric pollution can affect UV exposure locally and globally. The most important effect of the UV-B radiation is that it weakens people's immune system. Another important effect is that it causes temporary blindness in humans, damage to the cornea, and cataracts in older ages. Another harmful effect of UV-B rays on humans is skin cancer. If exposed to long-term UV-B rays, deterioration of skin cells may occur, tumor formation may occur at the age of 40, and advanced cancer may occur at the age of 50 . It is used in lighting systems and solarium lamps in industry [15-16].

UV-C ray: These are the rays with the shortest wavelength and the highest energy in the C band of UV, with a wavelength between 200-280 nm. It causes cancer when it comes into contact with skin or eyes. Protector you should not be exposed to UV-C radiation in any way without taking precautions [17-18]. UV-C rays originating from the sun are filtered by the ozone layer or retained by gases in the atmosphere. Therefore, it is produced using electrical energy only as a result of electronic industrial processes. Since it loses its energy as soon as it touches any surface, it has been used especially in surface modifications recently [19-20].

In this article, a predictive model was derived with fuzzy logic programming in order to investigate the effects of woven fabric construction on the ultraviolet protection factor.

2. Material and Method

The fuzzy logic tables created in this study were described using the MATLAB program and the resulting data were examined. The Mamdani model, which has two inputs and one output, was established with the fuzzy logic module of the MATLAB program. In this model, the method of obtaining results with the center of gravity method is taken as basis[21].

In the study, the type of membership functions used in the input sets is the Generalized Bell Membership Function (GBellMF) method, thus the trapezoidal shape, which is a geometric shape, is obtained. In this way, approximate values are obtained within the framework of fuzzy logic rules. The reason for using the GBellMF method is that trapezoidal fuzzy numbers have a special shape compared to triangular fuzzy numbers are more understandable with verbal variables [21]. The fuzzy logic rule is presented in Figure 1.

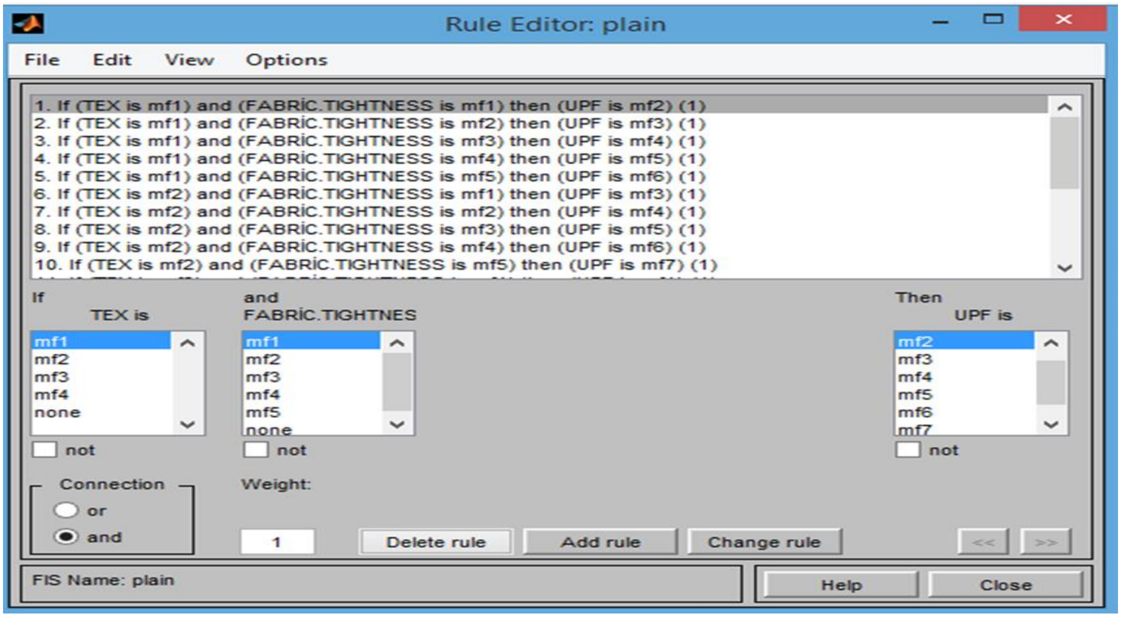

Figure 1. The Fuzzy Logic Rule

Plain, twill and satin weaves woven fabric constructions made of 100% cotton Open End (OE) yarns were used to analyze the effect of woven fabric constructions on the UPF. Weaving samples varied according to yarn fineness, weave type and fabric tightness. Three woven fabric samples were used to analyze the effect of woven fabric constructions on the UPF and define a prediction model for UPF, similar to the previous step, with variation of structural parameters. When the results of UPF measurements of woven fabrics with different structures were analyzed, it was revealed that samples with different woven constructions keeping constant the fabric tightness and yarn fineness offered different level of UV protection.

The combination of various structural features (weave type, fabric tightness, etc.), thickness, weight, porosity of fabrics have a great impact on the transmission of UV radiation through fabrics. Loosely textured thin fabrics provide less protection than tighter textured fabrics. The constructional parameters of the fabrics are presented in Table 1.

Table 1. Constructional Parameters of Woven Samples

Yarn fineness, tex	Type of weave	Cover factor %	Fabric Tightness %
10	Plain	60	55
10	Twill	70	55
10	Satin	80	55
20	Plain	62	65
20	Twill	73	65
20	Satin	81	65
30	Plain	63	75
30	Twill	75	75
30	Satin	82	75
40	Plain	65	80
40	Twill	76	80
40	Satin	84	80
50	Plain	68	85
50	Twill	79	85
50	Satin	87	85

Jasco V-570 spectrometer characteristics are presented in Table 2. Their behaviour under the UV radiation exposure was evaluated.

Table 2. The Characteristics of Jasco V-570 Spectrometer

Wavelength rang	190 – 2500 nm
Measurement	0.3 nm
Type of the lamp	Tungsten – Deuterium
Type of the detector	PbS Photocell – PMT

3. Results

Fuzzy logic prediction model was used for UPF of woven fabrics. To assist woven fabric makers by developing woven fabrics with optimum UPF, the prediction model for UPF has been developed through fuzzy logic programming on the basis of woven fabric constructions parameters. The method of modeling presented in this article clearly presents the dependence between UPF and the parameters characterizing the structure of the textile product.

3.1. Satin fabric constructions fuzzy prediction

For satin fabric, our entry membership functions, the yarn fineness, was chosen to be five, and the fabric tightness was chosen to be five feet. Our output function, UPF, is determined in the sixteen foot range. It was created with a hundred and twenty rule base in order to understand the effect of the relationship between the determined membership functions on the result. The relationship between the yarn fineness and fabric tightness of the satin fabric constructions and UPF is presented in Figure 2.

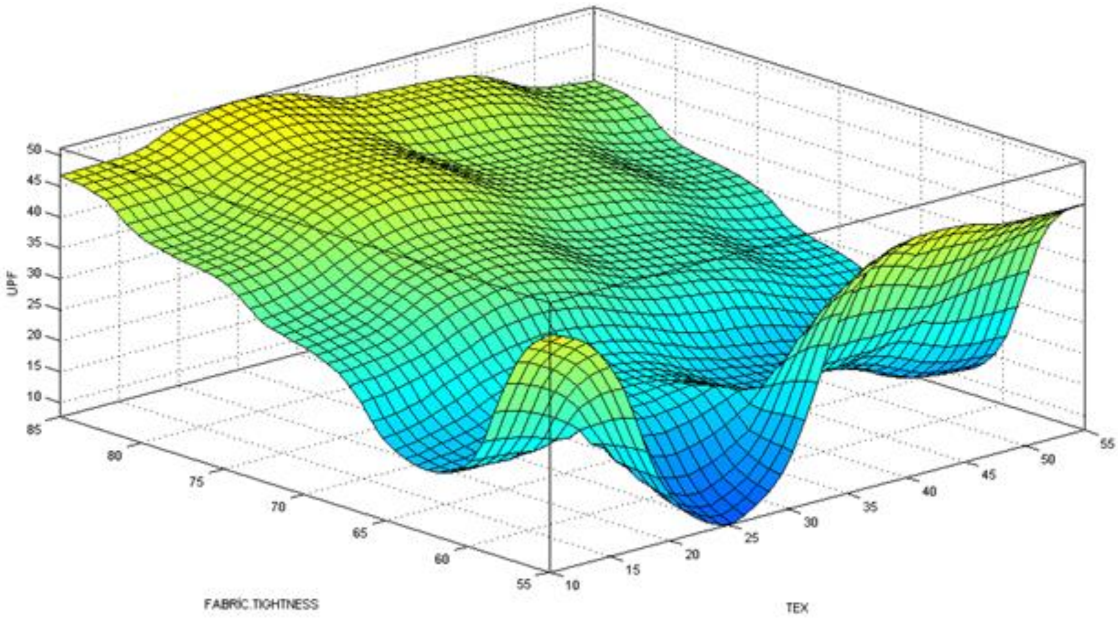

Figure 2. The Relationship Between Yarn Fineness and Fabric Tightness of Satin Fabric Structure and UPF

The junctions are far apart, causing the threads to float and cover the junctions. Fabrics woven with satin weave are therefore soft and shiny. If the fabric tightness is kept high, heavy fabrics can be obtained. Satin weave; it has higher warp and weft density than twill or plain weaves. As a result, the fabric pores are smaller and have less free space for UV radiation to pass through. Satin fabrics, on the other hand, are not stable due to their pores, have little thread passage and tend to group together, further reducing the free space.

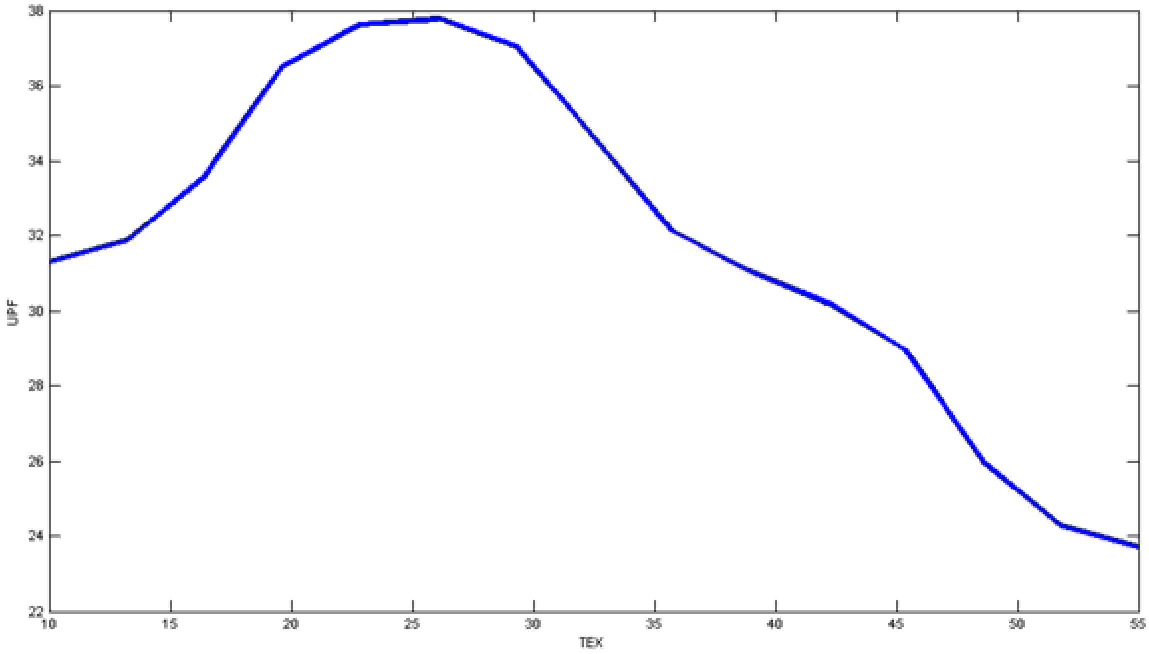

Figure 3. Variation Between Yarn Fineness and UPF of Satin Fabric Structure

Variation between yarn fineness and UPF of satin fabric constructions is presented in Figure 3. If we compare the UPF values of woven samples in terms of yarn fineness, we can observe that the UPF values first increase with yarn fineness (10 to 25 tex) and then decrease again, which means that the UV protection depends not only on the open area but also on the fabric thickness or volume porosity. Good UV protection in satin fabrics depends on the yarn fineness and the density of the fabric. Effect of yarn fineness on UPF in fabrics: 15 tex – 26 tex (good protection), 25 tex – 29 tex (very good protection), 45 tex – 55 tex (low protection).

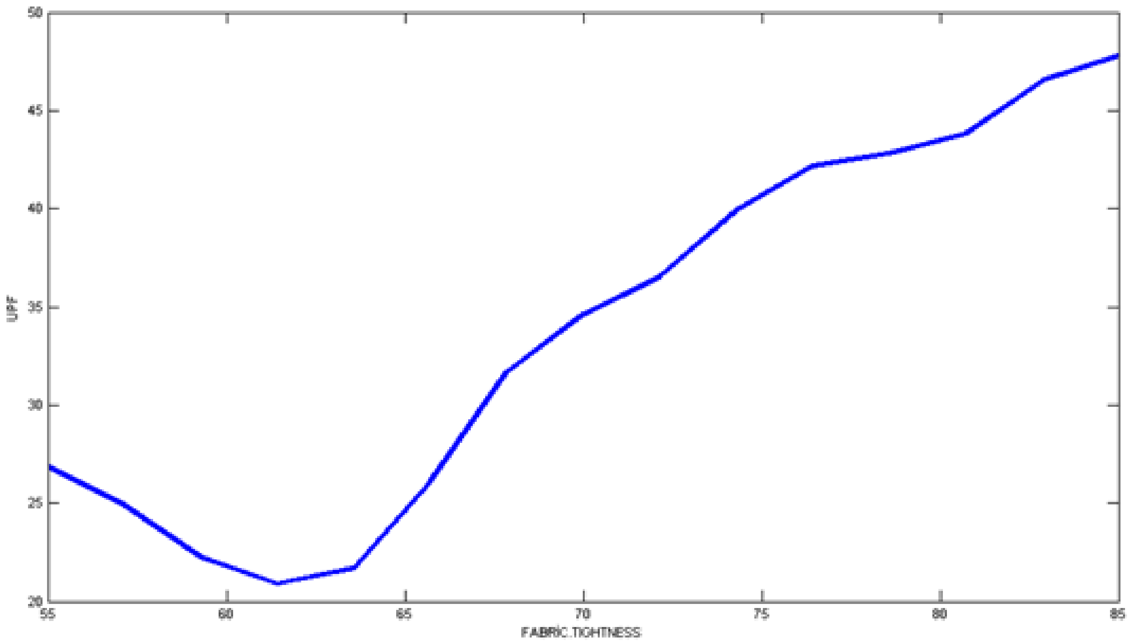

Figure 4. Variation Between Fabric Tightness and UPF of Satin Fabric Structure

Variation between fabric tightness and UPF of satin fabric constructions is shown in Figure 4. In any case, higher fabric tightness means higher UV protection, but there is a limit value at which each woven fabric provides good UV protection. Effect of fabric tightness on UPF: 60%- 65% (low protection), 65% - 70% (good protection), 70% - 85% (very good protection).

3.2. Twill fabric constructions fuzzy prediction

For twill fabric, our entry membership functions, the yarn fineness, are chosen to be five, and the fabric tightness is five feet. Our output function, UPF, is determined in the twelve feet range. It was created with a hundred and twenty rule base in order to understand the effect of the relationship between the determined membership functions on the result. The relationship between the yarn fineness and fabric tightness of the satin fabric constructions and UPF is shown in Figure 5.

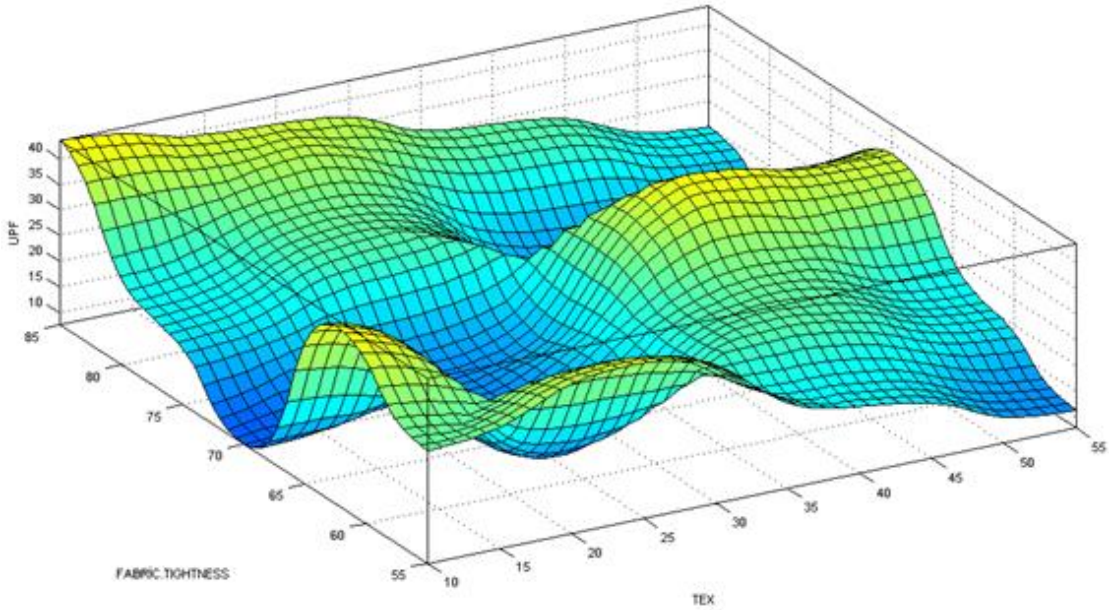

Figure 5. The Relationship Between Yarn Fineness and Fabric Tightness of Twill Fabric Structure and UPF

If warp skips are effective on one side of the fabric, weft skips are equally effective on the other side. Additionally, events may be equal to each other. In twill weave, there are many thread jumps from link to link. Twill fabrics have good UV protection when tightly woven. Higher warp/weft density per weave means higher fabric tightness and therefore higher UV protection.

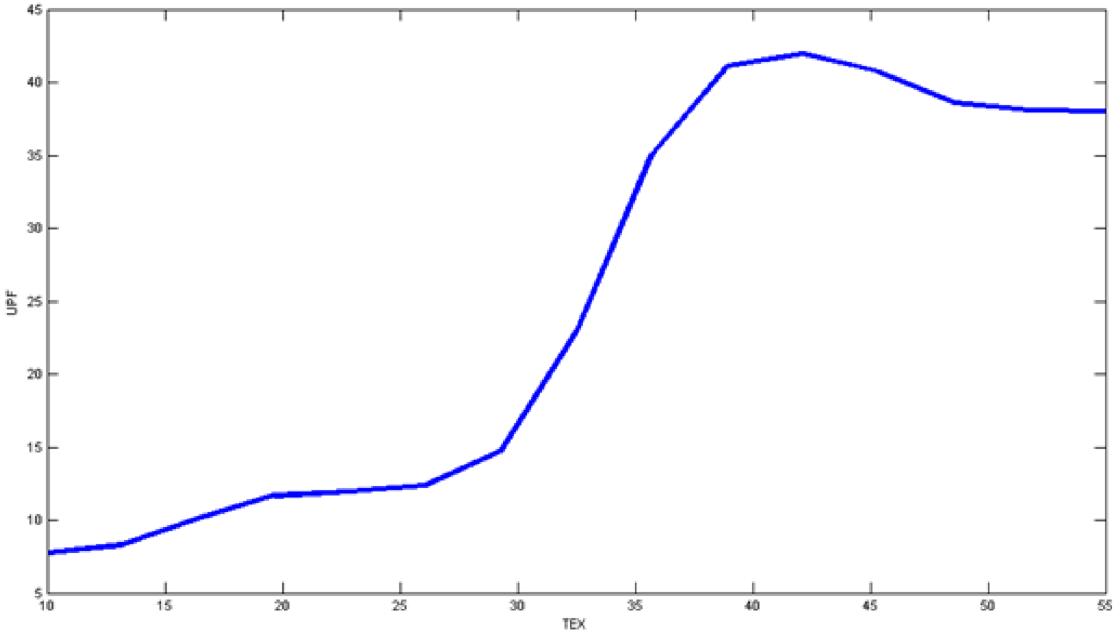

Figure 6. Variation Between Yarn Fineness and UPF of Twill Fabric Structure

Variation between Yarn fineness and UPF of twill fabric constructions is presented in Figure 6. Good UV protection in twill fabrics depends on the yarn fineness. The effect of yarn fineness on UPF in the fabrics: 10 tex – 30 tex (low protection), 35 tex – 40 tex (good protection), 40 tex – 55 tex (very good protection).

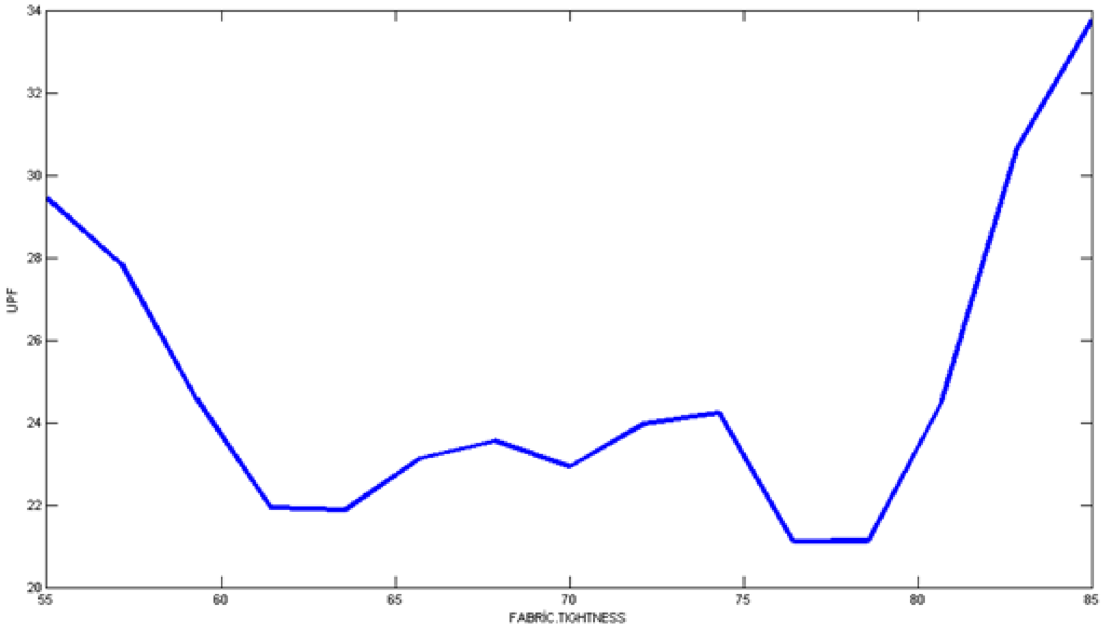

Figure 7. Variation Between Fabric Tightness and UPF of Twill Fabric Structure

Variation between fabric tightness and UPF of satin fabric constructions is shown in Figure 7. In any case, higher fabric tightness means higher UV protection, but there is a limit value at which each woven fabric provides good UV protection. Effect of fabric tightness on UPF: 55% - 60% (good protection), 62% - 78% (low protection), 80% - 85% (very good protection).

3.3. Plain fabric constructions fuzzy prediction

For plain fabric, our input membership functions, the yarn fineness, were chosen to be five, and the fabric tightness was chosen to be five feet. Our output function, UPF, is determined in the seven-foot range. It was created with a hundred and twenty rule base in order to understand the effect of the relationship between the determined membership functions on the result. The relationship between the yarn fineness and fabric tightness of the satin fabric constructions and UPF is shown in Figure 8.

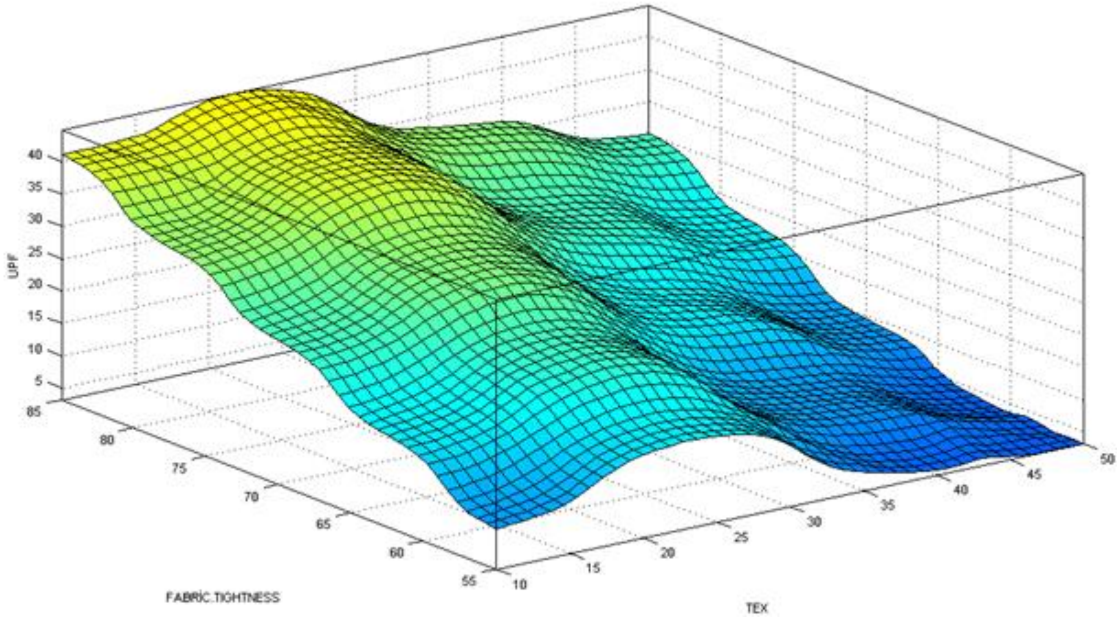

Figure 8. The Relationship Between Yarn Fineness and Fabric Tightness of Plain Fabric Structure and UPF

Plain braid is the simplest of braids. The smallest unit consists of two warps and two wefts. A plain weave fabric is the same on both sides. In a plain woven fabric with the same warp and weft density and the same warp and weft thread linear density, it is seen that the weft and warp threads are curled equally. In fabrics woven with plain weave, each thread gives maximum support to the adjacent thread. For this reason, the texture of these fabrics is stronger than other fabrics. It has a very stable and uniform form as a result of the macro pores and greater thread passage in plain fabrics. As a result, plain fabrics do not offer low UV protection.

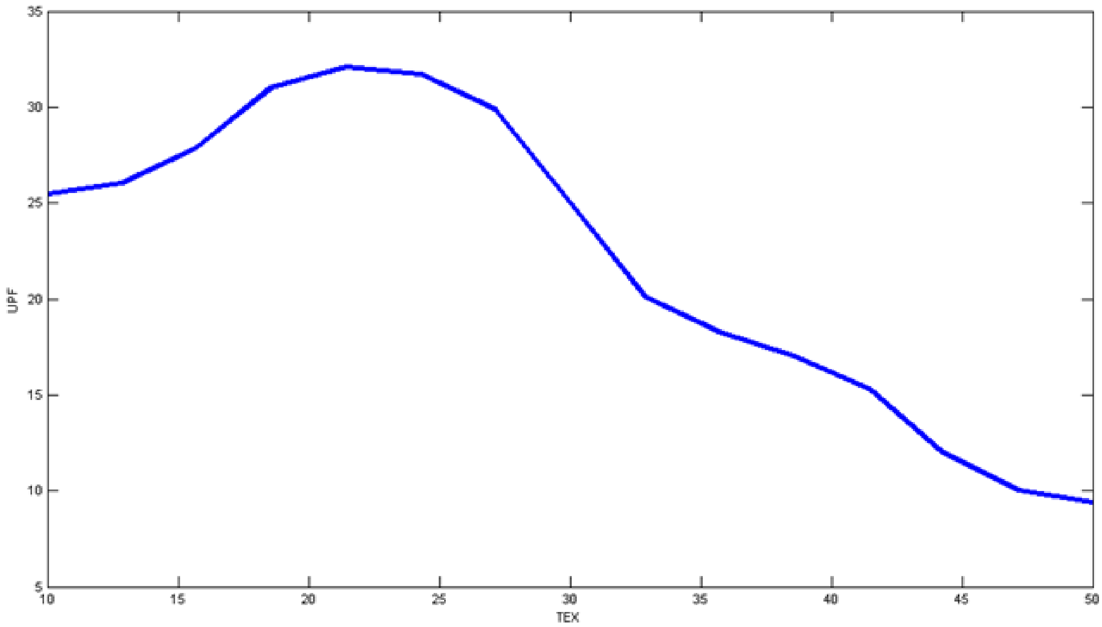

Figure 9. Variation Between Yarn Fineness and UPF of Plain Structure

Variation between yarn fineness and UPF of satin plain structure is presented in Figure 9. Good UV protection for plain fabrics depends on the yarn fineness and the fabric tightness of the fabric. The effect of yarn fineness on UPF in fabrics: 10 tex – 18 tex (good protection), 20 tex – 28 tex (very good protection), 30 tex- 55 tex (low protection).

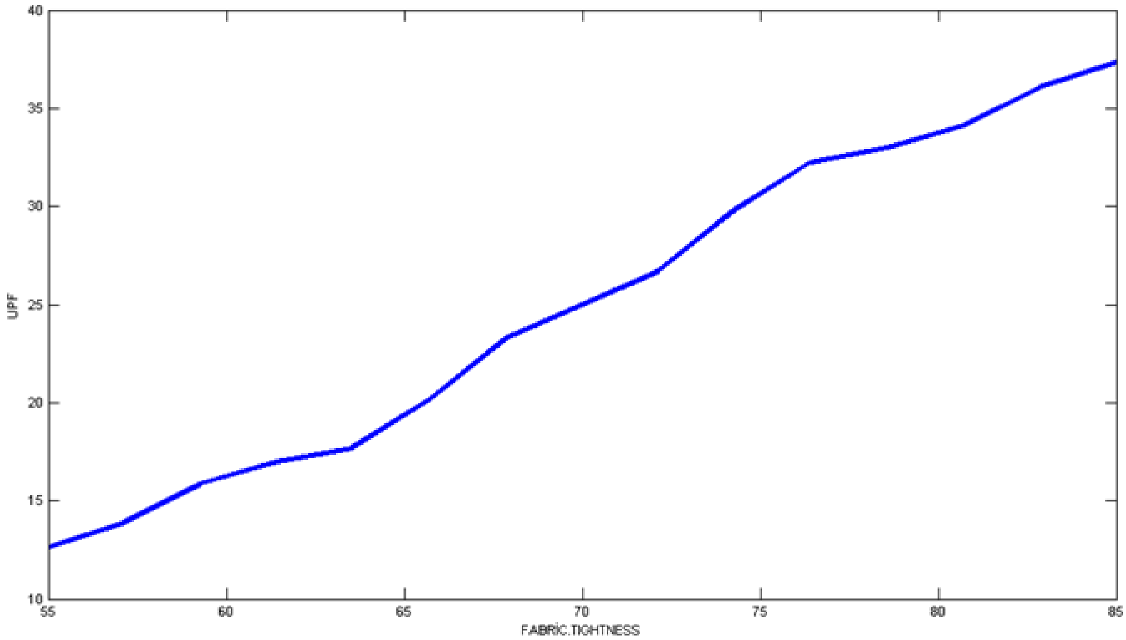

Figure 10. Variation Between Fabric Tightness and UPF of Plain Fabric Structure

Variation between fabric tightness and UPF of plain fabric constructions is presented in Figure 10. In any case, higher fabric tightness means higher UV protection, but there is a limit value at which each woven fabric provides good UV protection. Fabric tightness effect on UPF: 55% - 70% (low protection), 70%- 80% (good protection), 80% - 85% (very good protection).

Table 3. Comparison of Experimental and Fuzzy Values of Fabric Structures of UPF

TEX	FABRIC TIGHTNESS	SATIN UPF		TWILL UPF		PLAIN UPF	
		Fuzzy	Experiment	Fuzzy	Experiment	Fuzzy	Experiment
10	55	46	43	29,6	31	9,44	9,9
15	60	19,8	18,3	34,8	31,6	17,3	18,6
20	65	25,8	27	13,5	14,1	25,5	23
25	70	37,9	35	12	12,9	31,4	29,2
30	75	42,9	45	27,5	25	30,9	31,1
35	80	41,1	38	18,4	19	27,3	29
40	85	46,1	49	18,4	17	27,3	26
45	85	44,8	41	27,4	29	26,8	25,2
50	85	40,5	43	21,8	20,2	25	27
55	85	39,2	36	20,2	21,4	20	21,8

Comparison of experimental and fuzzy values of fabric structures is presented in Table 3. There is a 9% similarity between the experimental and fuzzy values of UPF. When the average values in Table 3. are compared; from the comparison of the average values it is obvious that there is a direct relationship between the yarn fineness and fabric tightness values of these fabrics with 3 different structures and the UPF value, on the basis of the structural features of the fabrics, regarding UV transmission. From the UPF results obtained for different woven fabrics, a higher UPF value was reached for satin fabrics according to the yarn fineness and fabric tightness values.

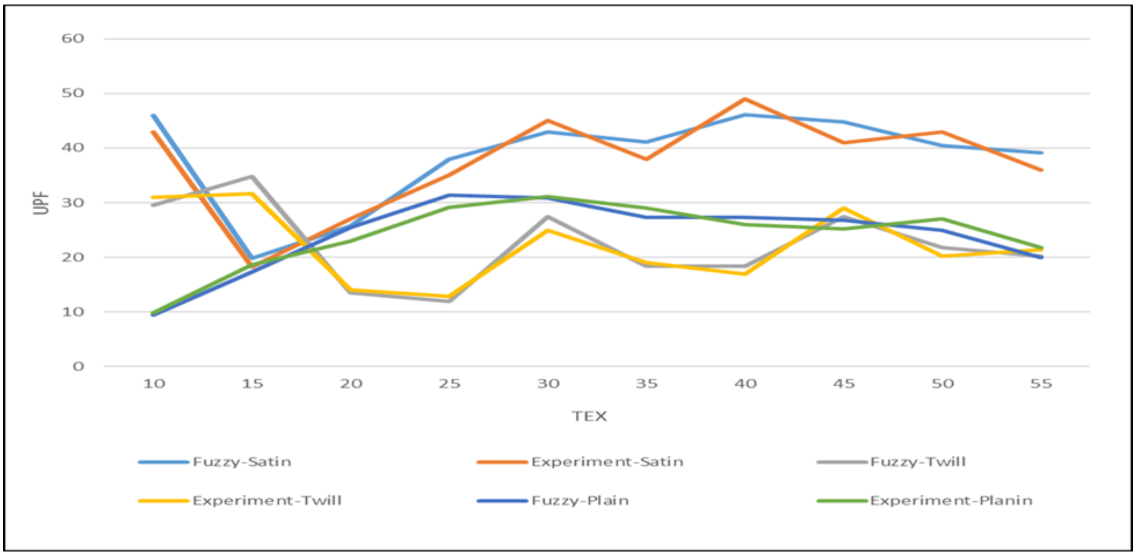

Figure 11. Comparison of Experimental and Fuzzy Values of Satin, Twill, Plain Woven Fabric Structures

Comparison of experimental and fuzzy values of UPF for satin, twill, plain woven fabric structures is presented in Figure 11. There are various factors that affect the UV protection properties of woven fabric.

4. Conclusion

In this study, it was seen that the production of clothes that can protect people from exposure to UV radiation can be achieved, especially in regions where sunlight is received more due to climatic conditions.

It is seen that the data obtained from the study conducted as fuzzy logic estimation contains positive results that can be applied in businesses. It is hoped that these data can provide initial information when considering further research studies on these topics. In the light of the data obtained from this study, the following conclusions can be drawn.

Fabrics such as yarn structure (fiber type, twist), fabric constructions are primary (weave type, warp/weft density, fabric tightness) and secondary (cover factor, porosity, thickness) fabric geometry parameters, knowing the UPF value of the garment will be more useful for the person wearing the garment made of UV protected fabrics. As a result, in terms of UPF value, satin fabrics can be considered as a widely used protective fabric constructions compared to other twill and plain fabrics, since the possibility of light transmission is low.

In order to protect the human skin from harmful UV rays, it is necessary to pay attention to fabric constructions. The high protection of satin woven fabric has revealed the necessity of further researching this woven constructions and ensuring its more widespread use.

Authorship contribution statement

M. Kodaloğlu: Conceptualization, Methodology, Data Curation, Original Draft Writing

F. Akarslan Kodaloğlu: Visualization, Supervision/Observation/Advice.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgment

As the authors of this study, we declare that we do not express any support or gratitude.

Ethics Committee Approval and/or Informed Consent Information

As the authors of this study, we declare that we do not have any ethics committee approval and/or informed consent statement.

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