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Acoustic Characteristics of Woven Jute Fabric

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ABSTRACT
The noise optimization using suitable absorbing materials is imperative due to significant impact on living beings by influencing various physiological and psychological factors. The research investigating the acoustic characteristics of woven fabrics compared to nonwoven and other fabrics are very limited. This research investigates the acoustic characteristics of woven jute fabric in relation to fabric structural variables. The research is designed to fulfil the existing gap on acoustic characteristics of woven jute fabrics. The focus was on the effect of woven jute fabric structural parameters such as weft yarn linear density, weft density and number of weft float over warp on sound absorption coefficient and noise reduction coefficient. The sound absorption coefficient was measured using impedance tube method as per ASTM E1050 standard. Noise reduction coefficient was measured from the mean value of sound absorption coefficient observed at 250 Hz, 500 Hz, 1000 Hz and 2500 Hz. A Box–Behnken experimental design was adopted for research design and woven jute sample planning. The experimental work revealed that the plain woven jute samples prepared with 40 tex weft yarn consisting of 8 weft threads/cm showed higher mean values of sound absorption coefficient and noise reduction coefficient compared to twill and satin weave. The experimental results and statistical analysis showed that the effect of number of weft yarn float over warp and weft yarn linear density is significantly influencing sound absorption coefficient and noise reduction coefficient whereas the effect of weft density is found not significant.

KEYWORDS
acoustic, jute, woven, sound absorption, noise reduction

INTRODUCTION

Noise plays a crucial role in human well-being as it influences productivity as well as health [1]. Noise pollution is the excessive sound which can disturb humans significantly influencing them physiological and psychological [2]. The noise pollution or excessive noise from varied sources adversely affect the humans by reducing their activity level, increase stress, low efficiency at work, hearing damage, increase insomniac behaviour cause sleep disorders as per the World Health Organization [3]. The noises from different sources such as machines, transport vehicles, construction work have a negative impact on humans which is proved by many research studies. The noise could be reduced by using a suitable textile based acoustic absorber.

The popularity of natural fibre based textiles increased due to porous nature which facilitates incident dissipation of sound energy, low cost, and minimal environmental impact. These materials are bulky in volume, soft, as well as highly porous and therefore are perfectly suitable for acoustic applications [4]. The use of such textiles materials is preferred over conventional acoustic materials by the architects and engineers due to low areal density, flexibility, durability, environment friendliness, availability, low cost and porous structure [5]. Many research investigated the relationship of acoustic characteristics of textiles with fibre properties, weave structure, yarn or fabric fineness, thickness, air permeability, manufacturing technique and surface effects [6-7]. Some of the natural fibres used for acoustic applications are, flax, hemp, kenaf, jute, agave, bamboo, coir (coconut husk), and wool [8-10]. It was reported that the density of the fabric as well as fabric porosity play a significant role in determining sound absorption coefficient. It was found that the plain woven fabric exhibits better sound absorption compared to other weaves due to higher number of yarn inter-sections, higher thread density, and less free-float length due to crimp [11]. The porous textiles absorb sound energy by converting it into heat energy due to viscous friction and heat exchange through dissipation mechanism [12-14]. It was found that more research was conducted on the acoustic characteristic of nonwoven fabrics compared to woven. As nonwoven fabrics were found suitable for many industrial acoustical applications and the gamut of application of nonwoven is considered wider compared to woven fabrics [15-16]. Jute is available, cost effective and biodegradable substitute of an effective sound absorbing media for various acoustic applications. Research reported that jute fibre has promising acoustical application areas including domestic applications such as vacuum cleaning, refrigerating, and architectural applications as sound absorbing medium [17-18]. Untreated jute fibre exhibits better sound absorption properties compared to treated jute fibre absorbents [19]. Previous studies found that jute fibre exhibits excellent sound absorption properties and can be used as an effective noise controlling material as well as in noise reducing applications without influencing the environment [20].

Despite intensive research on factors influencing sound absorption properties of porous textile based acoustic materials, limited research was performed using woven jute fabric. Therefore, the optimization of woven fabric structural variables for better sound absorption performance of woven jute fabric is required. Hence, a systematic study was conducted using woven jute fabric to assess sound absorption properties through recording responses such as sound absorption coefficient and noise reduction coefficient. The objective of this study is to investigate the effect of scrutinized factors of woven jute fabric such as weft yarn linear density, threads density or weft density and weft float over warp on normal incidence sound absorption coefficient and noise reduction coefficient subsequently.

EXPERIMENTAL

Materials

60 tex warp yarns in combination with three different weft yarn counts 25 tex, 40 tex and 55 tex were used to produce 100% woven jute fabric on a sample handloom. The fabric samples weight in grams per square meter was measured using standard testing equipment found in a range of 100 g/m^2 – 115 g/m^2. Hence, a light weighted, porous, loosely woven jute fabric was used to investigate the acoustic characteristics such as sound absorption coefficient and noise reduction coefficient.

Methodology

A three factor three level Box-Behnken experimental design was adopted for research design and sample planning. The detail of three levels of each control factor is given in Table 1. The weft yarn of different linear density (25 tex, 40 tex, and 55 tex) was used to prepare woven jute samples plain, twill and satin fabric structure. The weft fabric density is an imperative denoting number of filling yarn per unit length which can affect overall fabric density and porosity. The three levels of weft thread density (8, 12, 16 thread/cm) was considered while preparing fabric samples for acoustic analysis. A suitable randomization and replication technique was adopted at the time of sample preparation for an effective statistical analysis and to reduce the chances of error occurrence.

Table 1. Control factors and corresponding levels for material preparation

Control factors	Levels			Parameter type
	-1	0	+1	
Weft yarn linear density (tex)	25	40	55	Quantitative
Weft density (thread/cm)	8	12	16	Quantitative
Weft floats over warp	1	2	3	Quantitative

The sound absorption properties were measured in terms of sound absorption coefficient and the value of sound absorption coefficient lie in between 0 to 1. This parameter is represented by α and helps in evaluating sound absorption efficiency of the textile materials. In case the entire acoustic energy is absorbed by a material the value of α equals 1. The standard test method for measurement of sound absorption coefficient was adopted using impedance tube method. A two microphone acoustic impedance tube was used to measure acoustic impedance as well as sound absorption coefficient.

The fabric weights varies sample to sample due to variation in weft yarn linear density and number of weft thread/cm. Due to this a multi-layered arrangement of woven jute fabric samples of 6mm mean thickness were prepared for testing acoustic characteristics of fabric samples as per standard testing procedure using impedance tube method. The rest of fabric parameters except scrutinized factors were kept unchanged to study the effect of weft yarn linear density, thread/cm and number of weft float over warp on sound absorption coefficient and noise reduction coefficient.

The standard test method for measurement of sound absorption coefficient was adopted using impedance tube method as per the ASTM E-1050 standards. The impedance tube (combined type) as shown in figure 1 of inner diameter 100 mm for 100 Hz to 500 Hz acoustic testing and 29 mm sample diameter (equals to the inner diameter of tube) was used for acoustic testing at 500 Hz to 6400 Hz. The dimensions of the sample was kept same as inner diameter of the impedance tube which was 100 mm for testing at 100 Hz to 1600 Hz and 29 mm inner diameter for acoustic testing at 500 Hz to 6400 Hz. The mean value of sound absorption coefficient is recorded at 6000 Hz for all samples as per research design for comparison purpose. As at different sound frequency range, the value of sound absorption coefficient also varied. A multi-layered arrangement of woven jute fabric samples of 6mm mean thickness were tested using impedance tube method to get the value of sound absorption coefficient and noise reduction coefficient subsequently as mentioned below.

It was assumed that the woven jute sample has uniform pores and pore size distribution while calculating sound absorption coefficient and noise reduction coefficient. The sound absorption coefficient was measured using equation (1) and equation (2).

$$\alpha = I_i/I_r = (P^2_i - P^2_r)/\ P^2_i = 1 - (n-1/n+1)^2 = 4n/(1+n)^2 \tag{1}$$

$$n = P_{max}/P_{min} \tag{2}$$

where

α is the sound absorption coefficient,

I_i and I_r are intensities of incident and reflected waves respectively,

P_i and P_r denote pressure of incident and reflected waves respectively,

n is the standing wave ratio, which is the ratio of the maximum to minimum pressure of the sound wave,

P_{max} and P_{min} are maximum and minimum values of sound wave pressure respectively.

Noise reduction coefficient is an indicator revealing the information of percentage of sound that a surface absorbs. Noise reduction coefficient is the percentage of sound which hits the woven jute fabric surface and not reflected back. The mean or average value of sound absorption coefficient calculated at 250 Hz, 500 Hz, 1000 Hz and 2500 Hz is considered as noise reduction coefficient. Noise reduction coefficient provides simple quantification of how efficiently a surface absorbs sound in frequency range of 250 Hz to 2500 Hz. The noise reduction coefficient was measured using equation (3).

Noise reduction coefficient= (α250 Hz + α500 Hz +α1000 Hz+ α2000 Hz)/4 (3)

Figure 1. Impedance tube used for measuring sound absorption coefficient

All the fabric samples were conditioned under standard atmospheric conditions as required, in a tropical atmosphere of 27 °C± 2 °C temperature and 65 ± 2% relative humidity, while the number of readings was determined according to the variation in a fabric sample in order to achieve a 95% confidence interval. Appropriate numbers of woven jute samples were tested by calculating and considering the coefficient of variation in all cases as per the experimental design.

RESULTS AND DISCUSSION

The coded values of control factors along with corresponding responses including sound absorption coefficient and noise reduction coefficient are given as per table 2.

Table 2. Control factors and their corresponding responses

	Control factors			Acoustic responses of woven fabric	
Runs	Weft yarn linear density (tex)	Weft density (thread/cm)	Weft float	Sound absorption coefficient	Noise reduction coefficient
1	-1	-1	0	0.34	0.30
2	1	-1	0	0.25	0.24
3	-1	1	0	0.36	0.31
4	1	1	0	0.27	0.24
5	-1	0	-1	0.39	0.32
6	1	0	-1	0.34	0.31
7	-1	0	1	0.29	0.24
8	1	0	1	0.26	0.23
9	0	-1	-1	0.44	0.36
10	0	1	-1	0.41	0.35
11	0	-1	1	0.25	0.23
12	0	1	1	0.23	0.22
13	0	0	0	0.32	0.26
14	0	0	0	0.33	0.28
15	0	0	0	0.31	0.27

Effect of control factors on sound absorption coefficient

The previous studies found that the different fabric structures have a significant effect on sound absorption coefficient of sound absorbing media. In this study, it has been observed that the plain woven jute fabric due to higher number of interlacements, more binding points, and higher number of pores exhibits improved fabric porosity compared to twill and satin resulting in higher mean value of sound absorption. The woven fabric construction producing plain, twill and satin is shown in Figure 2.

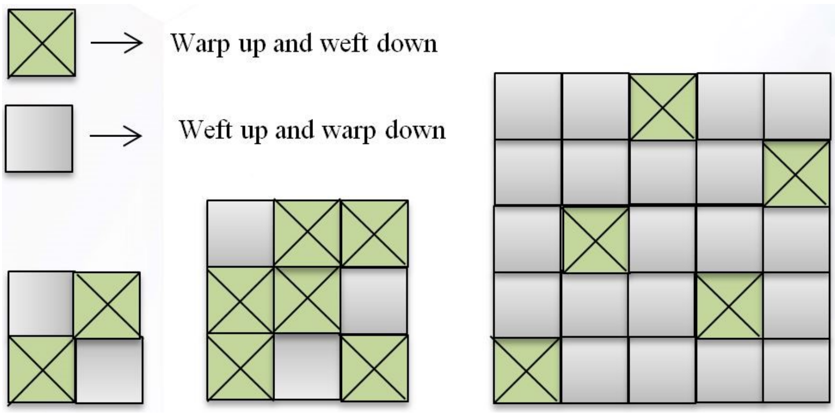

Figure 2. Plain, twill and satin weave repeat (left to right order)

Moreover, the size and the shape of the pores can also influence the sound absorption property of the woven fabrics by varying fabric porosity. Plain woven fabric produced with 40 tex weft yarn exhibits higher sound absorption coefficient compared to majority of the samples. The highest mean value of sound absorption coefficient was noticed in plain woven fabric of 40 tex with 8 weft thread/cm indicating that fabric porosity plays a crucial role in sound absorbing martials. From surface plots and contour plots as shown in Figure 3, it is clearly that finer weft jute yarn woven with lower number of weft floats (plain weave) and less number of weft threads/cm contributes towards increasing mean value of sound absorption coefficient. The satin weave (weft float over three warp yarn) made of 55 tex weft yarn at 16 weft/cm, due to presence of more weft float showed poor sound absorption coefficient compared to rest of the samples. The combined interaction effect of lower number of weft floats and finer weft yarn count was observed significant on sound absorption coefficient as shown in Figure 3.

Hence, it was observed that the effect of weft float followed by weft yarn linear density was found significant on sound absorption coefficient of woven jute fabric as show in Figure 3 whereas the effect of weft density was found insignificant.

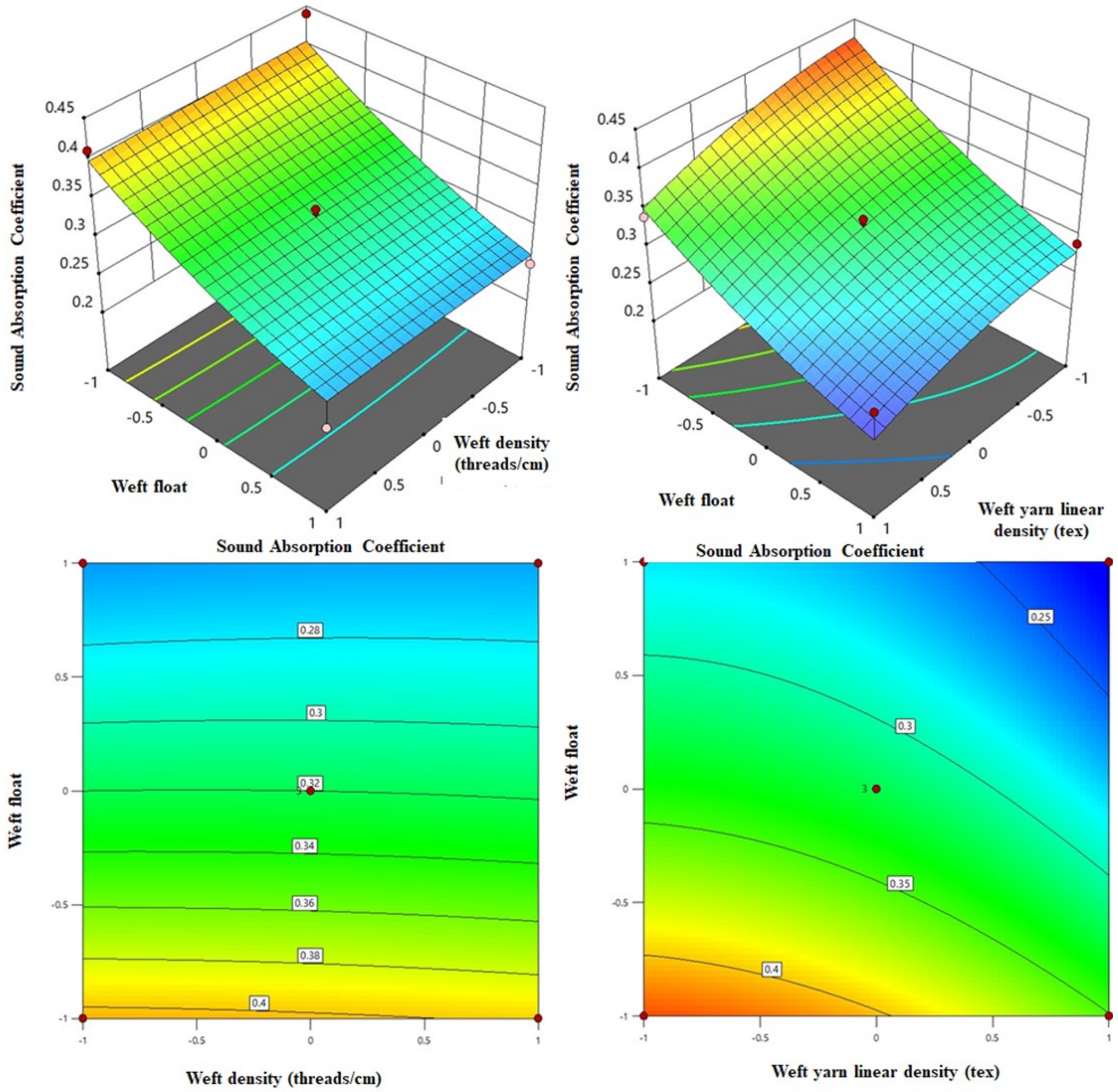

Figure 3. Effect of variables on sound absorption coefficient

Effect of control factors on noise reduction coefficient

The noise reduction coefficient was calculated by the mean value of sound absorption coefficient at 250 Hz, 500 Hz, 1000 Hz and 2500 Hz. The experimental results revealed that the trends of the effect of control variables obtained in sound absorption coefficient are similar in case of noise reduction coefficient as well. From surface plots and contour plots as shown in Figure 4, it is clearly visible that finer weft jute yarn woven with lower number of weft floats (plain weave) and less number of weft threads/cm contributes towards increasing mean value of noise reduction coefficient. Plain woven fabric made up of 40 tex at lower weft thread density showed better mean value of noise reduction coefficient. It has been found that lower weft float over warp yarn, a plain woven jute fabric samples made with finer weft yarn linear density showed higher noise reduction coefficient due to better absorption of sound at different frequencies as shown in Figure 4. The effect of weft float followed by weft yarn linear density was found significant on noise reduction coefficient of the woven jute fabric.

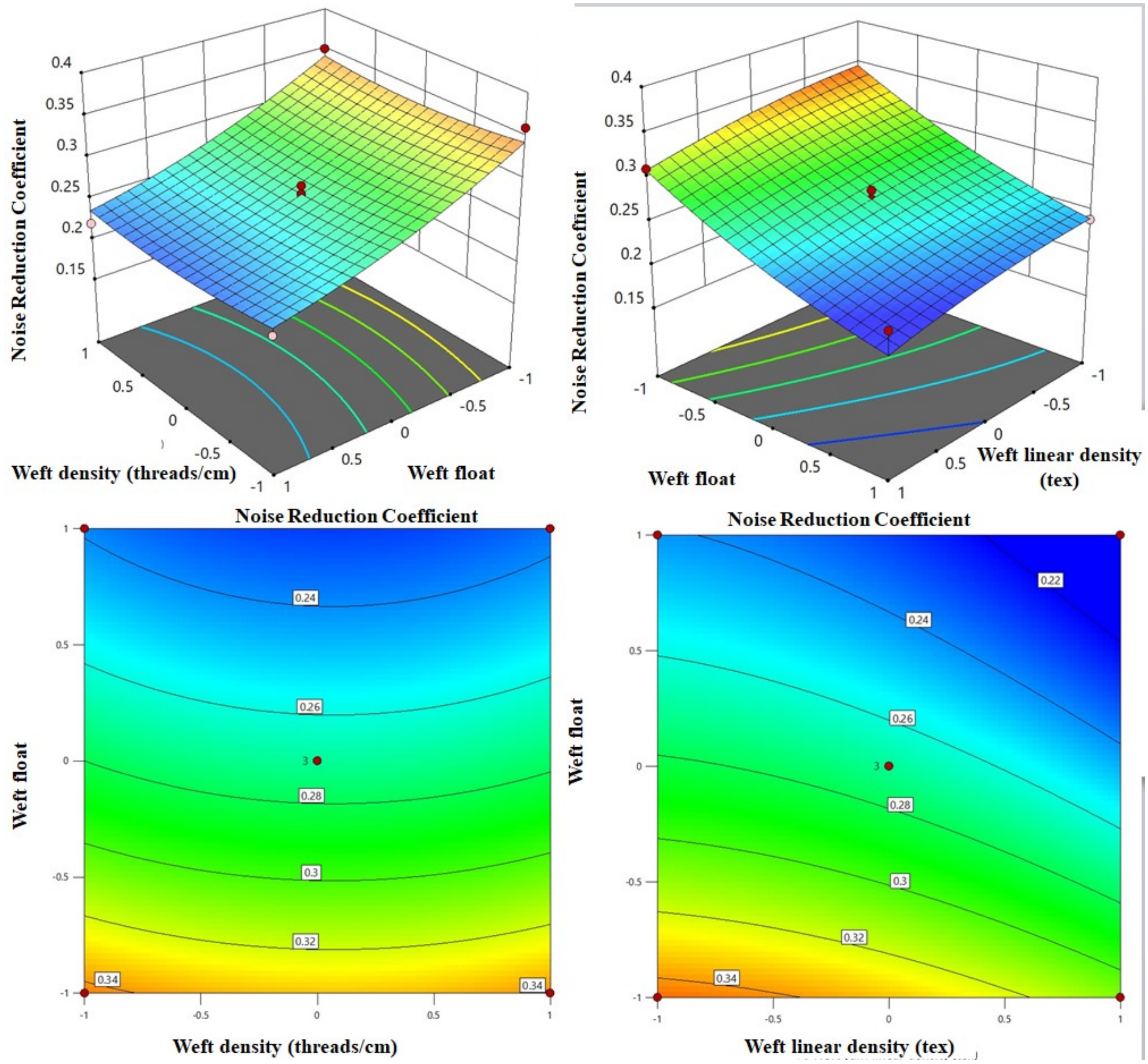

Figure 4. Effect of variables on noise reduction coefficient

Effect of weft yarn linear density and weft density on acoustic characteristics

It was found that there is no significant change in sound absorption coefficient as well as noise reduction coefficient with increase in yarn fineness and increase in number of weft thread/min the present study. There is no combined effect of weft yarn linear density and weft thread/cm either on sound absorption coefficient or on noise reduction coefficient. Hence, based on experimental results the effect of weft density (thread/cm) was found insignificant on both the observed acoustic responses as shown in surface plots and contour plots in Figure 5.

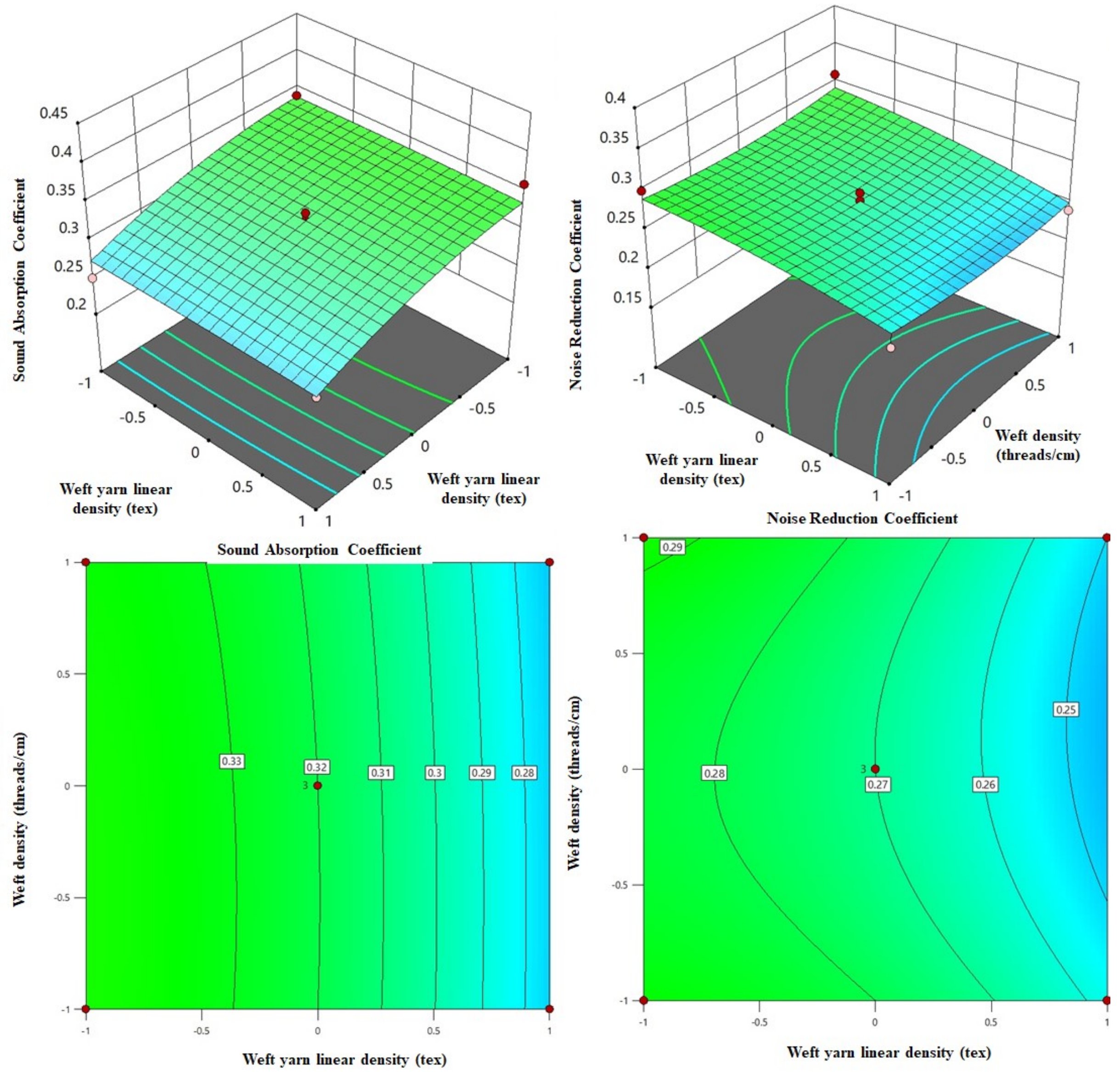

Figure 5. Effect of weft yarn linear density and weft density on sound absorption coefficient (left) and noise reduction coefficient (right)

Statistical analysis of variance

The influence of independent control variables was statistically investigated using ANOVA at 95% confidence level using statistical software. The p-value helped determining the significance of the results. A low p-value (≤ 0.05) indicates a strong effect of the control factor on the observed response, whereas a high p-value (> 0.05) indicates a weak effect as shown in Table 3. It was found that weft yarn linear density and weft float showed a low p-value (≤ 0.05) resulting in strongly influencing sound absorption coefficient and noise reduction coefficient whereas weft density showed a high p-value (> 0.05) which indicates weak relationship with observed responses.

Table 3. ANOVA general linear model summary through p-value analysis

Variables	Observed responses	
	Sound absorption coefficient	Noise reduction coefficient
Weft yarn linear density (tex)	0.00	0.01
Weft density (thread/cm)	0.90	0.85
Weft float	0.00	0.00

CONCLUSION

The present study was focused on investigating the effect of weft yarn linear density, weft density thread/cm and weft float or weave structure on acoustic characteristics of woven jute fabric. The following are the major findings of this study:

- It was found that the plain woven jute samples prepared with 40 tex weft yarn and 8 threads/cm weft density showed higher mean values of sound absorption coefficient as well as noise reduction coefficient compared to twill, satin weave and rest of the samples.
- This can be due to presence of more number of pores in case of plain woven samples, more inter-sections, and finer yarn result in better sound absorption compared to coarser yarn.
- The effect of weft yarn linear density and weft float on sound absorption coefficient & noise reduction coefficient was found significant whereas the effect of weft density (threads/cm) was found insignificant in current study.

Moreover, the effect of the shape and size of the pores present in fabric structure which may influence sound absorbing properties of woven fabrics through changing fabric porosity was not considered for evaluation in the current study.

Author Contributions

Conceptualization – Singh S and Kapoor RR; methodology – Singh S; formal analysis – Kapoor RR; investigation – Kapoor RR; writing-original draft preparation – Singh S and Kapoor RR; writing-review and editing – Kapoor RR; visualization – Singh S; supervision – Singh S. All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

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