Statistical analysis of yarn characteristics for multilayer fabric matrix meant for hemostasis and tissue regeneration

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ABSTRACT – REZUMAT

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Effective wound handling involves understanding the processes caused by several factors, such as the type of wound treated, the healing process, the general health of the patient (e.g., the existence of other diseases), the social environment, and the chemical and physical properties of available dressings. For the treatment of shot or burn wounds, the multilayer matrices that will be made must provide efficient oxygen permeability, but most importantly to simulate the structural and biological characteristics of the extracellular skin matrix (ECM). In order to achieve, by mechano-textile processing technologies, the textile structures that can be used as a base layer in the multilayer matrix, raw materials based on cotton, Lenpur, and bamboo mixed with zinc oxide were selected and analysed in accredited testing laboratories, from the point of view of the physical-mechanical characteristics. The results obtained in the case of the experimental program were analysed from a statistical point of view, the description of the statistical populations being made using a specialized program that allowed the calculation of the distribution parameters: mean, median, and standard deviation. To determine the outliers, for all the characteristics of the experimented variants the Q-Q Plot graphs were used. The information obtained as a result of the statistical analysis will be used to design the textile layers of the multilayer matrix using statistical techniques to create probabilistic prediction models that model the dependent variable Y is the hygroscopicity, depending on the independent variables x_1 – linear density, x_2 – twist/ply, x_3 – breaking force, x_4 – elongation at break.

Keywords: *database, descriptive statistics, Q-Q Plot graphs, skewness, kurtosis, probabilistic models*

Analiza statistică a caracteristicilor firelor pentru țesăturile matricii multistrat pentru hemostază și regenerarea țesuturilor

Gestionarea eficientă a rănilor presupune înțelegerea proceselor determinate de o serie de factori, cum ar fi tipul de rană tratată, procesul de vindecare, starea generală de sănătate a pacientului (ex. existența alor afecțiuni), mediul social și proprietățile chimice și fizice ale pansamentelor disponibile. Pentru tratamentul plăgilor împușcate sau generate de arsuri, matricile multistrat prevăzute a se realiza, trebuie să ofere o permeabilitate eficientă la oxigen, dar cel mai important să simuleze caracteristicile structurale și biologice ale matricei extracelulare a pielii (ECM). În vederea realizării prin tehnologii de prelucrare mecano-textilă a structurilor textile utilizabile ca strat de bază în componenta matricii multistrat, au fost selecționate materii prime pe bază de bumbac, Lenpur, bambus în amestec cu oxid de zinc care au fost analizate, în laboratoare de încercări acreditate, din punct de vedere al caracteristicilor fizico-mecanice. Rezultatele obținute în cadrul programului experimental au fost analizate din punct de vedere statistic, descrierea populațiilor statistice fiind realizată cu ajutorul unui program specializat, care a permis calcularea parametrilor distribuțiilor: media, mediana și abaterea standard. În vederea determinării valorilor extreme, pentru toate caracteristicile variantelor experimentate au fost utilizate graficele Q-Q Plot. Informațiile obținute ca urmare a analizei statistice efectuate vor fi utilizate pentru proiectarea straturilor textile din componența matricii multistrat, cu ajutorul tehnicilor statistice pentru crearea unor modele de predicție de tip probabilistic, ce modelează variabila dependentă Y ce este higroscopicitatea, în funcție de variabilele independente x_1 – densitatea de lungime, x_2 – torsiunea/răsucirea, x_3 – sarcina de rupere, x_4 – alungirea la rupere.

Cuvinte-cheie: *bază de date, statistica descriptivă, grafice Q-Q, asimetrie, curtoză, modele probabilistice*

INTRODUCTION

Wound dressings have to be designed to speed up the healing process and help protect the wound from contamination and moisture loss that could delay or affect its healing. The materials used as wound dressings involve films, sponges, fibres, or hydrogels of natural and synthetic polymers and combinations thereof. The ideal wound dressing has to provide efficient oxygen permeability, but most importantly has to simulate the structural and biological characteristics of the extracellular skin matrix (ECM) [1].

For the manufacture of multilayer dressings for the treatment of burns and wounds by shooting, by LBL technique, raw materials based on cotton/viscose/

acetate/bamboo/Lenpur, etc. for the base layer; carboxymethyl chitosan (CMC) for the middle layer and gelatine and alginate to obtain the porous layer are candidates.

The CMC can be grafted onto cotton fibres/yarns by an esterification reaction with the hydroxyl groups of the cellulose chains. The gelatine layer is deposited over the CMC layer. Alginate integration can be achieved by crosslinking reactions facilitated by Ca^{2+} ions in the gelatine layer [2].

Polyurethane/ polypropylene/polyethene films will be tested as an antibacterial barrier. The base layer, with the role of physical-mechanical support and rapid growth of an adhesive joint with healthy skin, adjacent to the lesion (not necessarily in the case of burns), will be made of fibres and yarns using weaving and nonwoven technologies. The layer will be sized and shaped in several variants and will include portions doped with reactive prepolymers or oligo polymers of the cyanoacrylates class, possibly seconded by fast-acting biocompatible crosslinking agents, such as functionalized poly (beta-amino-esters)/ polysaccharides.

A variant of stratified outer layer will be tested, by the physical-mechanical association of the textile material with a polyurethane film, able to protect the entire medical device against micro particulate physical impurities, excessive external moisture, including toxic compounds for military use, reached in solution in the conditions of theatres of military operations.

For the manufacture of these textile structures, raw materials based on cotton, Lenpur, and bamboo mixed with zinc oxide were selected, which were analysed from the physical-mechanical characteristics point of view. The results of the experimental program were interpreted using tools and programs dedicated to the description of statistical populations and the interdependencies between the analysed characteristics.

Table 1

EXPERIMENTED YARN VARIANTS		
Yarn variant	**Identify data**	
	Raw material	**Linear density**
V1	100% cotton	200 × 2 dtex
V2	80%/20% cotton/ZnO	150 × 2 dtex
V3	100% bamboo	300 × 1 dtex
V4	100% Lenpur	300 × 1 dtex
V5	100% acetate	130 × 1 dtex
V6	100% cotton	167 × 2 dtex

CHARACTERIZATION OF DISTRIBUTION PARAMETERS. DESCRIPTIVE STATISTICS

Description of statistical populations

The database presents the results obtained from the experiments of 6 yarn variants and represents the data regarding linear density, twist/ply, hygroscopicity, breaking force and elongation at break. The experiments were carried out in the testing laboratories within INCDTP and were coded as follows (table 1):

The description of the statistical populations was made by a specialized software application that allowed the calculation of the parameters of the distributions: mean, median, and standard deviation [3–5]. The variables and the options to be analysed were made according to the proposed statistical plan, respectively:

- statistical data processing: percentile values, dispersion, distribution, central tendency, skewness and kurtosis;
- plotting histograms and curves of normal distribution and Q-Q Plot graphs;
- output view.

The values obtained after processing the statistical populations for the linear density, twist/torsion, hygroscopicity, breaking force and elongation at break variables are presented in tables 2, 3, 4, 5 and 6.

Table 2

STATISTICS FOR LINEAR DENSITY V1 – V6							
Indicators		**Linear density V1**	**Linear density V2**	**Linear density V3**	**Linear density V4**	**Linear density V5**	**Linear density V6**
N	Valid	20	20	20	20	20	20
Mean		402.8500	296.5000	250.2000	298.8500	128.6500	347.4000
Median		402.5000	298.5000	252.0000	296.5000	129.0000	348.5000
Std. Deviation		4.20870	6.21120	6.22051	12.64609	1.46089	12.33480
Variance		17.713	38.579	38.695	159.924	2.134	152.147
Skewness		0.277	–0.170	–0.748	0.992	–1.567	–0.030
Kurtosis		–0.633	–0.536	–0.345	0.440	2.423	0.770
Minimum		396.00	285.00	238.00	283.00	125.00	323.00
Maximum		411.00	309.00	260.00	327.00	130.00	376.00
Percentiles	25	399.2500	290.0000	246.5000	290.2500	128.0000	341.2500
	50	402.5000	298.5000	252.0000	296.5000	129.0000	348.5000
	75	405.0000	301.5000	254.7500	303.7500	130.0000	353.5000

Table 3

STATISTICS FOR TWIST/ PLY V1 – V6							
Indicators		**Twist V1**	**Twist V2**	**Twist V3**	**Twist V4**	**Twist V5**	**Twist V6**
N	Valid	20	20	20	20	20	20
Mean		566.7000	719.6500	678.2500	601.2000	123.2000	705.8000
Median		568.0000	720.0000	668.5000	602.0000	124.0000	704.0000
Std. Deviation		22.66716	27.96102	39.52597	19.25343	6.78698	30.14282
Variance		513.800	781.818	1562.303	370.695	46.063	908.589
Skewness		–0.711	0.490	0.391	0.026	0.069	0.414
Kurtosis		1.560	–0.346	–1.061	–1.123	–0.035	0.949
Minimum		508.00	684.00	622.00	574.00	110.00	644.00
Maximum		612.00	784.00	756.00	636.00	138.00	776.00
Percentiles	25	557.0000	690.5000	644.5000	583.0000	118.0000	682.0000
	50	568.0000	720.0000	668.5000	602.0000	124.0000	704.0000
	75	583.0000	739.0000	719.5000	618.0000	128.0000	720.0000

Table 4

STATISTICS FOR HYGROSCOPICITY V1 – V6							
Indicators		**Hygroscopicity V1**	**Hygroscopicity V2**	**Hygroscopicity V3**	**Hygroscopicity V4**	**Hygroscopicity V5**	**Hygroscopicity V6**
N	Valid	20	20	20	20	20	20
Mean		5.162190	7.358095	11.987500	9.016500	6.300515	6.983635
Median		5.181600	7.333550	11.975000	8.980000	6.308150	7.052700
Std. Deviation		0.1406260	0.1512025	0.1560997	0.1642615	0.1224088	0.1416714
Variance		0.020	0.023	0.024	0.027	0.015	0.020
Skewness		–0.662	0.729	0.332	0.057	0.015	–2.229
Kurtosis		–0.984	–0.531	–1.586	–0.535	–1.039	5.359
Minimum		4.9230	7.1952	11.8000	8.7000	6.1263	6.5198
Maximum		5.3268	7.6685	12.2100	9.3000	6.4973	7.0891
Percentiles	25	5.019000	7.212975	11.852500	8.930000	6.224750	6.930000
	50	5.181600	7.333550	11.975000	8.980000	6.308150	7.052700
	75	5.291600	7.426150	12.177500	9.120000	6.405225	7.052700

Table 5

STATISTICS FOR ELONGATION AT BREAK V1 – V6							
Indicators		**Breaking force V1**	**Breaking force V2**	**Breaking force V3**	**Breaking force V4**	**Linear density V5**	**Breaking force V6**
N	Valid	20	20	20	20	20	20
Mean		8.1785	5.9430	3.6033	2.6075	1.3240	4.7510
Median		8.1250	5.8750	3.5700	2.7100	1.3200	4.8200
Std. Deviation		.37708	.22278	0.23297	0.35191	0.05113	0.37356
Variance		0.142	0.050	0.054	0.124	0.003	0.140
Skewness		0.023	0.266	0.135	–0.323	2.939	–0.920
Kurtosis		–1.408	–0.910	–1.310	–1.344	12.688	1.367
Minimum		7.57	5.57	3.25	2.00	1.25	7.57
Maximum		8.75	6.38	4.00	3.10	1.52	8.75
Percentiles	25	7.8475	5.7675	3.4200	2.2675	1.3200	4.5425
	50	8.1250	5.8750	3.5700	2.7100	1.3200	4.8200
	75	8.5525	6.1525	3.8150	2.9275	1.3200	5.0000

Table 6

STATISTICS FOR BREAKING FORCE V1 – V6							
Indicators		**Elongation at break V1**	**Elongation at break V2**	**Elongation at break V3**	**Elongation at break V4**	**Elongation at break V5**	**Elongation at break V6**
N	Valid	20	20	20	20	20	20
Mean		15.9310	7.4440	19.6815	8.7760	22.7085	7.1080
Median		16.6250	7.3900	19.8000	8.8950	22.3050	7.2400
Std. Deviation		2.39580	0.23002	0.95764	1.01828	2.30412	0.63678
Variance		5.740	0.053	0.917	1.037	5.309	0.405
Skewness		–0.409	0.918	–0.186	–0.522	0.344	–1.450
Kurtosis		–1.095	0.111	–0.633	–0.549	–0.813	2.845
Minimum		11.76	7.16	17.98	6.84	19.54	5.24
Maximum		19.23	7.98	21.30	10.40	27.18	7.98
Percentiles	25	13.7750	7.2800	18.9950	7.9500	20.6625	6.9050
	50	16.6250	7.3900	19.8000	8.8950	22.3050	7.2400
	75	18.0600	7.5650	20.3750	9.5875	24.7250	7.5300

By analysing the graphs from tables 2–6, can be concluded that the homogeneity of the populations is demonstrated by the fact that the value of the variability coefficient is below 11%, the average being representative and the asymmetry indicators highlight:

- for "linear density":
  - at V2, V3, V5 and V6 there is a tendency to remove the median (skewness > 1.96), with a more accentuated character in the case of V5;
  - for V1, V4 and V7 the movement trend is to the left (the average is higher than the median);
  - the distribution is leptokurtic in the case of V4 and V6 because the kurtosis values are positive;
  - the distribution presents a strong variation of the variable and a weak one of the frequencies, so it is platykurtic in the case of V1, V2, V3 and V5;
- for "twist/ply":
  - the average is higher than the median, so the displacement is to the left for variants V2, V3, V4, V5 and V6, and for V1 the displacement is to the right;
  - the negative values of kurtosis for V3, V4 and V5 determine the platykurtic curve of the distribution;
  - the positive values of kurtosis for V1, V2 and V6 determine the leptokurtic curve. For V1, the tendency to approach the maximum possible value of the normal distribution is noticeable (1.56 compared to 1.96);
- for "hygroscopicity":
  - skewness values higher than 1.96 impose the tendency to move away from the median, so the curve moves away to the right from that of N (0,1) for V1 and V6;
  - skewness values less than 1.96 displacement is to the left (average is higher than the median) for V2, V3, V4, and V5;
  - the positive values of kurtosis for the variable V6 demonstrate the leptokurtic distribution, for the rest of the variables the distribution is platykurtic, so it presents a strong variation of it in parallel with a weak variation of the frequencies;
- for "breaking force":
  - skewness for V1, V2, V3 and V5 demonstrates movement to the left and for V4 and V6 – movement to the right;
  - the vaulting index has positive values for V3, V4, V5 – the curve is leptokurtic and respectively platykurtic for V1, V2, V6;
- for "elongation at break":
  - the skewness values for V2 and V5 show movement to the left and for V1, V3, V4 and V6 – a movement to the right, so it can be said that for V2 and V5 the average is higher than the median;
  - the kurtosis index has positive values for V6 – the curve is leptokurtic so it has a weak variation in parallel with the strong variation of frequencies and respectively platykurtic for V1, V2, V3, V4 and V5.

Detection of outliers

For all the characteristics of the experimented variants, the Q-Q Plot graphs were used in order to determine the outliers, because apart from the possibility of detecting the aberrant values, they allow the verification of the normality of the distributions using the Van der Waerden estimation method [3, 5, 6]. This type of chart was preferred to boxplot charts that highlight only the indicators of level (average, median), dispersion and outliers. It is well known that for the theoretical distribution (in this case – the normal distribution) the quantile values are represented by a line that passes through the origin and has slope 1; if the points Q-Q Plot outline a line that overlaps with the line representing the normal distribution, then it can be stated that the distribution of the tested variable is normal [3, 4, 6].

The disposal of the values obtained following the experiments for the 30 characteristics is presented selectively, for 6 variables, in the graphs from figure 1. Although it was found that the points do not deviate from the straight line, which means that all the variables studied have a normal distribution, it was considered that only those with extreme data values should be viewed.

The analysis of the graphs shows:

- "linear density" – the value 295 for the V4 variant and the values: 335 and 376 for the V6 variant can be considered outliers because the values corresponding to the interquartile deviations from the corresponding straight-line of the normal distribution are high;
- "hygroscopicity" – for variant V6 the value 6.5 can be considered an outlier because it is located at a greater distance from the corresponding straight-line N(0,1);
- "twist/ ply" – the values 580 (V1) and 732 (V6) are considered outliers;
- "breaking force" – no variable shows outliers;
- "elongation at break" – the values 7.1 (V2) and 7.04 (V6) can be considered outliers.

Histograms and distribution curves

The histograms and distribution curves resulting from the calculation are illustrated for several variables from the statistical populations represented by the 6 yarn variants, respectively: "linear density V1", "twist

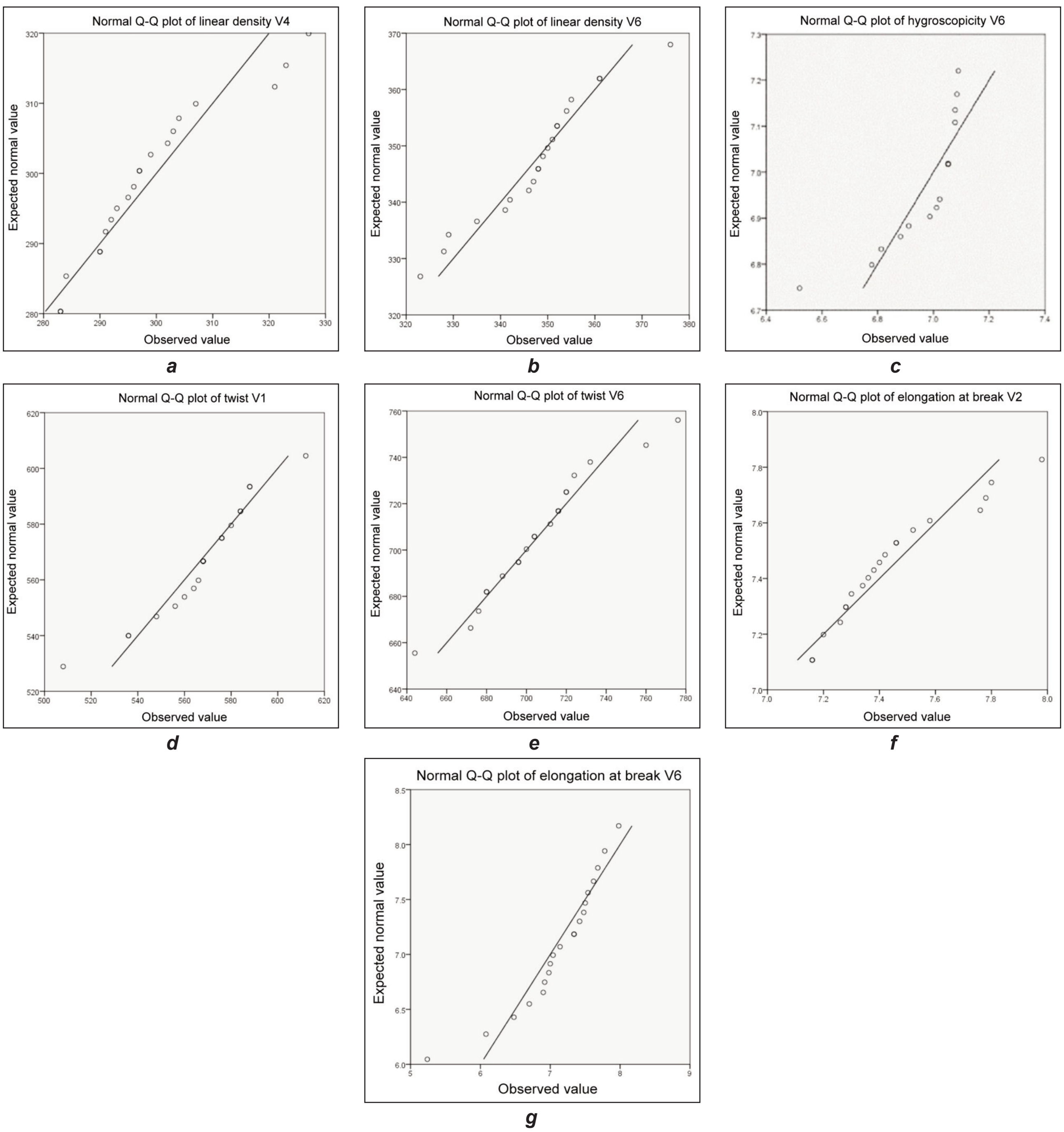

Fig. 1. The Q-Q Plot graphs for the variables: *a* – linear density V4; *b* – linear density V6; *c* – hygroscopicity V6; *d* – twist V1; *e* – twist V6; *f* – elongation at break V2; *g* – elongation at break V6

V2", "ply V5", "hygroscopicity V3", "breaking force V5", "elongation at break V4", shown in figure 2.

Interpretation of results:

- for the variable "hygroscopicity", histograms indicate an asymmetric distribution for all 6 variants tested. It should be noted that the population of the V3 variable tends to deviate from the normality of the distribution;
- in the case of the variable "breaking force", in variant V5 there was a tendency to leave the normality because the value kurtosis (1.94) is close to the maximum possible value in the case of the distri-

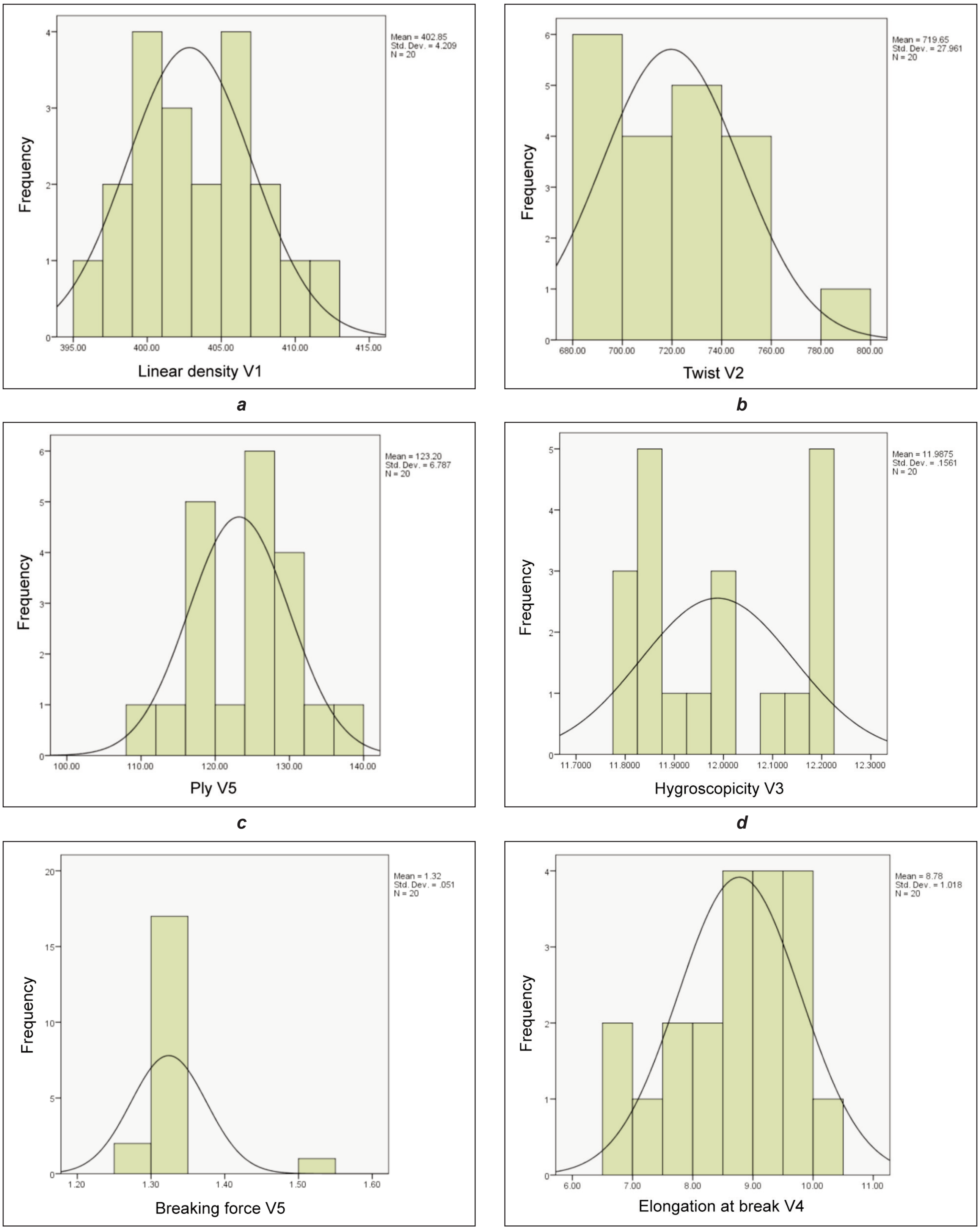

Fig. 1. Histograms and distribution curves for the variables: *a* – linear density V1; *b* – twist V2; *c* – ply V5; *d* – hygroscopicity V3; *e* – breaking force V5; *f* – elongation at break V4

bution N (0,1), which would mean the exit from the theoretical normality.

CONCLUSIONS

To describe the scores and group the obtained results after analysing the raw materials that will form the basis of the textile material layers in the multilayer matrix for hemostasis and regeneration of connective tissues in case of burns and shot wounds, the techniques provided by descriptive statistics were used.

The attributes of the 5 variables (600 values) obtained from the experiments were defined in Data Editor and Variable View of a specialized application that allowed: detecting outliers, calculating: percentile values, dispersion, mean, median, asymmetry and the skewness of the distribution; histograms and curves plotting of the normal distribution, as well as Q-Q Plot graphs.

The information obtained as a result of the statistical analysis will be used to design the textile layers of the multilayer matrix using statistical techniques to create probabilistic prediction models that model the dependent variable Y is the hygroscopicity depending on the independent variables x_1 is the linear density, x_2 is the twist/ply, x_3 is the breaking force, x_4 is the elongation at break.

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