CLASSIFICATION AND MEASURE OF QUANTITATIVE DIFFERENCE BETWEEN POLYESTER AND COTTON FABRICS BASED ON SENSORY ANALYSIS

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In this study we compare cotton and polyester (Polyethylene terephthalate) (PET) sensory attributes, as a precursor for sensory modification of polyester, for cotton replacement. We systematically identify the key sensory attributes that distinguish cotton from polyester fabrics. Rank Aggregation, Principal Component Analysis (PCA), Agglomerative Hierarchical Clustering (AHC), and the measure of distances are used to process elicited data.

1. Introduction

1.1. Fiber Market, Quality and Sensory Contexts

The proportion of global fiber consumption of cotton has steadily fallen from over 80% in the early 50's, to about 32% to date, while polyester now dominates at about 54%. PET competes with cotton in global apparel share, BOTH averaging between 31% and 36% since 2010 [1]. The exclusive use of PET in apparel is still limited due to some inferior properties, including sensory related. Textile sensory attributes may relate to: tactility, moisture, pressure, temperature, aesthetics, and acoustics; all influenced by characteristics of fiber,

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yarn, fabric, and finishing [2-4]. PET has good moisture wicking properties, and is well priced. Considering sustainability, polyester production requires less land and water to cotton. The lifecycle assessment of cotton and polyester has been detailed with pros and cons for both cotton and PET [5].

Sensory evaluation is premised on the competence of humans, to execute objective measurements of sensations. Studies have been undertaken to develop and use instruments to measure sensory related attributes [6-8]. But, measured parameters cannot directly reflect human sensation in a precise way. Multivariate analysis and methods based on intelligent techniques (e.g. neural networks, fuzzy logic) have been used to model fabric sensory attributes, in relation to process parameters and instrumental measurements [9-10]. Intelligent algorithms, which we partly employed, are particularly robust and effective, as they imitate the human process of intuition through pair-wise comparisons.

2. Experimental

2.1. Sensory Panel and Study Fabrics

The multicultural sensory panel (as per ISO 8586-1, 1993) comprised 12 adults between 20 and 50 years old, all with a textile knowledge background. Fabrics under assessment (Table 1) were handled according to ISO 5492: 2008 standard.

Table 1. Labels composition and physical properties of fabrics. The footnote describes symbols and abbreviations.

Fab**	Fiber**	Wv**	Finish	Warp Tex	Weft Tex	PPi**	EPi**	Wv Dens**	Wt** g/m^2	Thick**mm
SA	100% PET **F**	1x1 plain	None	31	28	65	76	847.3	149.2	0.276
SK	100% PET **F**	twill 5	None	38	38	53	97	1021.3	230	0.325
SC	100% CO **S**	1x1 plain	None	19	20	75	84	701.6	136	0.348
SE	100% PET **F** **M**	1x1 plain	None	18	10	65	103	709.8	94	0.17
SG	PET/CO; 33/67 **S**	twill 5	None	36	32	102	98	1182.3	258	0.76
SX	100% CO **S**	1x1 plain	Sunfo-rised	21	20	81	82	738.0	131	0.216

Fab-Fabric; **S- Spun yarn; **F**-Filament; **M**-Microfiber; PET- Polyester; **CO**- Cotton; Wv- Weave; PPi- Picks/inch; EPi- Ends/inch; Wv Dens-Weave density; Wt- Weight; Thick-Thickness.

2.2. Sensory Descriptors, Assessment and Data Processing

The judges first compiled a list of 96 sensory descriptors, from which they consensually chose 11 attributes (*Stiff, Soft, Smooth, Heavy, Noisy, Crispy, Stretchy, Drapy, Regular, Natural, and Compact*) based on frequency. For each descriptor a common evaluation protocol was then agreed. By pair-wise comparison of fabrics, each judge drew an ordinal rank list for each attribute. We then aggregated the rank lists using three methods; the Borda-Kendall (BK) method [13]; a Genetic algorithm (G.A) and Cross-Entropy Monte Carlo (C.E) algorithm based on Spearman's foot rule distance, and Kendall's Tau [14,15] using the package *Rank aggreg* in software R (The R Foundation, Austria). These intelligent iterative algorithms search for the "super"-list which is as close as possible to all individual ordered lists simultaneously. From three aggregation methods, the modal list ("super list") was taken for each descriptor. The Borda Kendall (BK) method awards weights based on position an object in a list. For a rank list $T = [x_1, x_2, ... x_k]$, *w.r.t.* universe U; $x_i \in T$; $i \in N$ (N is a set of integers of ranks of objects in T); $T(i)$ is rank of i in T; a low-numbered position indicates a higher magnitude, $\omega^T(i)$ is the normalized weight (score) of item $i \in T$.

$$\omega^T(i) = 1 - {(T(i) - 1)}/{|T|}\,; \quad \omega^T(i) = \left\{1, {1}/{|T|}\right\} \tag{1}$$

We also used the BK method to generate weights for each attribute using the "super lists" after rank aggregation. Using correlation analysis and PCA, we reduced the number of descriptors to seven. For highly correlated descriptors, we retained those with high variability of the first principal component (%age agreement) based on PCA of each descriptor. Considering textile properties and our research objective we also integrated to consider attributes that could be objectively measured, and functionally modified, in view of the research objective. PCA and AHC [13-15] were then used for further clustering. The Euclidean distance represents the gap between polyester and cotton fabrics.

3. Results and Discussion

3.1. Optimal Rank Lists, Weighting and Reduced Descriptors

Super rank lists included: *Stiff(inflexible)*- SA,SK,SC,SE,SG,SX; *Soft(not hard)*- SX,SE,SC,SG,SA,SK; *Smooth(not rough)*-SX,SE,SC,SG,SK,SA; *Heavy*- SG,SK,SC,SA,SX,SE; *Noisy(pitchy/harsh sound)*-SK,SA,SE,SX,SC,SG; *Crispy(brittle/firm)*- SK,SA,SE,SX,SC,SG; *Stretchy*-SK,SA,SX,SC,SE,SG; *Drapy*- SX,SG,SC,SE,SK,SA; *Regular(uniform/even)*-SE,SX,SK,SA,SC,SG; *Natural(non synthetic)*-SG,SC,SX,SA,SE,SK; *Compact(packed)*-

SK,SG,SC,SX,SE,SA. Variability (%age agreement) recorded from PCA of panelists: *natural* (88%), *heavy* (78%), *crisp* (75%), *noisy* (73%), *drapy* (65%), *soft* (63%), *compact* (61%), *smooth* (57%), *regular* (53%), and *stretch* (51%).

Table 2. Scores from weighted and normalized ranks for sensory attributes using the Borda-Kendall weighting method.

Fab**	Stiff	Soft	Smooth	Heavy	Noisy	Crisp	Stretchy	Drapy	Reg**	Nat**	Comp**
SA	1.00	0.33	0.17	0.50	0.83	0.83	0.83	0.17	0.50	0.50	0.17
SK	0.83	0.17	0.33	0.83	1.00	1.00	1.00	0.33	0.67	0.17	1.00
SX	0.17	1.00	1.00	0.33	0.50	0.50	0.67	1.00	0.83	0.67	0.50
SE	0.50	0.83	0.83	0.17	0.67	0.67	0.33	0.50	1.00	0.33	0.33
SC	0.67	0.67	0.67	0.67	0.33	0.33	0.50	0.67	0.33	0.83	0.67
SG	0.33	0.50	0.50	1.00	0.17	0.17	0.17	0.83	0.17	1.00	0.83

**Fab=fabric; Reg=Regular; Nat=Natural; Comp=Compact.

Correlation analysis of panelists, and factor loadings from PCA of each descriptor indicated cases of cross-over for *drapy*, *soft* and *compact*. Also, some panelists needed more training for descriptors; *soft* (4), *smooth* (5), *heavy* (1), *noisy* (2), *crisp* (2), *stiff* (2), *regular* (3), and *compact* (2). The highest positive correlations were observed between: *noisy* and *crisp* (1.0); *soft* and *smooth* (0.83*); crisp* and *stretchy* (0.83); *heavy* and *compact* (0.77); *smooth* and *drapy* (0.77); *soft* and *drapy* (0.71). Considering criteria in ***2.2***, we retained descriptors: *heavy, soft, crisp, regular, drapy, stiff, and natural.*

3.2. PCA, AHC, and Cotton-PET Distance Measure

With a factor score of 0.941, accounting for 12.65% of total variability, *crisp* was found to be the most important to the variability (Figure 1). This is very closely followed by *drapy*, with a factor score of 0.935, accounting for 12.48% of total variability. The least pertinent of the attributes was *soft*. The result shows that the perception of weight as a sensory attribute can be hinged to both actual fabric weight and fiber content; generally cotton fabrics were perceived heavier. The Euclidean distance (Table 3) indicates the measured gap between PET and cotton fabrics.

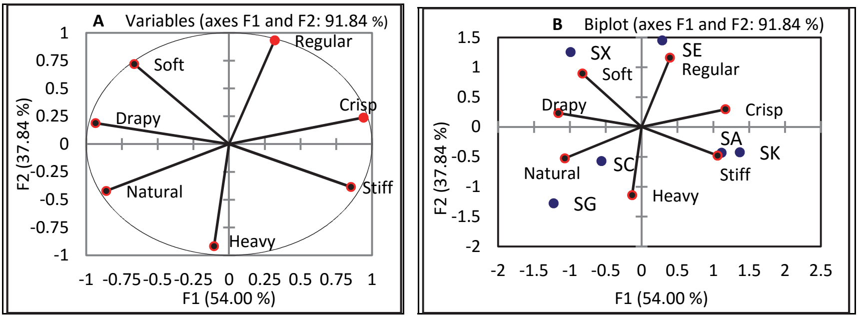

Figure 1. Correlation plot (**A**) and biplot plot (**B**) of seven sensory descriptors and six fabrics.

Table 3. Euclidean distance (d) measure between fabrics (Fab).

Fab1	SK	SE	SK	SA	SA	SK	SX	SK	SE	SA	SA	SX	SX	SA	SC
Fab2	SX	SG	SG	SX	SG	SC	SG	SE	SC	SE	SC	SC	SE	SK	SG
d	1.5	1.5	1.5	1.4	1.4	1.2	1.2	1.1	1.1	1.0	0.9	0.9	0.8	0.6	0.6

The largest distance is observed between PET and cotton, while same fiber generics exhibit less difference. From PCA and the AHC profile plot (Figure 2), polyester fabrics are particularly very *stiff*, *crispy*, moderately *regular* and substantially *heavy*. They are also the least *soft*, least *drapy*, and least *natural*. This is in contrast to Cotton fabrics in class 2 and 3.

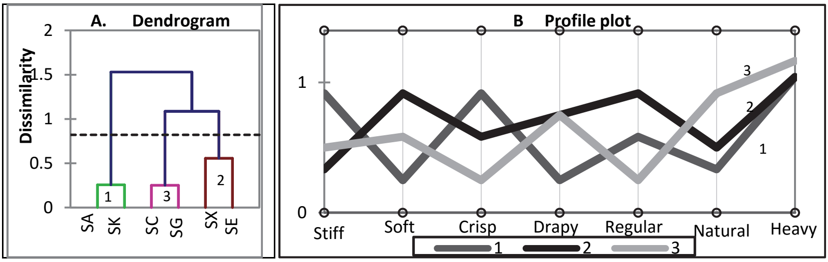

Figure 2. AHC Dendrogram (A) and Sensory profile (B) for fabric attributes showing classes drawn.

Our analysis suggests a strong correlation between *crispness* and *stiffness*, a function of several mechanical attributes. In principle, *crispness* is related to hardness, brittleness, and stiffness; mechanical properties, giving fabric less flexibility and low deformation (bending, compression). By appearance, such fabrics would appear/feel firm, *regular* (uniform surface) and less *drapy*. Polyester fabrics were defined intensive for this descriptor. In the context of cotton replacement by PET, focus should aim at reducing the crispness of PET; reducing stiffness of PET with reference to cotton. Obviously, beyond fiber generic, there's expected effect of the different fiber, yarn and fabric parameters on the sensations evaluated.

4. Conclusions and Prospects

This study has identified crispness and drape as key sensory attributes that account for variability, and the gap between polyester and cotton. Intelligent algorithms and multivariate analysis were precisely used in handling the multi-dimensional sensory data, leading to precise relationships. The Euclidean distance was used to establish the gap between cotton and PET fabrics. By using appropriate techniques, we can therefore modify the crispness, of polyester in reference to cotton, to reduce this gap. Our future analysis will present the use of specific functional techniques towards reducing the measured gap between PET and cotton fabrics, and the effect of such functionalization on fabric performance aspects. We will also present the comparison and modeling of objective measurements related to sensory parameters, with human evaluation.

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References

1. The Fiber Year 2014. World Survey on Textiles And Nonwovens.
2. H. Nakano, *J. Soc. Fib. Sci. Tech Japan.* **50 (8)**, 473 (1994).
3. M. Dhinakaran, S. Sundaresan and B. S. Dasaradan, *Indian Text J.* **32**, 2 (2007).
4. E. Kamalha, Y. Zeng, S. Kyatuhaire and J. I. Mwasiagi, *J. Sens. Stud.* **28**, 423 (2013).
5. N. M. van der Velden, M. K. Patel, J. G. Vogtländer, *Int J Life Cycle Assess*. **19(2)**, 331 (2014).
6. F. Sun, R. A. M. Asad, Z. Du, W. Yu, and N. Chen, *Fibers Polym.* **16 (6)**, 1395 (2015).
7. R. Abghari, A. H. Ostovari and S. M. Karbassi**.** *IJE Trans. B.***24 (4)** 387 (2011).
8. Z. Mei, W. Shen, Y. Wang, J. Yang, T. Zhou, and H. Zhou. *PLoS ONE* **10**.11 (2015): e0143648. doi:10.1371/journal.pone.0143648.
9. A. S. W. Wong, Y. Li, P. K. W. Yeung, and P. W. H. Lee, *Text Res J.* **71**, 331 (2003).

10. X. Zeng, L. Koehl, M. Sahnoun, M. A. Bueno, and M. Renner, *Int. J. Gen. Syst.* **33 (2/3)**, 243 (2004).
11. ISO 8586-1, (1993). Sensory analysis- General guidance for the selection, training and monitoring of assessors- Part 1: Selected assessors.
12. ISO 5492:2008: Sensory Analysis- Vocabulary.
13. D. Sculley. Proceedings of the SIAM International Conference on Data Mining. pp 587-592 2007.
14. V. Pihur, S. Datta and S, *BMC Bioinformatics,* **10,** 62 (2009).
15. I. T. Jolliffe, *Principal Component Analysis*. Springer-Verlag, 2002.