A Statistical Model to Assess the Softness of Hygiene Tissue Paper Containing Alternative Fibers

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ABSTRACT

Industrial standard tissue measurement techniques present challenges to correctly assess the softness of hygiene tissue products when containing alternative fibers such as wheat straw, switchgrass, miscanthus, bamboo, or sorghum fibers. To bridge this gap, the Sustainable and Alternative Fiber Initiative (SAFI) developed a statistical model that predicts the handfeel softness score for tissue products containing non-wood fibers. This model considers data from both the Fiber Quality Analyzer (e.g., fiber length) and the TSA (Tissue softness analyzer) parameters (e.g., TS7) to provide up to 98% correlation with handfeel values obtained from panel tests. The statistical model will enable the pulp & paper industry to assess softness adequately for hygiene tissue products containing alternative fibers.

1. INTRODUCTION

The hygiene tissue industry relies on attributes such as softness, bulk, tensile strength, and brightness. Among these, softness is one of the key attributes influencing consumer acceptance and preference [1–3]. Traditionally, softness evaluation has been conducted via panel tests employing methods like ranking, paired comparison, and rating tests [2]. These methods, however, are limited by their subjective nature. To overcome these limitations, instruments like the Tissue Softness Analyzer (TSA) have been developed, offering objective measurements of tissue softness by simulating human touch and measuring resulting vibrations. The TSA evaluates both surface components (fiber stiffness and surface roughness) and bulk softness, providing a more comprehensive understanding of tissue softness [2,4–7].

Various instruments have been developed for objective softness measurement of hygiene tissues, reflecting physical properties, yet their effectiveness has limitations. The Tissue Softness Analyzer (TSA) uses vibrations after a rotating lamella disturbance on the surface to measure surface softness (TS7) and surface roughness (TS750), crucial for softness perception. Additionally, TSA assesses bulk stiffness (D) by measuring sample displacement under force, integrating surface and bulk softness components [2,4]. Aiming to understand softness behavior in relation to tissue properties, some studies have identified a significant correlation between certain fiber and tissue

sample properties and panel test scores. These studies have led to the development of models that can explain and predict the softness of hygiene tissue products made from conventional fibers, effectively eliminating the need for time-consuming panel tests (Table 1) [2,8,9]. Nevertheless, the correlation between TSA measurements and panel test scores varies, especially when assessing handsheets made from alternative fibers (e.g., wheat straw, miscanthus, switchgrass, bamboo), indicating the need to develop an algorithm and mathematical model that allows predicting the softness of hygiene tissue with non-wood fibers content.

Table 1. Previous studies on the relationship of fiber properties, among them coarseness with the softness of hygiene tissue

Type of Pulps	**Case Study**	**Fiber Properties**	**Statement**	**Softness Measurement**	**Author**
Chemical Pulps	Hardwoods, Softwoods, Kenaf Bast, Bamboo	Low coarseness in non-woods, similar to hardwoods. Medium fiber length and width in Kenaf. Low fiber width and short fibers in bamboo, similar to hardwoods.	Coarseness highly correlated with softness.	Surface tester KES-SESRU	[10]
Chemical Pulps	Hardwoods, Softwoods, Deinked Pulp, Non-Woods	Low coarseness in hardwoods: thinner cell walls impart more softness, thicker walls more bulk and absorbency Deinked pulps: high rigidity, high fines content, low inter-bonding, and softness Bamboo: lower fines content and longer fibers than wheat straw pulps, higher fines content than wood pulps Bamboo's coarseness is like wheat straw and hardwoods (lower)	Low coarseness imparts surface softness High and flexible bulk imparts bulk softness Refining, densification, and bleaching affect softness	Panel test and Tissue Softness Analyzer (TSA), note low correlation	[3]
Chemical Pulps	Hardwoods, Softwoods, Bamboo (Creped and Uncreped)	BEK lower coarseness compared to SBSK BEK has short fibers, thinner cell walls, and high flexibility	Creping enhances bulk, porosity, absorbency, and softness Refining forms flat surface Creping promotes Z-oriented fibers on the paper surface	Panel test and Tissue Softness Analyzer (TSA), note: low correlation for creped and uncreped	[11]
Chemical Pulps	Hardwoods, Softwoods, Non-Woods (Creped)	Substitution of softwoods by non-woods forms slightly lower calipers.	TS7 correlated with D (Stiffness) and TS750.	Tissue Softness Analyzer (TSA), no panel tests	[12]

Herein, we introduce a novel approach using Thurstone's Law of Comparative Judgment to assess softness through paired comparison tests, aiming to provide a more effective evaluation of tissue softness across a diverse set of fibers. Then, we combine TSA parameters with fiber morphology and key handsheets properties to create a comprehensive statistical model for evaluating softness, particularly in samples made from non-wood fibers.

2. METHODOLOGY FOR ASSESSING THE SOFTNESS OF TISSUE HANDSHEETS

The methodology for assessing tissue softness involves a comprehensive approach that combines sensory panel tests, properties measurement, Tissue Softness Analyzer (TSA) and Fiber Quality Analyzer (FQA) measurements, and statistical analysis (Figure 1). The TSA measures three basic parameters: TS7 (real softness), TS750 (surface smoothness), and D (inverse bulk stiffness). Only TS7 and D were taken into consideration because TS750 presents large variability when using the TSA methodology for uncreped handsheets [13,14]. Uncreped handsheets were produced according to the modified TAPPI method (Figure 2) [15]. with a basis weight of 30 GSM and up to 30 % non-wood content. Unrefined wheat straw, switchgrass, miscanthus, bamboo, and sorghum fibers were obtained through alkaline peroxide mechanical pulping at 6 wt.% NaOH and 6 wt.% H_2O_2, NBSK (Northern Bleached Softwood Kraft) market pulp, refined at 1,000 PFI rev. by using a PFI refiner (PFI Mill – nr.312, The Norwegian Pulp and Paper Research Institute), and BEK (Bleached Eucalyptus Kraft) market pulp. Methods are presented in Table 2. An example of the data used in the present research is shown in Table 3, including basic furnish and handsheet properties, among them freeness, bulk (cm^3/g), tensile index (N.m/g) and tear index ($mN.m^2/g$). All the measured variables have a standard deviation lower than 5%.

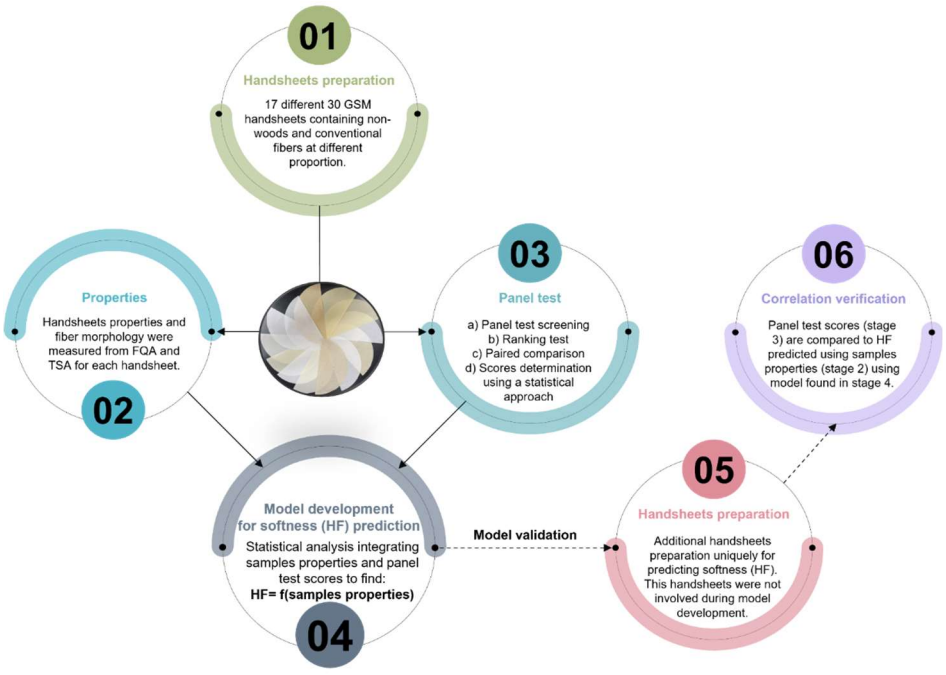


Figure 1. Methodology and algorithm to develop a statistical model to predict the handfeel of handsheets from FQA and TSA data.

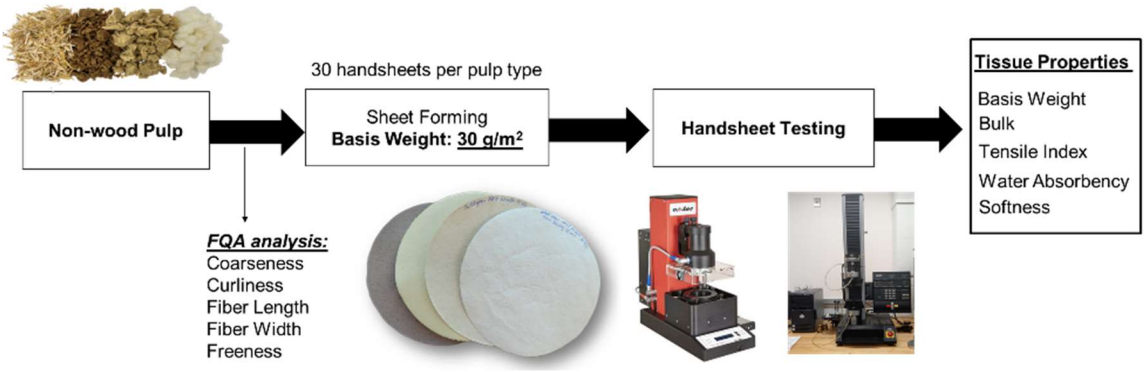


Figure 2. Schematic representation of handsheet formation and properties assessment for hygiene tissue applications. Non-wood pulp was obtained with alkaline peroxide mechanical pulping (APMP).

Table 1. Methods for the measurement of sample properties.

Method	Equipment/Specification	Reference
Fiber Quality Analysis (FQA)	OpTest, FQA-360, no chemicals added	[3]
Tissue Handsheet	Modified TAPPI T 205 sp-02, 2006 (NCSU method)	[16]
Freeness	TAPPI T 227 om-99	[16]
Tensile Index	Instron® model 4443 - TAPPI 231 cm-07	[16]
Bulk	ISO 12625-8	[16]
Softness	TSA, Emtec Electronic GmbH, Leipzig, Germany	[3,16,17]

2.1 Optimized Sensory Panel Test (O-SPT) Methodology

The panel tests comprised a three-stage methodology:

- Two-part screening of the panelists: A two-stage screening was designed comprising of discrimination tests. A three handsheet ranking test followed by a triangle test (Alternate Forced Choice, AFC), both conducted blindly (Figure 3), allowed discerning perceptible differences in softness.
- Ranking test: A blind panel test was conducted using a ranking-rating system, involving seventeen handsheets, each comprising a unique pulp blend, were used (Table 3). Among the samples, one served as the reference sample to establish the softest point along the attribute intensity continuum, with 0 representing the absence of the attribute and 100 representing the highest presence (softest).
- Round-Robin paired comparison tests: A round-robin paired comparison test was selected to assess the HF of the handsheets, considering the small differences between samples on the softness scale. However, one limitation of this approach is the increase in the number of comparisons as the sample size grows. Thurstone's theory addresses this issue by employing subgrouping, which reduces the number of comparisons by dividing the samples into smaller sets. In the present case 13 samples were subjected to a paired comparison test with 17 screened panelists and 4 subgroups, for a total of 24 comparisons by panelist. Thurstone's theory enables

the creation of a softness scale from the collected data. This method has been successfully applied in a study evaluating the softness of seven tissue samples, demonstrating its applicability to the tissue industry [6,18]

This methodology allowed us to ensure representativeness and reproducibility, as humans have different perceptions and are not always consistent. Controlled conditions were utilized, including washing, drying, and avoidance of creams. Upon entering, panelists washed their hands with a standard soap, and dried them with provided paper towels. The hand actions recommended to the panelists were the following [19]:

- 1st hand action: caress the sample surface in both directions with the fingertips or the hand wrist, applying minimal pressure.
- 2nd hand action: compress the sample inside the palm of the hand.
- 3rd hand action: rub the sample between the thumb and the finger, applying pressure

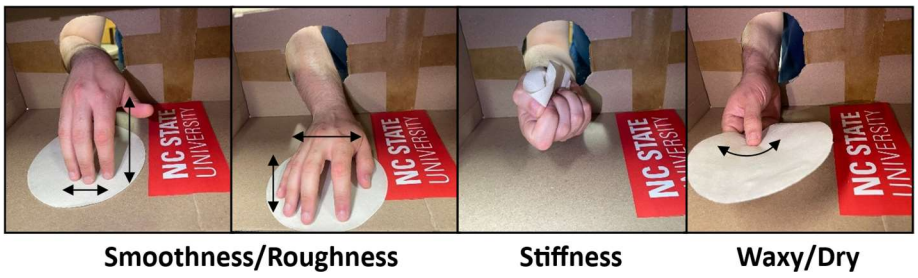


Figure 3. Hand action during panel testing.

Table 3. Results of sample properties. The handsheets are uncreped, with a basis weight of 30 GSM, and contain up to 30% non-wood content from unbleached APMP pulp.

Sample	NBSK	BEK	Freeness	Bulk (cm^3/g)	Tensile Index (N.m/g)	Tear Index (mN*m2/g)
A	0%	100%	605	4.30	8.4	1.7
B	15%	85%	610	4.48	11.2	3.4
C	45%	55%	650	4.90	13.8	7.1
D	Wheat Straw Up to 30%		635 - 650	4.87 - 4.91	9.7 - 12.7	2.7 - 4.2
E						
F	Miscanthus Up to 30%		645 - 670	4.90 - 5.20	10.7 - 12.9	3.2 - 3.4
G						
H	Switchgrass Up to 30%		625 - 635	4.80 - 5.10	12.3 - 13.2	4.0 - 4.1
I						
J	Bamboo Up to 30%		640 - 660	4.80 - 5.10	12.3 - 14.8	4.1 - 4.8
K						
L	Sorghum Up to 30%		630 - 635	5.00 - 5.20	11.5 - 13.6	3.5 - 4.0
M						

3. RESULTS AND DISCUSSION

This work demonstrates that the Tissue Softness Analyzer (TSA) alone cannot accurately assess the softness of tissue products containing non-wood fibers (e.g., up to 30% Wheat Straw) compared to those containing only conventional fibers (e.g., 100% BEK). In Figure 4, the D blend, as described in Table 3, despite having a lower TS7 value (19.8 ± 1.4 dB) which suggests higher surface softness, presents lower handfeel (HF) when compared to 100% BEK (TS7 = 20.8 ± 1.0 dB). This indicates that the concept of TS7 (lower value → higher softness) does not hold when alternative fibers are incorporated into tissue products. This discrepancy suggests that TS7 values might predominantly reflect surface properties and fail to fully capture the softness perception, especially in samples with notable bulk property differences. Mechanical pulps, with their higher lignin content, create bulkier and stiffer and coarse fibers, adversely impacting the softness of hygiene tissue products. Thus, the nature of the fibers, including their chemical composition and pulping method, plays a crucial role in determining the final product properties. In Figure 4, the correlation between HF from panel tests and TS7 from TSA measurements is shown to be around 58%, indicating that TS7 values might not sufficiently differentiate handsheets made from varied fiber types [3]. According to previous research, the behavior of softness is not just dependent on a single property but is believed to be a synergistic effect of surface and bulk components [11,14].

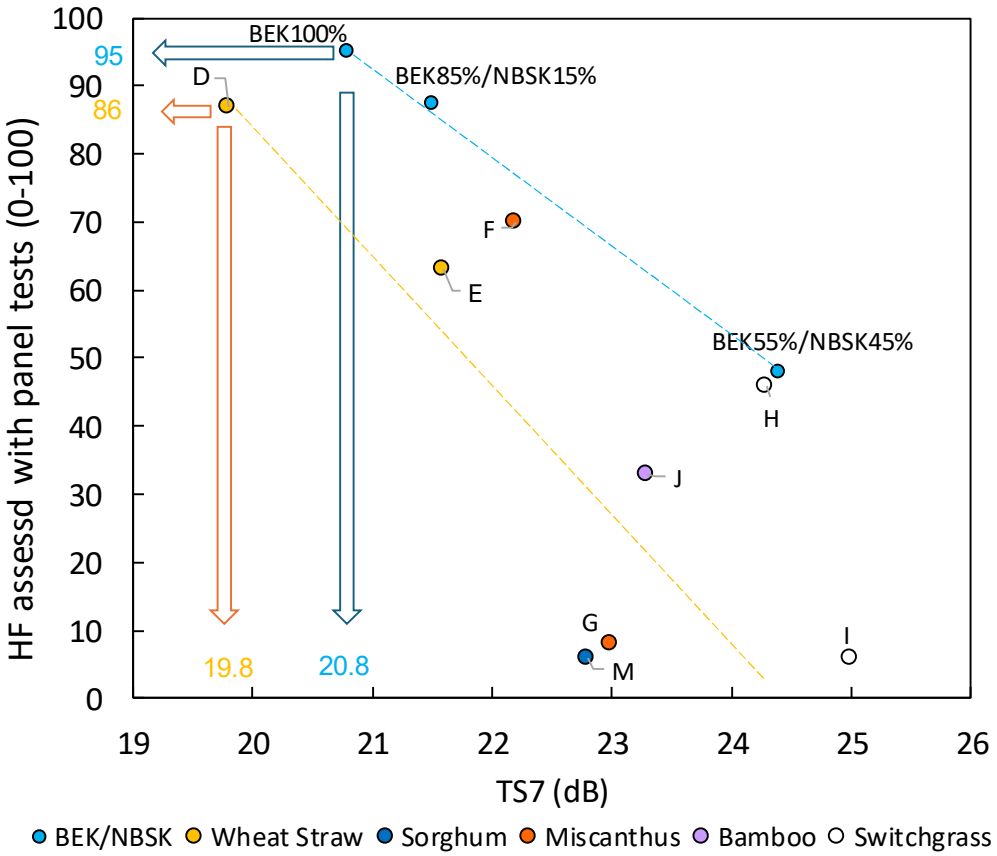


Figure 4. Handfeel score obtained with round robin paired comparison panel tests vs. TS7 measured with the tissue softness analyzer (TSA). BEK: Bleached eucalyptus kraft, NBSK: Northern bleached softwood kraft.

A correlation has been observed between sample properties, TSA, FQA, and handsheet properties such as bulk, and tensile index (Figure 5). The present research shows that the influence of bulk is linked to the addition of non-wood pulps to conventional blends, which increases bulkiness, resulting in coarser fibers that reduce softness [3]. This indicates that fiber morphology and the pulping method can significantly impact the final properties of tissue products, suggesting that higher bulk stiffness and fiber stiffness lead to less soft handsheets [20].

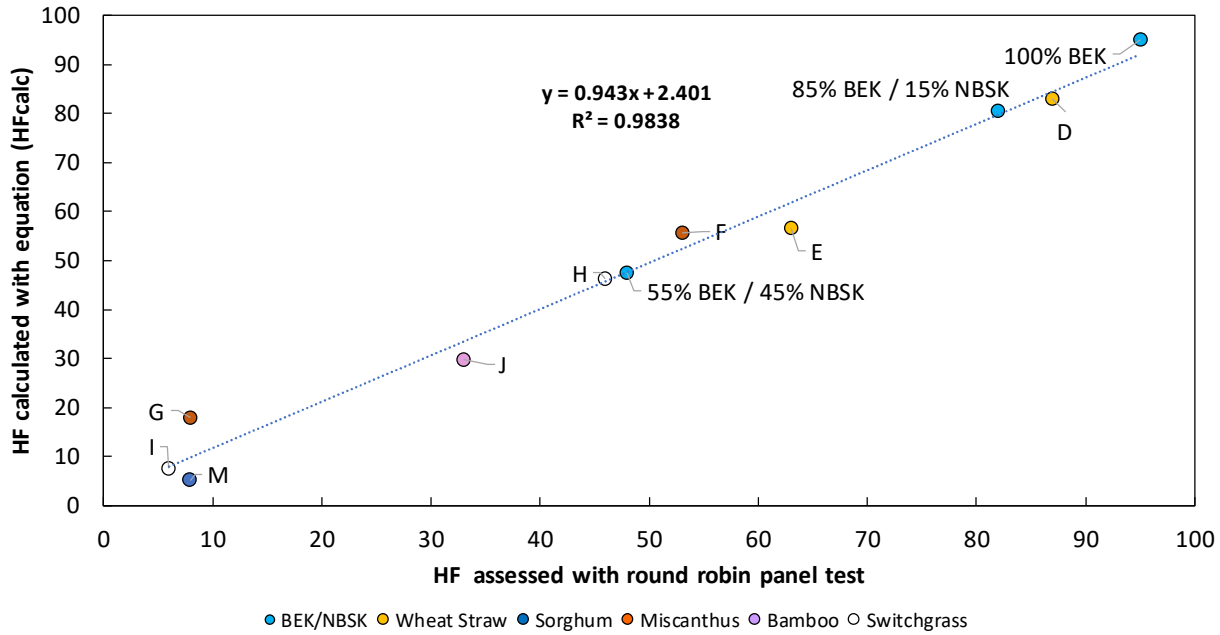


Figure 5. Handfeel score (HF) obtained with round robin paired comparison panel test vs. results calculated from the equation (statistical model) obtained from least squares fit with TSA, FQA and properties values performed in statistical software. BEK: Bleached eucalyptus kraft, NBSK: Northern bleached softwood kraft.

The statistical model developed in the present work (Eq. 1) shows that the handfeel score is negatively correlated with coarseness, length and TS7, while it shows a positive correlation with the inverse of stiffness (D). This is in agreement with previous works presented, as summarized in Table 1. Notably, a lower coarseness is strongly correlated with increased surface softness. Furthermore, lower stiffness (higher D values) has also been previously associated with a higher HF score [3,20]. We will further validate results in the future with studies on creped tissue sheets.

$$HF_{prediction} = f(-coarseness, +D, -Length, -TS7) \text{ (Eq. 1)}$$

4. CONCLUSIONS

The Tissue Softness Analyzer (TSA), while effective in evaluating certain aspects of softness, encounters limitations in accurately assessing uncreped tissue products containing non-wood fibers, such as wheat straw. The TSA's reliance on surface softness metrics like TS7 may not fully encapsulate the softness perceived by consumers, particularly in blends where the bulk properties significantly differ from those of conventional wood fibers. The type and nature of fibers used in tissue products are critical determinants of their final softness. Mechanical pulps, characterized by

higher lignin content, tend to produce bulkier and stiffer fibers, negatively impacting the overall softness of the product. This highlights the importance of considering both the chemical composition and the pulping method in the production of soft tissue products. Discrepancies between TSA measurements and panel test perceptions of softness, especially in blends incorporating non-wood fibers, indicate the necessity for a more comprehensive approach to softness evaluation that accurately reflects consumer perception. Understanding the complex relationship between fiber characteristics and softness is crucial for manufacturers aiming to develop soft tissue products that include non-wood fibers.

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