

PHYSICAL PROPERTIES CORRESPONDING TO COMFORT FEEL OF BEDDING FABRICS

Saracha Kitchagan¹, Phannaphat Phromphen¹, Aussama Soontrunnarudrungsri², and Pithalai Phoophat^{1,*}

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Abstract

The market for bedding products in Thailand now offers a wide range of physical attributes (fiber types, structures, fabric densities, thicknesses, and weights) that produce a variety of tactile sensations and comfort qualities. This study investigated the comfort properties of bedding fabrics in Thailand. Twenty-one bedding fabric samples were collected and measured for their mechanical and surface properties based on the Kawabata evaluation system for fabric (KES-F) as well as the horizontal wicking test and abrasion resistance, air permeability, wrinkle recovery, and thermal resistance (Qmax). The primary hand value (HV) and total hand value (THV) were calculated using the Kawabata hand evaluation equation KN-201-LDY describing women's thin dress fabric, using 5 different properties from the KES-F (tensile, shear, bending, compression, and surface friction). The principle component analysis (PCA) and cluster analysis of the physical properties of fabric samples showed that the samples could be placed in 4 groups. The first group was mostly cotton woven samples. The second group consisted of 2 samples that were both knitted, while the third group was mostly mixed (M) fabric samples. The last group contained cotton and M cotton samples. The first cluster was considered to provide the best hand-feel characteristics of all 4 clusters, while the second cluster was considered the least desirable based on hand-feel. The findings of this study should assist the bedding textile sector in developing new products.

Keywords: Bedding textiles; comfort properties; fabric properties; hand value; Kawabata evaluation system

Introduction

Currently, the market for bedding in Thailand offers a wide variety of products with a variety of physical characteristics such as fiber type, fabric structure, fabric density, thickness, and weight. These products also offer a diverse range of tactile sensations, comfortable qualities, sizes, and prices. Generally, people mostly spend at least six to eight hours per day on bedding, which means bedding fabrics potentially affect health and well-being based on the quality of sleep that the material used

¹ Department of Textile Science, Kasetsart University, Bangkok, Thailand. E-mail: pithalai.p@ku.th; saracha.k@ku.th, phannaphat.ph@ku.th

² Department of Product Development, Kasetsart University, Bangkok, Thailand. E-mail: aussama.s@ku.th

* Corresponding author

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in bedding provides. The quality of sleep should improve when the bedroom and bed environment are suitable.

The material used for bedding enhances the tactile experience but it is limited by budgetary considerations (Fahritdinovna *et al.*, 2022). Sensory evaluation for textile was essential in order to evaluate and analyze the components affecting fabric contact (Mäkinen *et al.*, 2005). The Kawabata evaluation system for fabric (KES-F) was introduced to evaluate the tactile properties of fabrics based on five characteristics including tensile, shear, bending, compression, and surface friction (Kawabata and Niwa, 1996). The primary hand value (HV) and total hand value (THV) in the Kawabata hand assessment equations (KN-201-LDY) are calculated and used to describe a woman's summer outfit using the following four keywords; stiffness, smoothness, fullness, and softness. Stiffness (koshi) is a sensation that is primarily associated with bending rigidity. This sensation is enhanced by a product that features springiness. A high value is assigned to a fabric that had a dense compact weave and was constructed from yarn that is springy and elastic. Smoothness (numeri) is a complex sensation that combines smooth, supple, and soft feelings. Fullness (fukurami) is the result of combining several sensations such as bulky, rich, and well-formed impressions. This attribute is directly related to a springy quality in compression and thickness, which is accompanied by a warm sensation. Softness (sofutosa) is a feeling derived from a combination of soft with a flexible, smooth, and bulky feelings. Some previous research used the KES-F to evaluate fashion and apparel (Phoophat and Sukigara, 2016; Basit *et al.*, 2018; Utkun 2021). Another study reported that the THV of cotton bed sheet fabric was higher than for a mixed cotton fabric (Sundaresan *et al.*, 2016), whereas the blending of viscose and cotton fiber with linen could improve the HV of linen fabric (Behera, 2007).

Skin temperature, rapid temperature change and sweating were also significantly influenced to sleep quality (Amrit, 2007). For example, the thermal properties of bedding and sleepwear in steady-state and transient ambient temperature conditions were logically important factors (Troynikov *et al.*, 2018). The amount of perspiration experienced during sleep and the impression of dampness affected on the emotional state of the person as well as their capacity to get to sleep (Zbikowski and Loker, 1992). The major requirements of a bed sheet were comfort, have a nice touch, durability and easy to care for (Babu *et al.*, 2021). In particular, the older people might have special problems and needs according to their physical changes. (Bubpa and Nuntaboot, 2017; Panyasaisophon *et al.*, 2019).

Bedsheets should offer certain thermal insulation and sufficient water vapor permeability and a dry contact feeling during sleeping even under sweating conditions. Research-based bedsheet recommendations include the suitability of, cotton/polyester knitted sheets was suitable for winter, while heavy and thin cotton woven sheets were recommended for summer (Hes *et al.*, 2014). In addition, 100% cotton warp and 80% lyocell/20% linen weft would be an optimal approach for bedding fabrics (Bilen, 2019). Comfort properties, such as moisture management, thermal resistance, horizontal wicking property, and air permeability, were used to evaluate the bedsheets made with different types of fabric (Hawas 2020, Dubale *et al.*, 2021). Other research has investigated properties such as abrasion resistance, pilling, snagging, drape, and crease recovery with comparisons among the different types of bedsheets in order to propose the best bed sheet (Atalie and Ashagre, 2020).

The current research aimed to study the mechanical and comfort properties of 21 different bedding fabrics currently available in Thailand. These fabrics were categorized according to their properties based on PCA analysis. PCA is one of the most popular multivariate data analysis methods that can investigate multidimensional datasets with quantitative variables. PCA projects observations from a p-dimensional space with p variables to a k-dimensional space (where $k < p$) to conserve the maximum amount of information in the form of the total variance. PCA dimensions are also called axes or factors. If the information associated with the first 2- or 3- axes represents a sufficient percentage of the total variability of the scatter plot, the observations could be represented on a 2 or 3-dimensional chart to make interpretation easier. PCA helps with visualizing the correlations between variables to be able to limit the number of variables to be measured as well as to identify uniform or different groups of observations. The evaluation of these comfort features of bedding fabric in Thailand should provide essential data on the properties of bedding fabric for future research.

Materials and Methods

Samples

Twenty-one different bedding sheets (Figure 1) were purchased from a local market and a department store in Bangkok, Thailand. The physical properties of these samples were evaluated. Fabric structure was examined under an Olympus CX31 Binocular microscope. A microscope images of a samples is shown in Figure 2. Nineteen samples were woven fabric (W) with various structures,

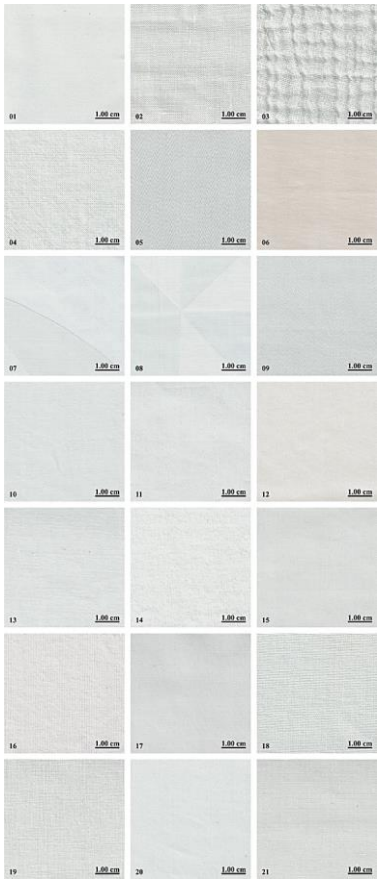


Figure 1. Shows Scanned images of samples

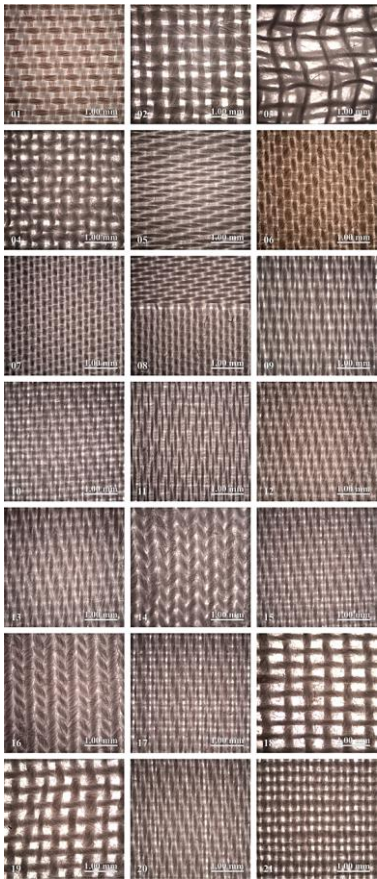


Figure 2. Shows Microscope images of samples

consisting of plain weave, twill, satin, and three layers. The other two examples were knitted fabric (K). Fiber types of fabrics were determined based on Thai Industrial Standards Institute No. 121 Volume 26-2009. There were two primary categories for fiber types: natural fiber (N) and mixed fiber (M). It was found that some bedsheets contained N fiber such as cotton, linen, and bamboo fiber. The others contained N fiber mixed with polyester or Tencel™ (known as lyocell fiber) which is regenerated fiber with 100 percent cellulose; the polymer chain length is longer than rayon but not long as cotton. The thread count was determined using a counting glass according to ISO/CD 7211-2. In the case of the W fabric structure, thread count was carried out along the warp and weft directions, using a dissection method which is appropriate for all types of fabric, including folded structures. For the K fabric loops were counted in the wales and courses directions. To ensure that the test piece was representative of the fabric sample, the yarn was counted three times at randomly selected locations. For woven fabric, the number of ends per inch was in a range of 52-215 threads whereas, the number of

picks per inch was in a range of 41-292 threads. Sample thickness was measured using a digital thickness gauge. The thickness of most fabrics was in the range of 0.21-0.34 mm, except for samples 03, 06, and 04 that had thicknesses 0.75, 0.58, and 0.46 mm, respectively. Fabric weight was measured according to ISO 3801 and was in the range of 92-186 grams per square meter (gsm).

The specification of all samples are shown in Table 1.

Characterization of Mechanical and Surface Properties

The mechanical and surface characteristics of the samples were evaluated at 20°C and 65% relative humidity based on the KES-F. Fabric specimens were cut into 20×20 cm pieces. Under the standard measuring conditions (Phoophat *et al.*, 2020), these characteristics, including tensile, shear, bending, compression, and surface properties, were measured repeating three times for each test. The characteristic values of all properties and testers are listed in Table 2.

Table 1. Shows Physical properties of samples

Sample	Structure	Fiber type	Warp/wale (per inch)	Weft/course (per inch)	Thickness (mm)	Weight (gsm)
01	W	M	136	187	0.21	119.00
02	W	N	62	58	0.31	137.85
03	W	N	98	118	0.75	132.10
04	W	N	71	76	0.34	121.55
05	W	M	208	95	0.24	150.75
06	W	M	194	126	0.24	150.47
07	W	M	134	287	0.26	157.93
08	W	M	132	292	0.23	149.17
09	W	N	206	83	0.24	133.45
10	W	N	181	123	0.22	122.30
11	W	N	91	248	0.22	119.60
12	W	N	215	103	0.22	125.40
13	W	N	196	94	0.25	119.55
14	K	N	40	60	0.46	153.70
15	W	M	207	115	0.24	128.50
16	K	M	40	70	0.58	185.60
17	W	M	202	118	0.24	126.30
18	W	M	58	41	0.30	92.15
19	W	N	52	53	0.30	100.60
20	W	N	195	105	0.22	113.40
21	W	N	114	84	0.21	107.30

*W=Woven fabric, K=Knitted fabric, M=Mixed fiber and N=Natural fiber

Table 2. Shows Surface properties based on Kawabata evaluation system

Property	Parameter symbol	Characteristic value	Unit	KES machine
Tensile	EM	Fabric extension at 500 N/m width	%	KES-FB1-Auto
	LT	Linearity of load-extension curve	-	
	WT	Tensile energy	J/m ²	
	RT	Tensile resilience	%	
Shear	G	Shearing stiffness	N/m	KES-FB1-Auto
	2HG	Hysteresis of shear force at a shear angle of 0.5 degrees	N/m	
	2HG5	Hysteresis of shear force at a shear angle of 5 degrees	N/m	
Bending	B	Bending rigidity	μNm	KES-FB2-Auto
	2HB	Hysteresis of bending moment	Nm	
Compression	LC	Linearity of compression-thickness curve	-	KES-FB3-Auto
	WC	Compression energy	J/m ²	
	RC	Compression resilience	%	
Surface	MIU	Coefficient of friction	-	KES-FB4-Auto
	MMD	Mean deviation of MIU	-	
	SMD	Geometrical roughness	μm	

The HV and THV parameters were rated to evaluate the fabric quality using the Kawabata hand assessment equation KN-201-LDY for women's thin dress fabric. This predictive equation was generated using fabric mechanical data for various materials, which were closest to the materials in this research. The 4 primary hands for a women's thin dress are stiffness (*koshi*), smoothness (*numeri*), fullness and (*fukurami*), and softness (*sofutosa*). The 5 parameter values from KES were substituted into the equation by adding the HV standardization and coefficient value for each parameter to obtain the HV values. The HV values were substituted into the equation to obtain the THV value. For the HV rating, a grade of 10 indicates the strongest feeling,

while a grade of 0 indicates that there is no feeling at all. For the THV rating, a score of 5 indicates high quality, while a score of 0 indicates that the fabric cannot be used in any application.

Characterization of Comfort Properties

Since the bedsheets should provide thermal insulation, sufficient water vapor permeability, and a dry touch feeling during sleeping, the comfort properties need to be investigated. Thermal resistance (Q_{max}) was evaluated by using KES-F7 from the Kawabata instrument. Air permeability was measured according to ASTM D737-2018. Abrasion resistance was evaluated according to standard ASTM D4966-98 using a Martindale 2000

Table 3. Shows Primary hand value and Total hand value of 21 samples

Sample	HV				THV
	Stiffness (koshi)	Smoothness (numeri)	Fullness (fukurami)	Softness (sofutosa)	
01	6.255	10.049	9.662	5.420	4.457
02	6.756	6.433	8.115	4.146	4.215
03	5.211	6.616	9.430	6.988	3.699
04	5.931	7.651	9.863	5.309	4.161
05	6.517	10.507	10.467	6.531	4.099
06	6.695	9.566	9.926	4.910	4.442
07	6.274	8.073	8.800	4.091	4.513
08	6.919	7.789	8.646	3.247	4.489
09	5.565	9.763	9.437	6.015	4.397
10	6.279	7.678	9.167	4.914	4.338
11	6.271	10.421	10.781	6.376	4.046
12	6.399	9.486	10.346	5.604	4.259
13	5.700	9.861	10.560	6.167	4.130
14	6.311	9.412	10.972	6.387	3.955
15	6.571	8.189	9.518	4.157	4.419
16	5.119	9.851	11.677	7.797	3.404
17	6.536	8.315	9.629	4.240	4.414
18	5.808	6.953	8.805	4.536	4.255
19	5.913	4.405	7.163	1.870	3.424
20	6.213	9.538	10.179	5.458	4.320
21	6.623	8.454	9.779	5.240	4.327

abrasion resistance tester based on 10,000 cycles at 9 kPa (Atalie and Ashagre, 2020). The percentage of weight loss was calculated using the equation.

$$\text{Weight loss (\%)} = ((A-B)/A) \times 100$$

where A is the weight before testing and B is the weight after 10,000 cycles.

Wrinkle crease recovery was carried out according to AATCC 66-2003 using a Shirley crease recovery tester. The horizontal wicking rate was tested in accordance with the requirements of standard the AATCC 198. The horizontal wicking rate in relation to the moisture management value was calculated using the equation.

$$W = (\pi/4) \times d_1 \times d_2/t$$

where W is the wicking rate (mm²/s), d₁ is the wicking distance in the length (mm), d₂ is the wicking distance in the width (mm), and t is the wicking time (s).

Statistical Analysis

A randomized complete block design (RCBD) was applied in the study using different types of fabric as the independent variables. The obtained data were analyzed using the SPSS 19.0 statistical software (IBM Inc. Chicago, IL, USA). The analysis method used descriptive statistics, analysis of variance, and multiple comparison at $\alpha = 0.05$. PCA (Pearson's correlation) and Hierarchical cluster analysis were calculated using

the XLSTAT software in the Microsoft Excel® package (Microsoft Corp.; Redmond, WA, USA) to obtain an overall picture of the data, as well as to identify groups of samples with similar assessed quality.

Results and Discussion

The Kawabata Evaluation System for fabric (KES-F) was conducted to determine surface attributes. Data on tensile stress, shear stress, bending stress, compression stress, and surface friction were used to determine HV and THV, as shown in Table 3, which indicated that samples 01, 06, and 07 had the highest THV values.

In addition, these samples have better air permeability, abrasion resistance, crease recovery, and wicking rate as a result of the blend of fibers and the high density that they contained. However, samples 03, 14, 16, and 19 had the lowest THV levels. In addition, the samples 03 and 19 have lower scores because of their woven construction and low density, while the knitted structure of samples 14 and 16 made them the heaviest.

Table 4 illustrates the comfort characteristics of the samples. Samples 01, 06, and 07 had high horizontal wicking rates, good crease recovery, and good air permeability, resulting in high THV values as well, perhaps because the blended fabric with high density contributed to the high THV value and comfort property.

Table 4. Shows Comfort properties of samples

Sample	Thermal resistance (Q _{max})	Air permeability (cfm)	Abrasion resistance (%)	Horizontal wicking rate (mm ² /s)	Crease recovery (warp)	Crease recovery (weft)
01	0.225 ^{efg}	15.733 ^{ab}	0.335 ^a	101.317 ^e	149.667 ^j	119.333 ^{gh}
02	0.184 ^{cd}	157.000 ⁱ	11.251 ^{ef}	15.117 ^{abc}	53.000 ^{ab}	61.667 ^a
03	0.097 ^a	543.667 ^m	7.431 ^{de}	0.869 ^a	107.000 ^{fghi}	105.000 ^{ef}
04	0.161 ^{bc}	99.433 ⁱ	5.027 ^{bcd}	6.422 ^a	91.333 ^{defg}	99.000 ^{cdef}
05	0.249 ^{gh}	13.767 ^{ab}	1.302 ^{ab}	33.388 ^{abcd}	73.333 ^{bcd}	143.333 ^{ijk}
06	0.239 ^{fg}	5.963 ^a	1.234 ^{ab}	97.608 ^e	79.333 ^{cde}	158.667 ^k
07	0.232 ^{efg}	11.000 ^{ab}	0.242 ^{ab}	71.497 ^{de}	123.333 ⁱ	149.000 ^{ijk}
08	0.275 ^h	20.633 ^{bc}	0.258 ^{ab}	23.936 ^{abcd}	94.000 ^{defgh}	129.000 ^{ghi}
09	0.238 ^{fg}	83.333 ^{gh}	2.879 ^{abcd}	13.112 ^{ab}	117.333 ^{hi}	119.000 ^{gh}
10	0.249 ^{gh}	85.533 ^{gh}	15.068 ^f	29.444 ^{abcd}	101.667 ^{efghi}	76.333 ^{ab}
11	0.222 ^{efg}	16.367 ^{ab}	1.852 ^{abc}	62.022 ^{bcde}	48.000 ^a	87.667 ^{bcde}
12	0.233 ^{efg}	31.567 ^{cd}	1.520 ^{ab}	6.094 ^a	106.333 ^{fghi}	70.667 ^{ab}
13	0.205 ^{de}	49.667 ^f	2.326 ^{abc}	64.533 ^{cde}	81.000 ^{cde}	112.667 ^{fg}
14	0.155 ^{bc}	79.033 ^{gh}	5.040 ^{bcd}	2.998 ^a	91.333 ^{defg}	153.000 ^{jk}
15	0.216 ^{ef}	35.767 ^{de}	0.811 ^{ab}	41.904 ^{abcd}	122.333 ⁱ	102.667 ^{ef}
16	0.139 ^b	74.433 ^g	0.660 ^{ab}	20.494 ^{abc}	96.000 ^{defgh}	138.000 ^{hijk}
17	0.205 ^{de}	35.200 ^{de}	1.069 ^{ab}	43.217 ^{abcd}	106.667 ^{fghi}	134.000 ^{ghij}
18	0.165 ^{bc}	491.333 ^l	6.766 ^{cde}	15.319 ^{abc}	112.000 ^{ghi}	101.667 ^{def}
19	0.181 ^{cd}	298.667 ^k	11.688 ^{ef}	35.401 ^{abcd}	86.333 ^{def}	86.667 ^{bcde}
20	0.234 ^{efg}	44.467 ^{ef}	2.193 ^{abc}	209.044 ^f	60.333 ^{abc}	81.000 ^{abcd}
21	0.232 ^{efg}	90.900 ^{hi}	3.209 ^{abcd}	44.588 ^{abcd}	80.000 ^{cde}	77.667 ^{abc}

*Mean values along the same column with different superscript letters are significantly different ($p \leq 0.05$)

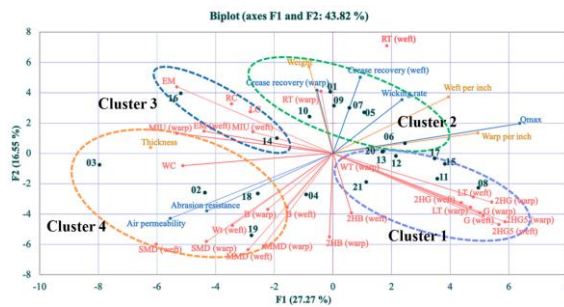


Figure 3. Shows PCA map showing different clusters of fabric samples (black number) using different colored dotted lines

The PCA and cluster analysis divided the 21 samples into four distinct groups, as shown in the four histograms in Figure 3. The 4 clusters were based on the dendrogram derived from the cluster analysis in Figure 4, classified by physical properties (the content of the fibers, structure, weight, and density). Cluster 1 consisted of 9 samples (04, 08, 11, 12, 13, 15, 17, 20, and 21), Cluster 2 contained 6 samples (01, 05, 06, 07, 09, and 10), Cluster 3 contained the 2 samples (14 and 16) and Cluster 4 contained 4 samples (02, 03, 18, and 19). The first group of samples was mostly woven cotton. The second group was mostly mixed (M) fabric samples, while the 2 samples in the third group were knitted. The last group included cotton and M cotton samples. In Figure 5, the highest THV value was in the first group, which consisted primarily of cotton-W samples. This equation is

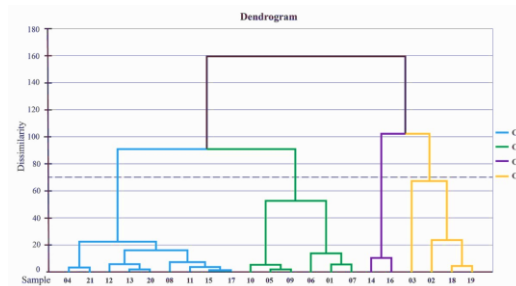


Figure 4. Shows Dendrogram of cluster analysis

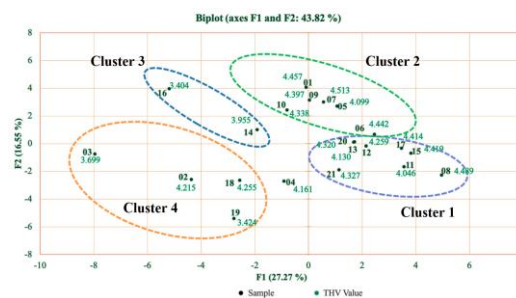


Figure 5. Shows Association between fabric (black numbers) and THV (green values) showing different clusters of fabric samples using different colored dotted lines

used for garments, suggesting that it is unlikely to be appropriate for use with a fabric intended for use as bedding, due to its lack of comfort quality appraisal. In the second set, there were two

Table 5. Shows means value of fabric quality in each cluster

Fabric Characteristics	Cluster 1	Cluster 2	Cluster 3	Cluster 4
Construction	weave	weave	knit	weave
Thickness (mm)	0.241	0.235	0.522	0.413
Weight g/m ²	123.419	139.133	169.650	115.675
warp per inch	143.778	135.000	40.000	67.500
weft per inch	151.556	191.667	65.000	67.500
B(gf.cm ² /cm) warp	0.050	0.047	0.025	0.103
B(gf.cm ² /cm) weft	0.069	0.040	0.018	0.093
2HB (gf.cm/cm) warp	0.050	0.029	0.031	0.066
2HB (gf.cm/cm) weft	0.069	0.025	0.026	0.058
LT (warp)	0.781	0.711	0.170	0.683
LT (weft)	0.756	0.701	0.173	0.629
WT (warp)	14.015	9.442	10.467	9.396
Wt (weft)	10.607	9.219	12.770	15.125
RT (warp)	39.968	53.544	44.270	46.216
RT (weft)	43.068	50.535	43.160	35.005
EM (warp)	7.234	5.369	24.422	6.316
EM (weft)	5.760	5.313	29.192	9.717
MIU (warp)	0.134	0.163	0.193	0.204
MIU (weft)	0.127	0.163	0.194	0.173
MMD (warp)	0.015	0.011	0.011	0.054
MMD (weft)	0.011	0.010	0.011	0.047
SMD (warp)	2.517	1.424	2.991	10.090
SMD (weft)	1.970	1.116	3.222	8.091
G(gf/cm*d) warp	0.889	0.439	0.688	0.392
G(gf/cm*d) weft	0.874	0.408	0.688	0.375
2HG(gf/cm) warp	1.039	0.073	0.820	-0.193
2HG(gf/cm) weft	1.048	0.039	1.258	-0.049
2HG5(gf/cm) warp	3.092	0.772	0.935	0.605
2HG5(gf/cm) weft	3.021	0.674	1.290	0.694
LC	0.280	0.295	0.334	0.287
WC (gf/cm ²)	0.157	0.081	0.322	0.323
RC (%)	29.916	35.342	40.215	34.818
Qmax (W/cm ²)	0.220	0.239	0.147	0.156
Air permeability (cfm)	47.111	35.888	76.733	372.667
Abrasion resistance (weight loss%)	2.030	3.509	2.850	9.284
Crease recovery (warp)	87.778	107.444	93.667	89.583
Crease recovery (weft)	99.370	127.611	145.500	88.750
Wicking rate (mm ² /s)	43.781	75.682	11.746	16.676

examples, both of which were knitted textiles. The THV value of the Cluster 3 was the lowest of any of the groups, while the majority of the samples in the third group were made of M fabrics, which have a high-quality comfort property as a result of their high density. The samples in the last group were made of cotton, and the M cotton samples had average scores for all properties. The first cluster was thought to have the most ideal hand-feel characteristics among the four clusters, while the second cluster was thought to have the least desirable hand-feel characteristics.

Nonetheless, these findings were insufficient to definitively determine which fabric type was appropriate for which use. Consequently, further customer research is essential assess their levels of contentment for and the suitability of specific fabric samples.

According to the PCA map, the samples were grouped based on 2 distinct quality attributes. The first group included Qmax, G warp, 2HG warp, and 2HG5 warp, while the opposite group of attributes

were thickness, SMD (weft), SMD (warp), and air permeability. PC2 identified 2 groups of attributes, with group 1 consisting of weight, RT (weft), and crease recovery, while group 2 consisted of MMD (warp) and MMD (weft).

Table 5 shows that clusters 3 and 4 were superior to clusters 1 and 2 in terms of the physical feature of thickness. Clusters 1 and 2 had a higher warp per inch than Clusters 3 and 4. Clusters 3 and 4 had the lowest warp per inch. In addition, cluster 4 has the highest rating possible for the properties of air permeability, abrasion resistance, and wicking rate.

Conclusions

The fabrics used in the Thai bedding fabric market have various types of physical properties, such as fiber types, structures, thicknesses, and density, which affect the surface and comfort properties. People make purchasing decisions based on hand-

feel and comfort. Future research should study more with human sensory attributes to identify suitable characteristics for each target group.

The current study classified the samples into one of four groups according to the type of fiber and the structure. The conditions of use should be taken into consideration when selecting the sort of bedding to use. Sample 7 was a material that had general comfort attributes resulting in it providing the overall highest grade of comfort, in terms of density and thickness of the fabric; furthermore, it was the heaviest among the samples, with the second highest density and modest thickness, resulting in the highest THV and abrasion resistance value. In addition, crease recovery had a quite high value, and the sample had a medium horizontal wicking rate. The Qmax values are comparable for all samples. The purpose of the study was to gain a better understanding of the fundamentals of the materials used in bedding as well as their characteristics. The results of the study should aid the bedding textile industry in the process of creation and development of new products.

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