Performance and Sustainability *vs.* the Shelf Price of Tissue Paper Kitchen Towels

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This study aimed to identify the performance properties that drive the shelf price of kitchen paper towels and evaluate whether sustainability is an important driver for pricing. Nineteen products were compared according to their performance (softness, absorbency, and strength), technology, and fiber morphology. Metrics to rank the products in different grades (economy, premium, and ultra) according to their performance were provided. A multiple linear regression showed that absorbency and softness are the most significant properties used to predict the price. Market data indicates that there is a segment of consumers willing to pay a premium price for products marketed as "sustainable", even though their performance is comparatively inferior to the majority of the samples. Sustainable products are up to 85% more expensive than regular products. The metrics obtained in this work can contribute to improvement in market transparency, and aid companies in deciding strategies for product development and new investments.

Keywords: Kitchen paper towel; Softness; Absorbency; Dry strength; Wet strength; Fiber morphology; Tissue machine technology; Embossing; Performance; Premium price; Sustainability

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INTRODUCTION

The tissue paper industry is a highly competitive industry worth USD 100 billion globally (Euromonitor 2017). Companies in this industry have been in the middle of a perfect storm, characterized by huge increase and volatility in raw material cost (due to the decrease in availability of post-consumer fibers) and price erosion of finished products (due to heavy competition and evolving consumer preferences) (Essity 2017; Terlep 2018). Identifying product features driving the market shelf price allows companies to formulate (*via* value stream mapping) efficient strategies for capital investment and research and development (R&D) expenditure. In a previous publication, the authors reviewed how different tissue paper features (absorbency, softness, and strength) can be manipulated to drive the performance and value of tissue paper products by using different types of fibers, technologies, and chemicals (de Assis *et al*. 2018). Additionally, there is a growing interest in sustainable practices in the manufacturing of these massive consumer products (Lewis 2016). This study focused on identifying and quantifying the product features (properties) that influence the value of tissue paper products. Additionally, this study sought to identify whether sustainability is an important driver for pricing. To gather evidence to answer these questions, a case study is presented for the paper kitchen towel product category.

Paper towels can be defined as tissue paper products used for drying and cleaning (Council of Europe 2004). To fulfill its purpose, toweling products should have high water absorbency. Because towels are mainly used under wet conditions, they also need to have high wet strength to maintain the integrity of paper structure during use. Consequently, absorbency and wet strength are among the essential or functional properties that define the performance of paper towels (Kim *et al*. 1994; Gigac and Fišerová 2008; Kullander *et al*. 2012). Other properties, such as softness, brightness, and appearance (*e.g*., embossing design, graphic printing), are not so essential because they do not directly contribute to the main purpose (performance) of toweling products (drying and cleaning surfaces). However, these additional properties are frequently explored by manufacturers to reach various segments of consumers. For example, it is common to find kitchen towels in the market place that are advertised for having superior softness, which are designed for consumers looking for hand feel comfort (Kim *et al*. 1994; Kan and Wong 2015). Another product feature that has been explored by the tissue paper industry to develop a new consumer market segment is the use of environmental sustainability label (Seventh Generation 2018). In a previous study developed for clothing and electronics, Luchs *et al*. (2012) reported that consumers' choice is based on a trade-off between performance and sustainability. A major segment of the consumers tended to choose products with better performance (and average sustainability) over products with superior sustainability (and average performance). However, there is a minimum threshold of performance that shifts the preference of consumers toward products with superior sustainability. In other words, when a minimum difference in performance is achieved, the majority of consumers tends to choose products with superior environmental sustainability (Luchs *et al*. 2012). Another aspect related to the commercialization of labeled products (*e.g.*, social label, environmental sustainability label) is the willingness of consumers to pay a premium price. A small segment of consumers is willing to pay a premium price for labeled products (*e.g*., food, clothing, toys, candles) (Székely and Knirsch 2005; Basu and Hicks 2008; Roheim *et al*. 2011). Additionally, the number of consumers that choose labeled products decreases with an increase in premium price. Many factors might explain consumers' resistance to choosing labeled products and paying a premium price (*e.g.*, label credibility, label transparency, label information, product category, product brand, product quality, product aesthetics, market segment, consumer social/environmental value, and the consumer's understanding of sustainability) (de Boer 2003; Basu and Hicks 2008). In this work, the relationship among performance, price, and market size for kitchen towels that are advertised as sustainable products was evaluated.

The properties observed in tissue paper products, including kitchen paper towels, are typically a function of manufacturing technology, raw material (Gigac and Fišerová 2008), and the chemistry used (de Assis *et al*. 2018). Paper machine technologies (*e.g.*, wet pressing, creping, structured fabrics) have an important influence on tissue paper properties. Conventional machine technologies (*e.g.*, dry crepe), where wet-pressing is used to partially dewater the tissue paper web, produce denser and stronger tissue paper products with lower bulk, softness, and absorbency. However, advanced technologies (*e.g.*, through air drying – TAD), where minimum pressing is applied on the wet tissue paper web, enable the production of higher quality tissue paper products with enhanced properties (high bulk, absorbency, and softness). However, TAD is a more expensive technology with higher energy consumption (Sanford and Sisson 1967; Ramaswamy and Cui 1999; Ramaswamy *et al.* 2001; Klerelid 2002; Weineisen and Stenström 2005; Ryan *et al.* 2007). The creping process is commonly used to enhance tissue paper properties. During the creping process, the creping blade scrapes the tissue sheet of the Yankee dryer surface, resulting in a delaminated tissue paper structure with higher bulk, softness, and absorbency (Nanko *et al.* 2005; Raunio and Ritala 2012; Boudreau and Germgard 2014). Structured fabrics can be used to enhance tissue paper properties by imparting compressed and uncompressed areas in the tissue paper web. The uncompressed areas (pillows) provide softness and absorbency, while the compressed lines provide strength to the tissue paper web (Smurkoski *et al*. 1992).

Another variable related to the production of tissue paper products is the converting process. Many different process steps are used to convert tissue machine jumbo rolls into final products (*e.g.* unwinding, embossing, printing, perforation, winding, tail sealing, log sawing, wrapping, packaging). Among these processes, embossing is used to provide texture and improve appearance of tissue products. Additionally, embossing is known to affect other tissue properties, such as softness and absorbency (de Assis *et al*. 2018). Two major embossing technologies are used when two LDC plies are embossed together, nested embossing and knob to knob embossing. In the nested embossing configuration, the embossing projections of one ply are positioned between the embossing projections of the other ply. In the knob to knob configuration, the embossing projections of both plies are aligned to each other. The knob to knob embossing provides superior bulk, absorbency and compressibility. However, exact registration is more difficult on knob to knob embossing and the roll wear is higher. Therefore, nested embossing is used to increase converting efficiency (Enderby and Straten 2001). A third embossing technology, top sheet embossing, is used when two TAD plies are combined. The space created between plies improves water absorbency capacity and rate due to the creation of inter-ply channels that increase water storage and reduce water flow resistance (de Assis *et al*. 2018).

Different types of fibers impact the final properties of tissue paper. Recycled fibers have lower wet-flexibility and are stiffer than virgin fibers. As a result, paper products made from recycled fibers tend to have lower strength and softness. On the other hand, stiffer fibers yield products with reasonable bulk and absorbency. Chemical pulps are more flexible, conformable, and more prone to readily flatten into ribbon-like fibers that tend to form stronger inter-fiber bonding. Conversely, mechanical pulps are stiffer and less conformable, and the lumen structure tends to be more resistant to the papermaking process (Hubbe *et al.* 2007). Mechanical pulps provide good bulk and absorbency while chemical pulps are a source of softness. Softwood fibers are primarily used as a source of reinforcement of the paper structure, while hardwood fibers are used to provide bulk, smooth surface, and softness for tissue paper products. Additionally, different species will present various morphological characteristics that impact tissue paper properties. For example, northern bleached softwood kraft (NBSK) is a softwood pulp that is highly desired as a source of strength due to the low fiber coarseness to fiber length ratio (Nanko *et al*. 2005). NBSK presents better softness than other softwoods (Byrd and Hurter 2013). Among hardwood fibers, eucalyptus is capable of producing tissue paper products with sufficient strength, high bulk, and high softness due to its low content of fines, and its high population of short and low coarseness fibers having a thick cell wall (Hall 1983; Nanko *et al*. 2005).

Wet end chemistry also plays an important role in tissue paper properties. Various chemicals (*e.g.*, wet strength, dry strength, surfactants, softeners) are used to improve tissue paper performance (Forbess 1997). Wet strength additives are used in paper towels to promote resistance to wet conditions. Wet strength performance depends on having a coherent network of fibers reinforced with a crosslinked network of wet strength additives that repress fiber swelling and inhibit fiber-fiber separation. Some wet strength additives, such as urea-formaldehyde, will self-crosslink and form an insoluble network around fiber contacts that preserves some of the original dry strength (protection mechanism). Besides self-crosslinking, other wet strength additives, such as azetidinium resins, will also form water-resistant covalent bonds in the cell wall of fibers or between fibers that will reinforce fiber bonding (reinforcement mechanism) (Espy 1995).

Because of their properties, tissue paper products are usually qualitatively classified into three major grades: economy, premium, and ultra products (Fisher 2016; Zou 2017). Economy products are manufactured with conventional technology and have a high recycled fiber content. Premium products can also be manufactured with conventional technologies. However, they have a lower recycled fiber content than economy products. Ultra products are manufactured using advanced technologies and chemicals (*e.g.* softeners) and have a high virgin fiber content (Fisher 2016; Zou 2017).

Previous publications have evaluated the various properties of paper towels related to absorbency, softness, and strength (Hollmark 1983; Kim *et al*. 1994; Kan and Wong 2015; Kan *et al.* 2016; Ko *et al.* 2017). However, to the authors' knowledge, there are no published works presenting a comprehensive discussion about the impact of technology and fiber on towel properties, and about the relationship between performance, sustainability, and shelf price. Additionally, there are no defined standards or metrics in the literature to quantitatively classify the different tissue paper grades based on their physical properties. It is of great value for the tissue paper industry to have metrics that can be used to understand how tissue paper products are compared to each other according to their features (*e.g.*, physical properties, sustainability) and relationship to price. This information would improve market transparency, aid companies in deciding on product targets, and contribute to further development of tissue paper products.

The objective of this work is to understand which physical properties can be used to classify kitchen towels among the different tissue paper grades (*i.e.*, economy, premium, ultra) and understand the relationship between performance, sustainability, and shelf price. The physical properties (*e.g.*, basis weight, apparent density, dry and wet strength, water absorbency, softness), paper machine technology, embossing technology and fiber morphology (fiber length, width, and coarseness) of different samples and grades of kitchen towels were evaluated. A multiple linear regression was executed to evaluate which physical properties can be used to predict the shelf price of kitchen towels.

EXPERIMENTAL

Kitchen Towel Samples

Nineteen samples of kitchen towels were sourced across the USA and evaluated in this work. All major consumer brands and most private labels were included in this study, representing more than 80% of the total consumer market for kitchen towels in the USA. The samples were purchased in different stores across the USA. The shelf price for each sample was collected from major retailers in different locations across the USA, excluding any price discount. The USA map was divided in four regions (northeast, south, midwest, west) and four major cities in each region were selected for price collection. Finally, the average price for all regions and cities was calculated for each sample. The deviation between the minimum and maximum prices observed for each sample represents less than 15% of the corresponding average price. Because the size of the packages (*e.g.*, number of rolls, number of sheets per roll, total area) influences the product price, careful attention was given to select packages with approximate same total area (tissue paper area). Table 1 describes each sample, including the market segment, number of plies, paper machine technology, embossing technology, and content of recycled fibers of each sample. Machine and embossing technologies used to produce the towels were determined by a tissue paper machine specialist (ReiTech 2018). The content of recycled fibers was collected from the packages when the information was available.

Only three samples provide the information about their content of recycled fibers. These products are advertised as having superior sustainability because they are manufactured with 100% recycled fibers (products N, R, and S), whitened with chlorine-free chemicals (products N and R) and for being unbleached (product S). In addition, product N has a “FSC Recycled” label, which is a certification provided by the Forest Stewardship Council to assure that all the paper in the product comes from reclaimed (re-used) material. The other two products (R, S) do not display any sustainable label. It is important to note that our analysis indicates that other products evaluated were also manufactured with a high content of recycled fibers; however, they are not advertised as sustainable products and they do not display any type of sustainable label.

In this work, the term “sustainable product” refers to kitchen towels that are advertised as having superior sustainability because they are manufactured with recycled fibers. It is important to note that the authors have not compared products in terms of their sustainability. This aspect will be evaluated in future works. The objective in this study is to evaluate if the perceived sustainability (by consumers) influence the price of kitchen towels.

Physical Properties

The presented values for all measured properties are the average of a minimum of five measurements. Before the evaluation of physical properties, all kitchen towel samples were properly conditioned in a room maintained at 50% relative humidity and temperature of 23 °C for 24 h (TAPPI T 402 sp-08 2013).

Basis weight, defined as mass of paper per unit of surface area, was determined according to TAPPI T 410 om-08 (2013). Thickness was measured according to TAPPI T 411 om-97 (1997). Basis weight and thickness were used to calculate paper apparent density, defined as mass of paper per unit of apparent volume.

The maximum tensile force per unit of width that a sample can withstand before breaking in a tensile test was measured under dry conditions (tensile strength) and after soaking the samples in water (wet tensile strength), according to ISO 12625-4 (2005) and ISO 12625-5 (2005), respectively. Tensile strength was divided by basis weight to calculate tensile index. Wet tensile energy absorption (wet TEA), defined as the amount of energy absorbed per unit of surface area when a sample is stretched until the onset break (moment of maximum wet tensile force) in a tensile test, was calculated as the integral of the wet tensile force over the range of wet tensile strain from zero to the strain at the maximum wet tensile force. The stretch at break was calculated as the ratio of the elongation of a sample, over its initial length, at the moment when the maximum tensile force was reached during the tensile test. Because fiber orientation is significantly present in industrial tissue paper making, tensile strength, energy absorption, and stretch at break were measured for both directions (paper machine direction and cross direction) and the values presented in this work were the arithmetic mean of both directions.

Table 1. Description of Kitchen Towel Samples

Sample	Market Segment*	Nº Plies	Tissue Paper Machine Technology**	Embossing Technology***	Recycled Fibers - %****
A	Consumer National Brand	2	CTAD structured belt	Top Sheet Embossing	-
B	Consumer National Brand	1	DRC	No Embossing	-
C	Consumer National Brand	1	UCTAD	No Embossing	-
D	Consumer Private Label	2	CTAD	Top Sheet Embossing	-
E	Consumer Private Label	2	CTAD	Top Sheet Embossing	-
F	Consumer National Brand	2	CTAD	Top Sheet Embossing	-
G	Consumer Private Label	2	LDC	Nested Embossing	-
H	Consumer Private Label	2	LDC	Nested Embossing	-
I	Consumer Private Label	2	LDC	Nested Embossing	-
J	Consumer National Brand	1	CTAD structured belt	Embossing	-
K	Consumer Private Label	2	CTAD	Top Sheet Embossing	-
L	Consumer - Private Label	2	Sheet 1 - LDC; Sheet 2 - CTAD	Nested Embossing	-
M	Consumer National Brand	1	UCTAD	Embossing	-
N	Consumer National Brand	2	Sheet 1 - LDC; Sheet 2 - ATMOS	Top Sheet Embossing	100 %
O	Consumer Private Label	2	LDC	Nested Embossing	-
P	Consumer National Brand	2	LDC	Nested Embossing	-
Q	Consumer National Brand	2	LDC	Knob to Knob Embossing	-
R	Consumer Private Label	2	LDC	Nested Embossing	100 %
S	Consumer National Brand	2	LDC	Knob to Knob Embossing	100 %

*Market Segment (Consumer = products designed and sold for domestic consumption; National Brand = brands owned by tissue paper manufacturers; Private Label = brands owned by wholesalers or retailers); **Tissue Paper Machine Technology (LDC = Light Dry Crepe; UCTAD = Un-Creped Through Air Drying; CTAD = Creped Through Air Drying; DRC = Double Re-Crepe; ATMOS = Advanced Tissue Molding System). A specialist in tissue paper manufacturing reviewed each sample to determine the technology used (ReiTech 2018). Details on each tissue machine technology can be found elsewhere (de Assis *et al.* 2018). ***Embossing Technology (Top Sheet Embossing: only 1 ply is embossed; Knob to Knob Embossing = the plies are embossed such that the projections of both plies are aligned to each other. Nested Embossing = the plies are embossed together and the projections of 1 ply are positioned between the projections of the other ply). A specialist in tissue manufacturing technology reviewed each sample to determine the technology used (ReiTech 2018). Details about embossing technology can be found at (Enderby and Straten 2001); ****Recycled Fiber - % (The information about the content of recycled fibers was collected from the package of each kitchen towel sample. Out of the 19 samples, only samples N, R and S presented information about the content of recycled fibers. Although other samples might have recycled fibers in their formulation, no information about it was presented.

Water absorbency capacity, defined as the mass of water absorbed per unit of sample mass, was measured according to ISO 12625-8 (2010). Basis weight was used to calculate water absorbency capacity, defined as the mass of absorbed water per unit of surface area.

Ball burst strength, defined as the maximum penetration force that a sample can withstand when a perpendicular force is applied by a ball, was measured under dry conditions (bursting force) and wet conditions (wet bursting force) according to ISO 12625-9 (2005) and ISO 12625-11 (2012), respectively. Bursting force was divided by basis weight to calculate the burst index.

Softness, smoothness, and stiffness were assessed using a Tissue Softness Analyzer (TSA) manufactured by EMTEC Electronic GmbH (Leipzig, Germany) (Grüner 2016). This equipment performed two measurements. In the first moment, a vertical force of 0.1 N was applied to the sample surface by a moving part containing a group of vertical lamellas. Those lamellas rotated horizontally on the sample surface, producing vibration, and a sensor captured the sound spectrum generated. Two peaks of the sound spectrum were analyzed. The peak in the range 200 Hz to 2000 Hz (TSA smoothness, also called TS750) is mainly related to the surface structure and geometry, and it is influenced by surface finishing, creping, embossing. This peak is an indication of surface smoothness, defined as the degree to which a surface contains short-span or fine irregularities. A lower TS750 peak indicates higher surface smoothness. The second peak around 6500 Hz (TSA softness, also called TS7) is mainly related to the flexibility of the fibers and micro compressibility of the creping waves. This peak is an indication of "real" softness and it is influenced by many variables (*e.g.*, type of fibers, fiber bonding strength, free fiber ends, internal structure, machine technology, creping chemicals). A lower TS7 peak indicates higher softness. During the second measurement, the moving part applied a vertical force from 0.1 N to 0.6 N while the vertical displacement of the sample was measured. Stiffness, defined as the degree which a paper sample resists to bending when subjected to a bending force, was calculated as the ratio between the displacement and applied vertical force. Stiffness can be used as an indication for bulk softness. Stiffness is influenced by type of fiber, machine technology, and chemicals. Because significant differences may exist between the top and bottom sides of tissue paper products (*e.g.*, layered tissue paper, embossing, plies with different fibers and technology, Yankee dryer side vs. wire side), the softness measurements were performed on both sides of each sample and the values presented in this work are the arithmetic mean of both sides.

Fiber Morphology

The HiRes Fiber Quality Analyzer (FQA) from OpTest Equipment Inc. (Hawkesbury, ON, Canada) was used to measure fiber length, width, and coarseness. Before FQA analysis, each sample was chemically treated with sodium hypochlorite ($NaOCl$) at 65 °C for 30 min to break the wet strength additives and properly disperse the fibers. Different amounts of $NaOCl$ were used for each sample as needed, ranging from 10% to 25% w/w. After chemical treatment, samples were disintegrated using a British disintegrator (Manufacturer, City, Country) for 15,000 revolutions and diluted to about 1 mg/L to 5 mg/L. Fiber length was measured for fibers longer than 0.2 mm, and at least 10,000 fibers were analyzed for each FQA run. A distribution of fiber length was obtained and the fiber length weighted was calculated. Fiber width was measured for fibers longer than 0.2 mm for width values ranging from 7 µm to 60 µm. The arithmetic mean of fiber width was calculated. Separate experiments were executed for coarseness measurement.

One gram handsheets were made using the disintegrated fibers (TAPPI T205 sp-02 2006). Handsheets were dried in a room maintained at 50% relative humidity and temperature of 23 °C. After drying the hand sheets, moisture content was measured (TAPPI T550 om-08 2013). About 30 to 40 mg of the handsheets on a dry basis was disintegrated and diluted in 5 L of water. 200 mL of the dilute fiber suspension was collected, diluted to about 2 mg/L, and used for coarseness measurement. During coarseness measurements, all fibers in the dilute suspension were measured. Coarseness was calculated by dividing the total mass of fibers by the total length of fibers measured.

Multiple Linear Regression

A Multiple linear regression was performed using the software SAS 9.4 from SAS Institute Inc. (Cary, NC, USA) to evaluate which physical properties (thickness; basis weight; apparent density; dry/wet tensile strength; wet tensile energy absorption; dry/wet bursting force; water absorbency capacity; TSA hand feel factor; TSA softness; TSA smoothness; TSA stiffness; fiber length; fiber width; fiber coarseness) can be used to predict the shelf price of kitchen towels. For the multiple linear regression, stepwise procedures were executed using forward, backward and stepwise methods to evaluate what variables are statistically significant to the model at 95% confidence. Prior to running the regression models, a correlation analysis among all variables was performed to eliminate input variables that had strong linear relationship.

Performance Ranking

As discussed in the introduction section, the current literature shows that absorbency and wet strength are the most important or essential properties for kitchen towels to fulfill its purpose (drying and cleaning surfaces). However, it is common to find kitchen towels in the market place that are advertised for having superior softness. These products are designed for consumers that are sensitive to hand feel comfort. Therefore, absorbency, softness and wet strength were the properties selected to create the performance ranking.

After testing, samples were ranked, on a scale of 1 to 10, according to their water absorbency capacity (g/m^2), TSA softness (TS7 - dB), and wet TEA (J/m^2). Samples presenting the best performance for each one of the three properties were given a score of 10 points. Samples presenting the worse performance for each property were given a score of 1 point. The scores for samples with intermediate values were proportionally calculated based on the scale (1 to 10) used. Table 2 brings the ranking created for water absorbency capacity. Similar tables were also built to rank the products according to TSA softness and wet TEA, as presented in Table 3. The final score for each sample was calculated as the summation of the individual scores for each one of the three properties. No weighting factor to differentiate the relative importance of each property was applied in the calculation of the final score. Sample A had the highest final score among all samples. Sample S had the lowest final score. It was assumed that sample A had the best performance, while sample S was the sample with the lowest performance.

It is important to highlight that the main purpose of the performance ranking is not to absolutely compare the relative performance of each product. Consumer panels are probably the best way to assess the relative performance of different samples. However, consumer panels were not employed in this work. The main purpose of the performance ranking is to create a systematic method that could be used to easily compare the different samples in terms of the observed properties, manufacturing technology and fiber type.

Table 2. Performance Ranking Based on Water Absorbency Capacity

Sample	Water Absorbency Capacity (g H_2O/m^2)	Score
1	828 ± 13	10.0
2	798 ± 7	9.5
3	784 ± 4	9.3
4	711 ± 5	8.1
5	685 ± 6	7.7
6	639 ± 5	7.0
7	622 ± 13	6.7
8	567 ± 12	5.8
9	531 ± 8	5.2
10	527 ± 6	5.2
11	517 ± 17	5.0
12	480 ± 7	4.4
13	466 ± 8	4.2
14	462 ± 7	4.1
15	449 ± 6	3.9
16	379 ± 7	2.8
17	379 ± 13	2.8
18	353 ± 4	2.4
19	268 ± 3	1.0

Sample 1 had the best absorbency with a score of 10 points. Sample 19 had the worse absorbency with a score of 1 point. The scores for samples 2 to 18 were proportionally calculated.

Table 3. Final Performance Ranking Based on Water Absorbency Capacity, TSA Softness, and Wet Energy to Break

Sample	Individual Scores			Total Score
	Absorbency Capacity (g H_2O / m^2)	TSA Softness (dB)	Wet Energy to Break (J/m^2)	
A	10.0	8.9	9.2	28.0
B	8.1	7.8	9.3	25.1
C	6.7	7.1	10.0	23.8
D	9.3	6.1	8.2	23.6
E	9.5	5.7	7.8	23.0
F	7.7	4.3	8.5	20.5
G	5.2	10.0	4.7	19.9
H	4.4	9.1	5.1	18.7
I	5.2	8.2	4.8	18.2
J	5.8	4.6	7.6	18.0
K	7.0	5.0	5.4	17.3
L	5.0	6.8	4.8	16.6
M	4.2	1.8	6.3	12.2
N	3.9	2.0	5.8	11.8
O	2.8	3.2	3.0	9.0
P	4.1	1.4	3.5	9.0
Q	2.8	4.1	1.0	7.9
R	2.4	1.0	3.9	7.3
S	1.0	1.9	2.5	5.4

The total score was calculated as the summation of the individual scores obtained for water absorbency capacity, TSA softness and wet energy to break. Sample A had the highest total score and was assumed to have the best performance. Sample S had the lowest total score and was assumed to have the worst performance.

RESULTS AND DISCUSSION

Characterization of Kitchen Towel

Basis weight varied from 37.6 g/m^2 to 63.4 g/m^2, and the most common values were between 40 g/m^2 to 50 g/m^2 (Fig. 1). Apparent density varied from 0.14 g/cm^3 to 0.27 g/cm^3, and a significant difference in apparent density was observed between samples manufactured with conventional technology (LDC) and advanced technology (TAD, DRC). The average apparent density for samples manufactured with LDC technology (G-H-I-O-P-Q-R-S) was 0.24 g/cm^3, while samples manufactured with advanced technology (A-B-C-D-E-F-J-K-M) were bulkier, having an average apparent density of 0.16 g/cm^3. Products having multiple plies manufactured with LDC technology and advanced technology (L-N), presented intermediate apparent density of 0.19 g/cm^3.

Bursting force and index ranged from 3.0 N to 11 N and from 79 mN m^2/g to 213 mN m^2/g, respectively (Fig. 2). However, most of the samples had bursting forces within 6 N to 8 N and burst indexes within 125 mN m^2/g to 175 mN m^2/g. Bursting forces and indexes that were measured at wet conditions followed the same pattern as dry bursting. Samples with a high bursting force and index tended to present high wet bursting and vice-versa. Wet bursting force varied from 0.4 N to 4.6 N and wet burst index varied from 11 mN m^2/g to 90 mN m^2/g. Most of the samples had a wet bursting force between 2 N to 3 N and a wet burst index between 25 mN m^2/g to 75 mN m^2/g. Samples manufactured with 100% recycled fibers tended to have lower dry and wet burst resistance.

A very broad group of values for tensile strength was observed, ranging from 192 N/m to 500 N/m (Fig. 3). Nevertheless, the tensile strength for most of the samples ranged between 350 N/m and 450 N/m. The tensile index varied from 3.0 Nm/g to 11.3 Nm/g, and values between 7.5 Nm/g to 9.5 Nm/g were observed for most of the samples. The wet tensile strength and index of the samples also presented a broad range of values (from 20 N/m to 136 N/m and from 0.5 Nm/g to 3.1 Nm/g, respectively). The wet tensile strength values of most of the samples were between 75 N/m to 120 N/m, and the wet tensile indexes were between 1.5 Nm/g and 2.5 Nm/g.

An interesting trend was observed for wet tensile energy absorption and water absorbency capacity, where paper machine technology contributed to differentiation among the samples evaluated (Figs. 4 and 5). The average absorbency and wet tensile energy absorption for the samples that were manufactured with LDC technology (G-H-I-O-P-Q-R-S) was 8.9 g H_2O/g paper and 3.6 J/m^2, while the samples that were manufactured with advanced technology (A-B-C-D-E-F-J-K-M) were more absorbent and stronger in wet conditions, presenting average values of 13.7 g H_2O/g paper and 8.5 J/m^2.

Products containing plies that were manufactured with different technologies (L-N) presented intermediate absorbency (10.7 g H_2O /g paper) and wet tensile energy absorption (5.5 J/m^2). The maximum and minimum observed values were 16.1 g H_2O/g and 7.1 g H_2O/g for absorbency, and 10.7 J/m^2 and 0.8 J/m^2 for tensile energy absorption. On the other hand, water absorbency capacity, calculated as a function of paper surface area, and the wet tensile energy absorption index presented a broader range of values (from 268 g H_2O/m^2 to 828 g H_2O/m^2 and 0.02 J/g to 0.20 J/g). It was also observed that samples made of 100% recycled fibers presented the lowest absorbency and wet tensile energy absorption.

A relationship between wet tensile energy absorption and the wet stretch at break was also noted (Fig. 4). Samples with high stretching capability tended to have higher wet tensile energy absorption. The average wet stretch at break for samples that were manufactured with advanced technology (A-B-C-D-E-F-J-K-M) was 11.5%, while samples that were manufactured with conventional technology presented 5.6% as an average value for the wet stretch at break. Products containing plies that were manufactured with different technologies (L-N) had an intermediate average wet stretch at break (7.0%).

The results obtained with the Tissue Softness Analyzer are presented in Fig. 6. TSA smoothness displayed a very broad distribution of values (from 36.4 to 160.9) and did not present any particular behavior among samples. On the other hand, machine technology correlated well with TSA softness and stiffness. Except for samples G, H, and I, the average stiffness and TSA softness for the samples manufactured with conventional technology (O-P-Q-R-S) were 2.0 mm/N and 25 dB, while samples manufactured with advanced technology were more flexible (2.4 mm/N) and softer (21.1 dB). Most of the samples had stiffness between 2.0 mm/N and 2.5 mm/N with the exception of samples B (3.4 mm/N) and C (2.7 mm/N), which had higher flexibility. Samples manufactured with 100% recycled fibers were stiffer.

Figure 7 presents the results obtained with the Fiber Quality Analyzer. The average fiber length weighted among all samples was around 1.6 mm. Many samples (D-E-F-G-H-I-K-P) had a high content of long fibers, presenting fiber lengths that were longer than 1.8 mm. Some samples (A-C-J-L-M) had an intermediate content of long fibers, presenting fiber lengths measured between 1.3 mm and 1.5 mm. Samples made with 100% recycled fibers (N-R-S) had a high content of short fibers, presenting the lowest measured fiber length (1.0 mm to 1.2 mm). Other samples (O-Q) also have high content of short fibers (1.1 mm and 1.1 mm, respectively) and are likely to have very high amount of recycled fibers. The distribution of fiber length showed that the samples that were manufactured with advanced technology tended to have a higher content of short fibers (hardwood) as can be seen by the narrow fiber length distribution, with the exception of samples D and E. On the other hand, samples manufactured with conventional technology tended to have a broader distribution of fiber lengths, which indicated a higher content of long fibers (softwood) and higher content of very short fibers (length < 0.5 mm). Most of the samples had fiber widths and coarseness of around 17 µm to 21 µm and 9 mg/100m to 12 mg/100m, respectively.

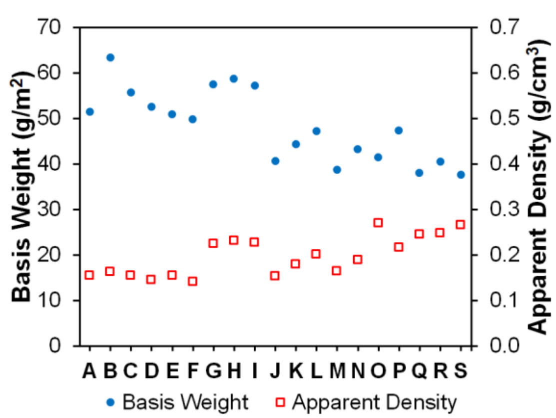


Fig 1. Basis weight in grams per square meter of sample and apparent density in grams per cubic centimeter of sample

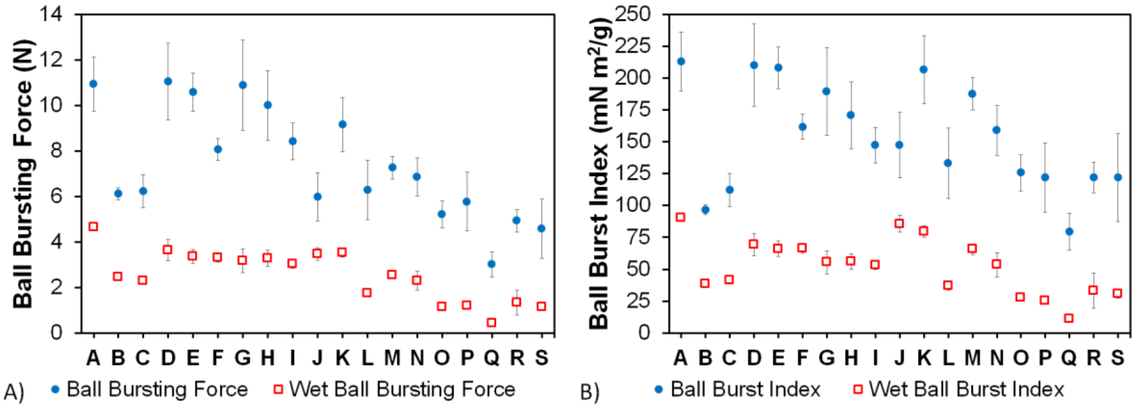


Fig. 2. Ball bursting force in newtons and ball burst index in milli-newtons square meter per gram measured at dry and wet conditions. A) Ball bursting force B) Ball burst index

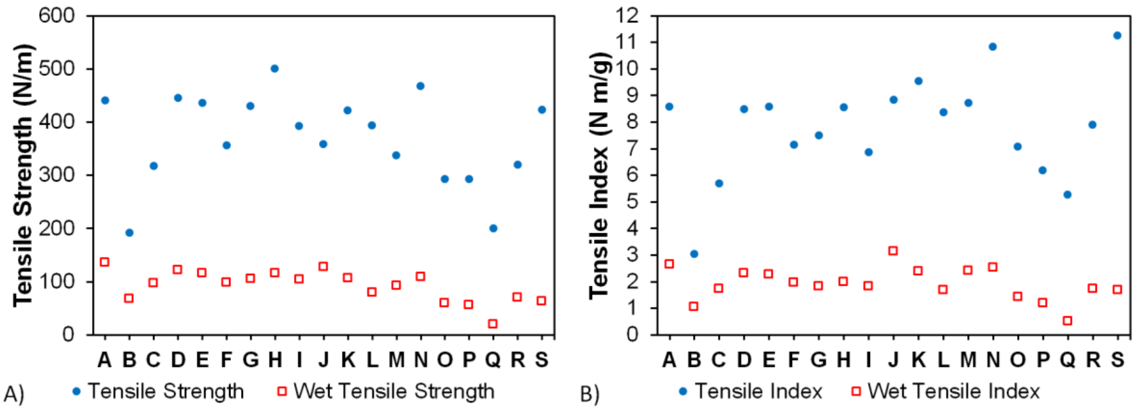


Fig. 3. Tensile strength in newtons per meter and tensile index in newtons meter per gram measured at dry and wet conditions. Values are the arithmetic means of paper machine direction and cross direction. A) Tensile strength. B) Tensile index. Values are calculated as the arithmetic mean of machine and cross directions.

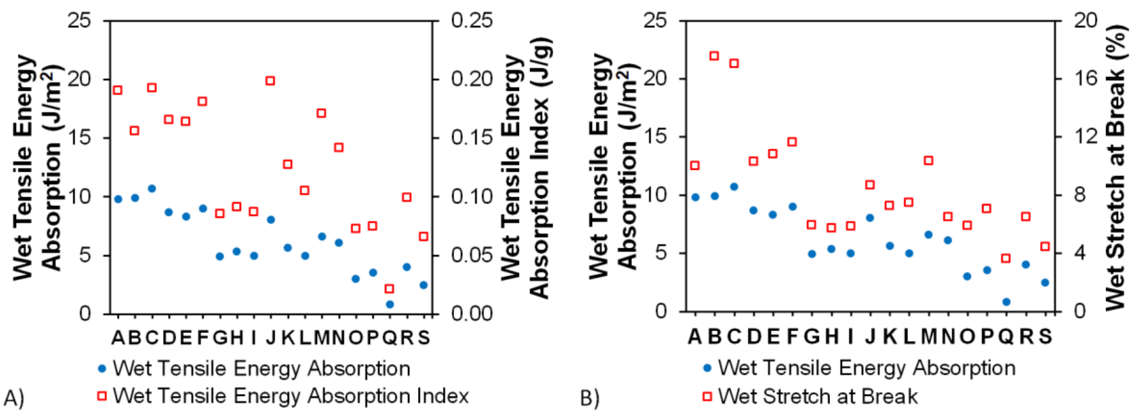


Fig. 4. Wet tensile energy absorption in joules per square meter, wet tensile energy absorption index in joules per gram and wet stretch at break as a percentage. A) Wet tensile energy absorption and index. B) Wet tensile energy absorption and wet stretch at break (values are calculated as the arithmetic mean of machine and cross directions).

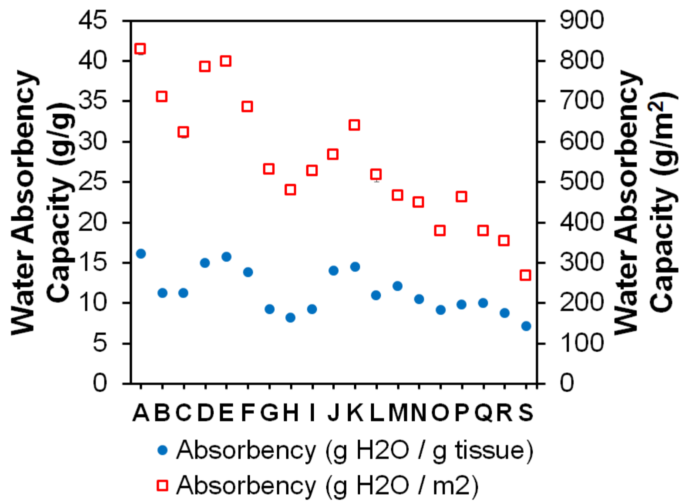


Fig. 5. Water absorbency capacity in grams of water per gram of sample and grams of water per square meter of sample

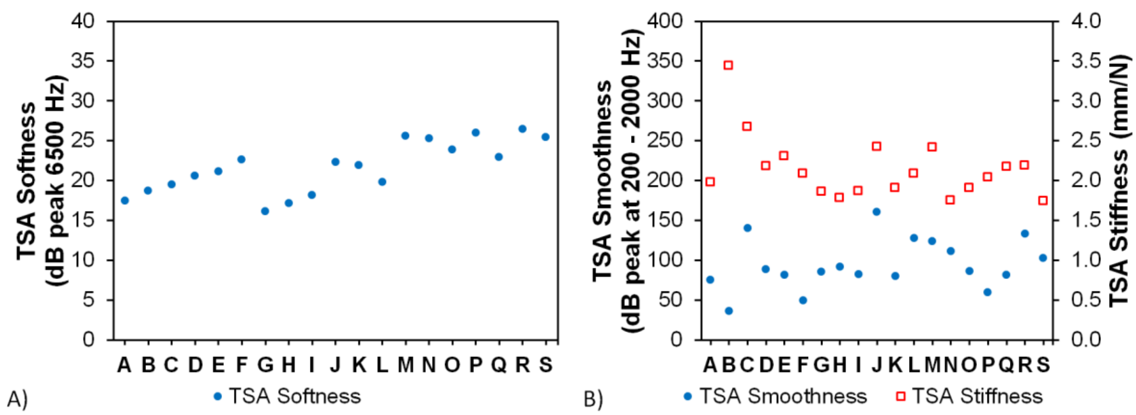
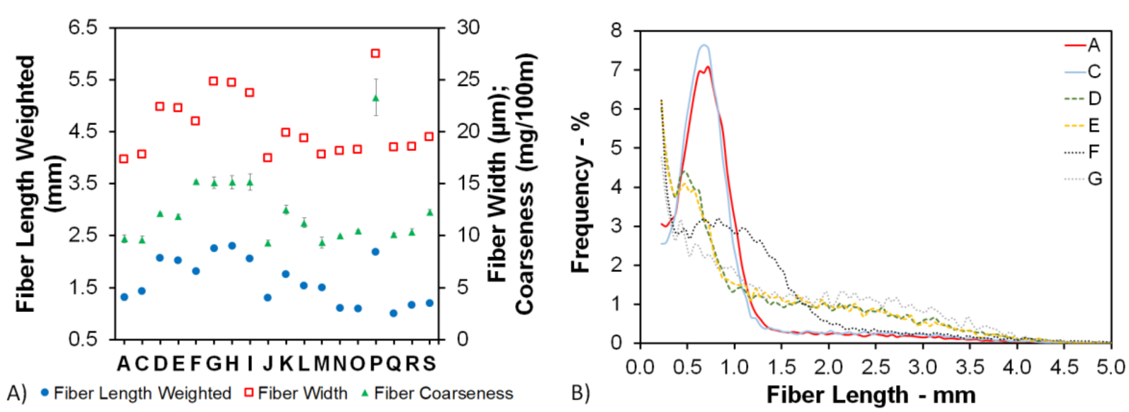


Fig. 6. Tissue Softness Analyzer results. A) TSA softness in decibels (lower values translate into better softness). B) TSA smoothness in decibels (lower values translates into better smoothness) and paper stiffness in millimeters per newton (lower values translate in to higher stiffness). High TSA softness indicates low softness. High TSA smoothness indicates low surface smoothness.



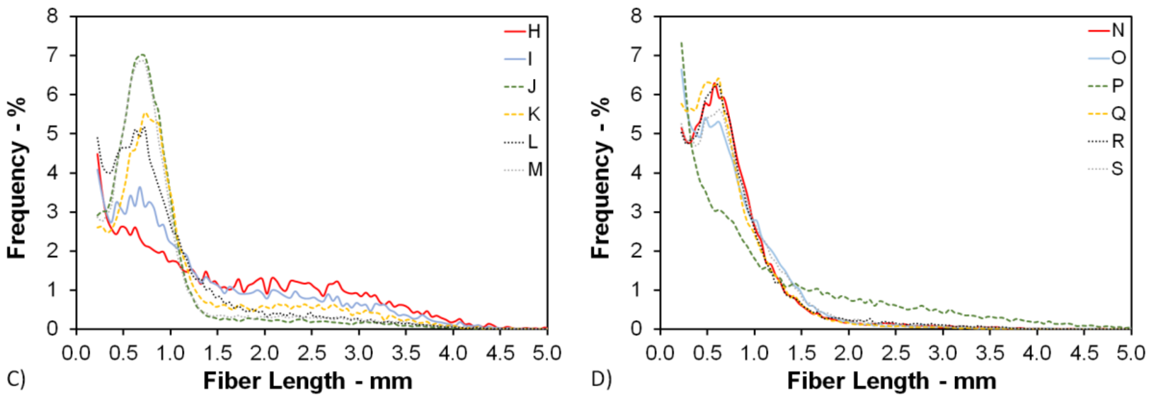


Fig. 7. Fiber quality analyzer results: A) Average fiber length weighted in millimeters for fibers longer than 0.2 mm; average fiber width in millimeters for fibers longer than 0.5 mm and width values between 7 and 60 µm; fiber coarseness in grams per 100 meters reported as fiber mass per fiber length. B), C), D) Distribution of fiber length based on the frequency of particles

Effect of Manufacturing Technology and Fiber Type on Kitchen Towel Performance

The final properties of tissue paper products are a function of manufacturing technology, raw material (Gigac and Fišerová 2008), and the chemistry used (de Assis *et al*. 2018). In conventional tissue paper machines, such as the Light Dry Crepe (LDC) machine, dewatering is accomplished by pressing the paper web to a consistency of 40% to 55% before the final thermal drying at the steam-heated Yankee cylinder surface. On the other hand, in advanced processes, such as Creped Through Air Drying (CTAD), dewatering is performed by vacuum until a consistency of about 25% (Weineisen and Stenström 2005). After vacuum dewatering, the paper web is transferred to the through air drying section, where the passage of high temperature air at moderate velocity throughout the paper web contributes to enhance product attributes. Additionally, the use of structured fabrics also plays a significant role. Besides supporting and carrying of the paper web, the structure of TAD fabrics impart quality attributes to tissue paper products (Ramaswamy and Cui 1999). TAD fabrics will imprint patterns on tissue paper web creating knuckles (dense and strong areas) and pillows (bulk, absorbent, and soft areas) resulting in a final product with good strength, enhanced softness, and absorbency (Sanford and Sisson 1967). At the end of the through air drying process, the partially dried paper web is transferred to a Yankee cylinder at a high consistency (up to 85%) where the final thermal drying is performed (Kullander 2012). The combination of structured fabrics, lower level of pressing, and through air drying results in tissue paper products that are bulkier, softer, and more absorbent (Weineisen and Stenström 2005). Another variation of through air drying technology is the Un-Creped Through Air Drying (UCTAD), where the tissue paper web is dried in the through air drier from about 25% consistency to final dryness (Wendt *et al*. 1998). Tissue paper products manufactured with Double Re-Crepe (DRC) technology are creped once, imprinted with latex on both surfaces, and then creped for the second time. DRC tissue paper products are very soft, absorbent, and stretchable (Gentile *et al*. 1975). The Advanced Tissue Molding System (ATMOS) uses mechanical ways to dewater a structured tissue paper web to about 40% before the final drying at the Yankee dryer (Voith 2018). Therefore, it is expected that kitchen towels manufactured with advanced technologies (A-B-C-D-E-F-J-K-M) would have better softness and absorbency than kitchen towels manufactured with conventional technology (G-H-I-O-P-Q-R-S). Different embossing technologies (*e.g.* top sheet embossing, nested embossing, knob to knob embossing) are used by producers to provide the best appearance, firmness and performance combined with their tissue paper machine technology. Embossing was applied in 1 ply products (J-M) to improved firmness and appearance. However, other 1 ply products (B-C) do not present any type of embossing probably because their paper machine technologies already provide the desired appearance. In the case of 2 ply products, the space created between the plies is known to improve water absorbency capacity and rate due to the creation of inter-ply channels or capillaries. These channels increase the volume available for water storage and reduce the viscous flow resistance. All the 2 ply samples manufactured with TAD technology (A-D-E-F-K) had only the top sheet embossed. The unique structure provided by TAD technology and structured belts produces enough bulk that nested or knob to knob embossing would provide very little improvement in absorbency. Indeed the embossing reduces absorbency on the portions of the top sheet that became flattened, but it provides a more dramatic top sheet appearance. The 2 ply products produced with LDC technology (G-H-I-O-P-Q-R-S) were embossed using nested or knob to knob technologies. No conclusion about the effect of embossing technology (nested or knob to knob) on LDC samples can be established probably due to effect of other variables (*e.g.* fiber type, basis weight).

According to the results of this study, there was an interesting trend among apparent density, softness, and absorbency. From sample S to sample A, there was a decrease of apparent density, decrease of stiffness, and increase in absorbency. Tissue paper products with low apparent density, with a porous paper web structure filled with large amounts of air spaces among fibers, are more likely to have high water absorbency capacity (Hubbe 2006). Softness is also proportional to apparent density. The inter-fiber bonding in tissue paper products with low apparent density is not well developed, which results in better bulk softness (Kullander 2012; Boudreau 2013). Figure 8 shows a good correlation between bulk (inverse of apparent density) and absorbency. Although the correlation between apparent density and stiffness was not strong, it is possible to see a trend from Fig. 1 and Fig. 6. Basis weight also increased from sample S to sample A.

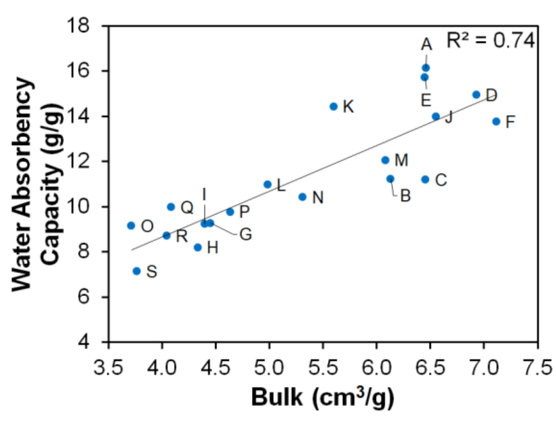


Fig. 8. Correlation between bulk in cubic centimeters per gram of sample and water absorbency capacity in grams of water per gram of sample

Stretchability is also an important property of tissue paper products. The stretchability can indicate softness (Hollmark and Ampulski 2004). Additionally, tissue paper products with higher stretchabilities tend to have higher wet tensile energy absorptions

(Kan *et al*. 2016). Machine technology and the creping process have a significant impact on the stretchability of tissue paper products. During the creping process, the creping blade scrapes the tissue sheet of the Yankee dryer surface, resulting in a delaminated and stretchable tissue paper structure. (Nanko *et al*. 2005; Raunio and Ritala 2012; Boudreau and Germgard 2014). Advanced technology also contributes to higher stretchability in tissue paper products because the inter-fiber bonding is not well developed. As shown in Fig. 4, tissue paper products manufactured with advanced technology are more stretchable and have higher wet tensile energy absorption. The measured stiffness (Fig. 6) can be used as an indication of the perceived softness (Hollmark and Ampulski 2004) and stretch-ability. An upward trend can be observed from sample S to sample A, which indicated an increase in stretchability. Among all samples, B showed the best stretchability, which was likely the result of the DRC machine technology, where the paper web was creped twice.

Another important factor that influences tissue paper properties is the type of fiber. Toweling products have different amounts on short, long, virgin, and recycled fibers depending on the type of product. TAD towels are typically produced with 35% to 50% of NBSK and 20% to 40% of bleached chemi-thermo mechanical pulp (BCTMP), complemented by bleached hardwood pulp. This combination provides high bulk and absorbency with good strength and softness. LDC towels are typically made with a very high content of softwood fibers to provide good absorbency and strength. LDC towels are also manufactured with high content of recycled fibers, which results in a product with lower absorbency and minimal strength (Nanko *et al*. 2005). Among the studied samples, the samples with high TSA softness tended to have higher contents of hardwood fibers, while samples with higher contents of softwood fibers tended to have lower TSA softness. However, it is possible to find some samples having high content of softwood fibers and good softness. No conclusions can be drawn about strength or TSA smoothness in relation to the content of hardwood and softwood fibers, probably due to the influence of many other variables (strength additives, creping, embossing).

The content of recycled fibers is also an important factor for tissue paper properties. Recycled fibers are less flexible and stiffer than virgin fibers, resulting in paper products with lower strength and softness. Mechanical refining is usually used as an alternative to improve the strength of recycled fibers. However, refining of once dried fibers will only recover part of the lost strength. Additionally, most of the recycled fibers have been refined at least once and it is expected that they would be more prone to fragmentation than virgin fibers, which would increase the content of fines and small fibers (Hubbe *et al*. 2007). Because of their stiffness, recycled fibers are not able to provide good flexibility, which is necessary for surface softness. Additionally, recycled fibers have been refined before, which gives them a higher bonding ability than unrefined hardwoods, resulting in reduced bulk softness (McKinney 1995). It is possible to see from the results that samples made with 100% recycled fibers tended to have higher content of small fibers, low strength (ball bursting and tensile strength), and softness.

Classification of Kitchen Towel in Different Grades

Kitchen towels should have high water absorbency capacities and high wet strength in order to effectively clean and dry surfaces (Kim *et al*. 1994; Gigac and Fišerová 2008; Kullander *et al*. 2012). Therefore, these products are typically made from lightly refined fibers to maintain the initial relative stiff and tube-like nature of fibers that are necessary to achieve high bulk, water absorbency, and softness (Thorp and Kocurek 1991; Hubbe 2006).

Because of the tissue paper making process, inter-fiber bonding in tissue paper is not as well developed as it is in the case of other paper products (*e.g.*, packaging, printing). However, tissue paper products have to be strong enough to withstand papermaking, converting, and use applications. Even though these products do not present very high ball bursting or tensile strength, they are manufactured in such a way to have high stretchability, which will give them good capacity to absorb energy during various conditions. Therefore, the total energy that a tissue paper product can absorb under stress is more important than the maximum force that a tissue paper product can withstand. Although softness would not be classified as an essential property for kitchen towels, tissue paper manufacturers frequently use softness to add additional value to their products. In essence, most would try to reach a balance between strength, absorbency, and softness, *i.e.*, tissue paper makers perhaps attempt to get to the minimum required strength to optimize absorbency and softness.

Figure 9 maps the properties of kitchen towels and compares their overall performance in terms of wet strength, water absorbency, and softness. Water absorbency capacity is represented as a function of wet TEA and TSA softness (Fig. 9). Sample A had the best combination of absorbency, wet TEA and softness, and therefore, sample A was considered to have the best performance among all samples. Performance decreased from sample A to S, and sample S was considered as the sample with the worst performance. This map of properties (Figure 9) was used to arbitrarily separate the samples studied among three different zones or grades (Table 4). Samples with water absorbency smaller than 450 g H_2O/m^2, wet TEA smaller than 4 J/m^2, and TSA softness bigger than 23 dB, were defined as "economy" kitchen towels. "Premium" products had values between 450 g H_2O/m^2 and 650 g H_2O/m^2 for absorbency, 4 J/m^2 to 7.5 J/m^2 for wet TEA and 19.5 dB to 23 for dB for softness. Products with absorbencies bigger than 650 g H_2O/m^2, wet TEA bigger than 7.5 J/m^2, and TSA softness lower than 19.5 dB, were defined as "ultra" kitchen towels.

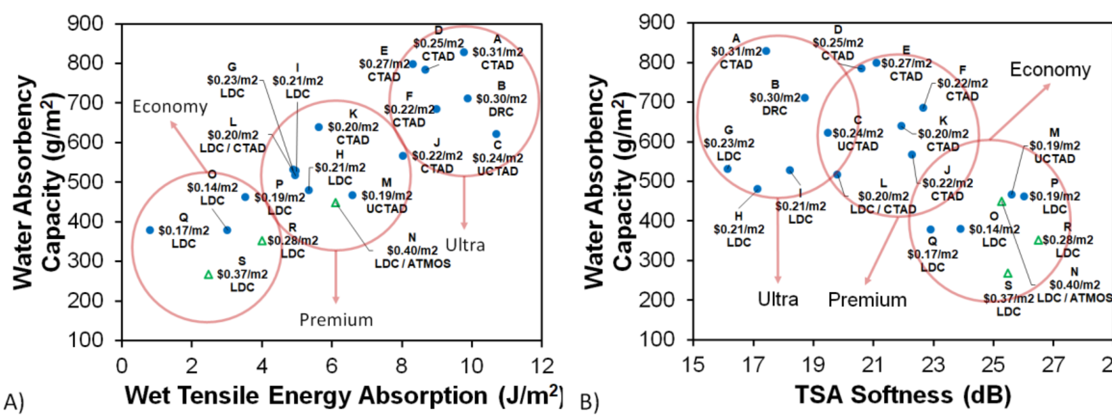


Fig. 9. Relationship between water absorbency capacity in grams of water per square meter, wet tensile energy absorption in joules per square meter, and TSA softness in decibels and their relationship to price in USA dollars per square meter. A) Relationship between water absorbency capacity and wet tensile energy absorption. B) Relationship between water absorbency capacity and TSA softness. Samples represented by triangles (N-R-S) are manufactured with 100% recycled fibers and advertised as sustainable products

Table 4. Classification of Kitchen Towels Grades Based on Water Absorbency Capacity, Wet Tensile Energy Absorption, and TSA Softness

Kitchen Towel Grades	Water Absorbency Capacity (g water/m^2)	Wet Tensile Energy Absorption (J/m^2)	TSA Softness TS7 (dB)
Economy	Absorbency < 450	Wet TEA < 4	TS7 > 23
Premium	450 < Absorbency < 650	4 < Wet TEA < 7.5	19.5 < TS7 < 23
Ultra	Absorbency > 650	Wet TEA > 7.5	TS7 < 19.5

Evaluation of the Relationship among Performance, Sustainability, Price and Market Size

A correlation between performance and price was expected. In other words, products with better performance should have a higher market price (Weineisen and Stenström 2005). Figure 9 also presents the price per square meter at the retailer shelf for all samples considered. A reasonable trend was observed from sample A to sample S between some performance characteristics (properties) and price. In other words, samples having better performance tended to have higher price, and vice-versa. However, there were three samples (N-R-S) that did not follow the trend between performance and price. Samples N, R, and S were more likely to be “economy” products (lower performance and lower manufacturing costs relatively). However, their prices were similar or even higher than “ultra” products (higher performance and higher manufacturing costs relatively). This behavior can probably be explained by the segment of consumers targeted for those products. Samples N, R, and S were made with 100% recycled fibers and were advertised by their manufacturers as “environmental friendly” or “sustainable” products. There were two aspects that must be taken into consideration to better understand the relationship between performance, sustainability, shelf price, and market size.

The first aspect is the trade-off between performance and sustainability. Typically, the majority of consumers choose products with better performance over products with improved sustainability, as long as the difference in performance outweighs consumers’ sustainability value (Luchs *et al*. 2012). Because the difference in performance among sustainable kitchen towels (N-R-S) and regular kitchen towels was significant, it was expected that a very small fraction of consumers would choose to buy such sustainable products. The second aspect to be evaluated is the willingness of consumers to pay a premium price for sustainable products. Literature shows that there are real cases where consumers are willing to pay a premium price for sustainable products (Roheim *et al*. 2011). However, a small segment of consumers choose to pay more for sustainable products, and the number of these consumers decreases with the increase in premium price (Basu and Hicks 2008). Because there was a significant difference in price among the sustainable kitchen towels (N-R-S) and kitchen towels with similar performance that are also manufactured with high content of recycled fibers (O-Q), once again, it was expected that few consumers would prefer to pay a premium price for such sustainable products. The data in this study show that there is a segment of consumers willing to pay a premium price for sustainable kitchen towels with inferior performance. However, the market size for those sustainable products is expected to be very small relative to the total market size of kitchen towels in the USA. Nevertheless, the sustainable products represent a high margin opportunity for tissue paper manufacturers because their manufacturing cost is relatively low (LDC technology and recycled fibers). The authors do believe that there is an opportunity for manufacturers to capture additional consumers and value by offering sustainable products with improved performance.

Prediction of Kitchen Towel Price as a Function of Performance

A multiple linear regression was performed to predict the shelf price of kitchen towels with respect to their physical properties. Samples N, R, and S were excluded from the regression because they were considered outlier samples (anomalous observations), given the previous discussion. Two linear models were developed to predict the shelf price, one on the mass basis (USD/ton) and one on the area basis (USD/m^2). Price on mass basis is an important reference for manufacturers because it relates to the perspective of profitability (difference between selling price and production cost). However, the final selling unit of tissue paper products is defined by the total area in a package. For example, the selling unit for kitchen towels is defined by the number of rolls in a package, number of sheets per roll, and size of each sheet. Therefore, price on area basis is perhaps a more important consideration than price on a mass basis.

Among all physical properties evaluated, water absorbency capacity (g H_2O/m^2) and TSA softness (dB) were the most significant variables that can be used to predict the shelf price of kitchen towels on area basis (USD/m^2) with 95% confidence. Prior to the multiple linear regression, a correlation analysis was performed to evaluate whether water absorbency capacity (g H_2O/m^2) and TSA softness (dB) have strong linear correlation, which would require the elimination of one of the variables. The results show that water absorbency capacity (g H_2O/m^2) and TSA softness (dB) have low degree of linear correlation, and therefore, both variables were used in the model. Figure 10 presents the correlation between the actual price and predicted price and the respective coefficient of determination (adjusted R2).

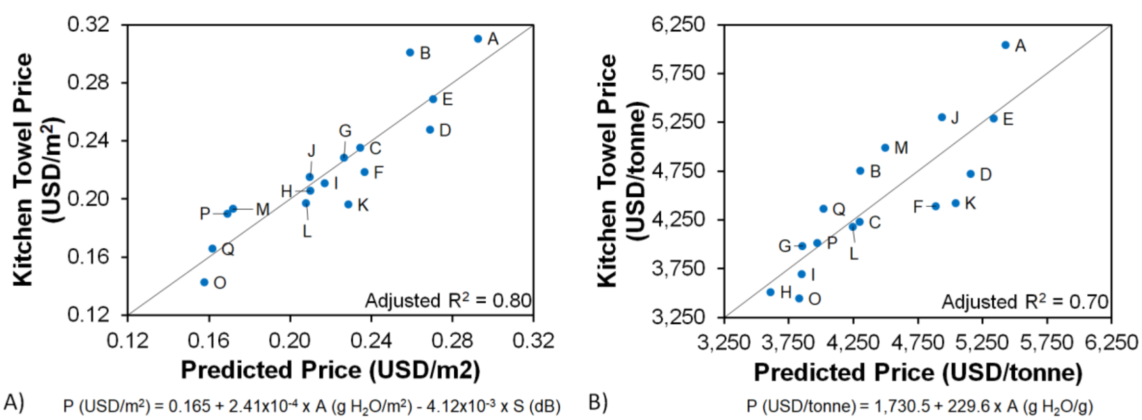


Fig. 10. Kitchen towel price versus predicted price using multiple linear regression. A) Predicted price in USA dollars per square meter [*P* (USD/m^2)] calculated as a function of water absorbency capacity in grams of water per square meter [*A* (g H_2O/m^2)] and TSA softness in decibels [*S* (dB)]. B) Predicted price in USA dollars per ton [*P* (USD/ton)] calculated as a function of water absorbency capacity in grams of water per gram [*A* (g H_2O/g)]. Samples N, R and S were not included in the multiple linear regression

Water absorbency capacity (g H_2O/m^2) was more significant than TSA softness (dB). The partial contribution of water absorbency capacity (g H_2O/m^2) to the model R2 was 0.76. Water absorbency capacity (g H_2O/g) was the most significant variable that can be used to predict the price of kitchen towels on a mass basis (USD/ton). The linear equations used to predict the shelf price are illustrated in Fig. 10, where P (USD/m^2 and USD/ton) is the predicted price of kitchen towels, A (g H_2O/m^2 and g H_2O/g) is the water absorbency capacity measured according to ISO 12625-8, and S (dB) is the intensity of the peak around 6500 Hz (TSA softness - TS7) obtained from the TSA sound spectrum.

Among all properties evaluated in this study, absorbency was the most important variable to determine the final shelf price of kitchen towels. Figure 11 shows the price of kitchen towels as a function of water absorbency capacity for all samples. There was a positive relationship between price and absorbency. As previously discussed, samples N, R, and S were outlier observations that did not follow the same relationship between performance and price as the rest of the samples. Their price was much higher than the regular price for a product with average absorbency. For example, the price of sample N (USD 0.40/m^2) was 85% more expensive than the average price of samples that were not marketed as sustainable products (0.22/m^2). Although the market size for environmental friendly products is small, it represents a high margin opportunity for tissue paper manufacturers in an industry that is approaching commoditization.

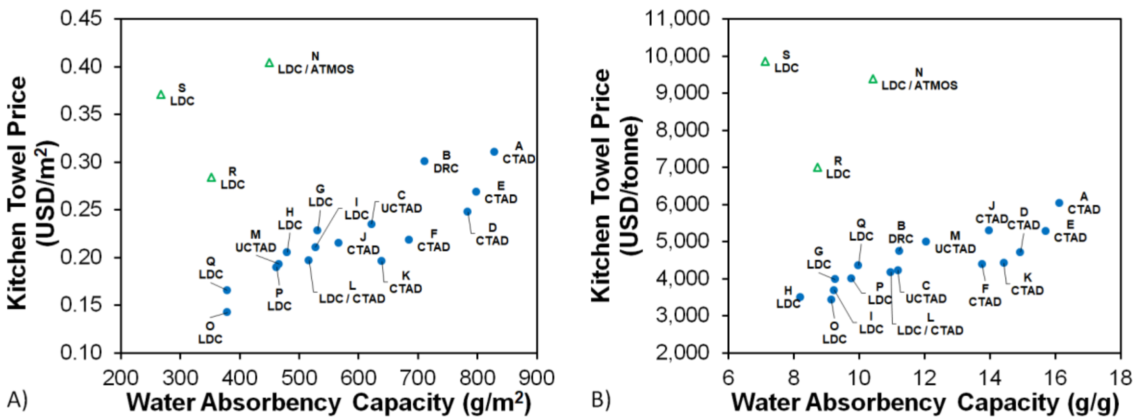


Fig. 11. Water absorbency capacity a function of kitchen towel price. A) Price in USA dollars per square meter (USD/m^2) as a function of water absorbency capacity in grams of water per square meter (g H_2O/m^2). B) Price in USA dollars per ton (USD/ton) as a function of water absorbency capacity in grams of water per gram (g H_2O/g). Samples represented by triangles (N-R-S) are manufactured with 100% recycled fibers and advertised as sustainable products

The metrics classifying kitchen towels among different grades, and their relationship to price add significant value for the tissue paper industry. Based on those metrics, tissue paper companies can easily understand what the actual value of their products is and how they can be compared with other products within their category in the marketplace. The results of this study also provide valuable information to evaluate the upgrade potential of a product within their grade category or even upgrades to a higher grade category. Manufacturers can identify what changes could be made in terms of type and content of fibers, technology, or chemistry to upgrade a product, and what types of tradeoffs are necessary between incurred cost and product price.

CONCLUSIONS

1. The value of kitchen towels is determined by how consumers evaluate the relationship between performance (absorbency, softness, and wet strength) and price. The analysis showed that products having higher performance were manufactured with higher contents of virgin fibers and advanced technology and were more expensive. However, some of the samples did not follow the same observed relationship between performance and price as the rest of the samples. These samples were made with 100% recycled fibers and advertised as "sustainable products", which attracted the attention of a segment of consumers that seemed to be willing to pay more for sustainable products. Some of the sustainable products evaluated were 85% more expensive than the average price of regular kitchen towels. Among all properties studied, water absorbency capacity was the most significant variable used to predict the shelf price of kitchen towels, followed by softness.
2. The properties observed on the kitchen towels were a function of manufacturing technology, raw material, and chemistry. This work showed an interesting trend among tissue machine technology and the type of fiber with kitchen towel properties (apparent density, TSA softness, and water absorbency capacity). Kitchen towel samples with lower apparent density, higher TSA softness, and higher absorbency were usually manufactured with advanced technologies (*e.g.*, CTAD, UCTAD, DRC) having higher content of hardwood fibers. On the other hand, samples having higher apparent density, lower TSA softness, and lower absorbency were typically manufactured with conventional technology (LDC) using higher content of softwood and recycled fibers.
3. Kitchen towels are tissue paper products used for cleaning and drying surfaces, and to do so, high levels of water absorbency capacity and wet strength are expected by consumers. Although softness would not be classified as an essential property, tissue paper manufacturers frequently use softness to reach different slices of the market. For most of the cases, the best products presented high absorbency, wet TEA, and high softness. A map of properties (Fig. 9) was used to classify kitchen towels into three grades (economy, premium, and ultra) quantitatively (Table 4). Economy products have low performance because they are manufactured with conventional technology and a high content of recycled fibers. Premium products can also be manufactured with conventional technology; however, they have lower content of recycled fiber. Ultra products have the best performance because they are manufactured with advanced technology and virgin fibers.

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