Original Research Article

Moisture Transfer of Paper for Food Packaging Applications– A Laboratory Study

ABSTRACT

Since paper has been invented in Chana in 105 BC by Cai Lun it has transformed human live. Sustainable developments favor paper as packaging media to replace plastic packaging materials.

Laboratory tests were performed on commercially available packaging papers for the assessment of mechanical properties and vapor transmission rates that might affect the packaging of perishable goods to further develop paper-based packaging materials.

Research results of the mechanical paper properties values cannot be directly related and compared between the different packaging papers analyzed due to their different basis weight, composition and intended use.

Research results revealed that the application of a coating material can affect paper properties negatively but decrease the vapor transmission rate measured at 23°C and 50% relative humidity below 1.06 g for wax coating and 0.3 g for polyvinyl coatings. Parchment type paper products without coating can achieve a water vapor transmission rate of 1.35 g per 240 hours. an important factor for packaging perishable goods.

Therefore, packaging paper are specifically designed for their intended use and application including the application of a coating to the paper material to keep perishable goods longer fresh.

Keywords: Food paper, packaging paper, moisture transfer, pargement paper, wrapping paper

1. INTRODUCTION

The invention of paper allowed humans to communicate with each other in written form, and this is linked inextricably with development of culture, society and science. The spark was set during the Eastern Han Dynasty in ancient China in 105 BC where Cai Lun invented paper [1-5].

The invention of paper allowed humans to communicate with each other in written form and preserve knowledge over long periods of time. Paper was a new material that was light weight, durable and could be easily transported. Soon it replaced parchment and papyrus like writing products, because it could be easier manufactured in large quantities [1].

The papermaking process was kept as a secret in China for a long time, till it reached eventually Japan 500 years later. The European continent was reached over one millennium later. It took another 500 years to spread over Europe, to Mexico, and the US and Canada [6].

Writing products made out of paper led to the replacement of animal skin pargament as the dominant writing material during that time. The invention of the printing press by Gutenberg (*1400-†1468) in 1446 led to a higher demand for paper which led to the invention of machine-made paper in 1799 when Nicolas Louis Robert, a mechanic at the Didot paper mill in the French town of Esous, invented the first paper machine, which allowed the continuous production of a paper sheet. The invention of the fourdrinier paper machine followed in 1808 by the brothers Henry and Sealy Fourdrinier. Available raw materials such as rags, straw, hemp, and jute could not be supplied in sufficient quantities for the manufacture of paper, this lead to the use of wood as raw material for papermaking in 1840 with the invention of the wood grinding process [1,2] and the introduction of chemical pulp in 1890 [2].

Paper as we know it today is produced on large machines paper that can be over 600 m long, with a production width of approximately 12.0 m. These machines can be considered marvels of technology. Each machine is designed for the specific paper product requirements. Paper machines today can operate at speeds of over 2000 m/min at a daily production rate of over 4,500 tons [5,7-9].

Today, the board, paper, and associated packaging and retailer industries as a whole face increasing production costs by raising energy costs, stringent environmental laws, globalization, high competitiveness, and pressure on profit margins. The paper industry around the world is in search for new ways to decrease production costs and the need to find alternative materials to sustain global competitiveness [1-3]. The packaging and retail industry faces drawbacks by using plastic based packaging materials due to rising environmental concerns such as microplastic pollution. In addition, with consumers requiring more sustainable packaging solutions the industry is required to shift to more sustainable and plastic free packaging solutions.

According to Statista, the 2021 global production of paper and paperboard was approximately 417.3 million metric tons [10], with a global consumption of paper and paperboard totaling at 408 million tons. Paper and Paperboard consumption is projected to continue rising over the coming decade to reach approximately 476 million tons by 2032 [11].

Fabric cloth is one of the oldest forms of packaging goods prior to the invention of paper. The invention of paper opened a new avenue to protect and preserve goods. Paper was initially used to protect small pieces of food and valuable items. Companies used paper to protect and ship their items. Paper packaging materials as we use them today were improved numerous times, but the original intent, to protect, preserve and deliver goods is still its fundamental purpose and the result of continuing improvement and research.

For example, in the U.S. cotton sheets and bags were used around 1850 to store flour and sugar. During the civil War the supply of cotton was interrupted, and paper sheets and glued paper bags replaced the cotton material [12,13].

In 1871, American Albert L. Jones was granted the first U.S. Patent No. 122,023 for corrugated paper as packaging material [14] which then started to replace wooden boxes [12].

Since the introduction of paper as packaging material in the late 1800’s, paper as packaging material has come a long way and can be found today in almost every item that is shipped and or packaged in the food, beverage, pharmaceutical, retail, and industry sector.

Today every industry sector, including the pulp and paper industry around the world faces more rigid environmental regulations, globalization, high competitiveness, pressure on profit margins. Threads, such as digital media is replacing paper products, and triggers the need to find alternative materials to sustain global competitiveness [15-17]**.** Despite that, the demand for pulp and paper products is still growing, especially in the packaging industry due to the paper products favorable environmental footprint. Paper has been rediscovered as a valuable packaging material, and our society is far away from becoming paperless [18,19].

To replace microplastic pollution legislature and consumers put pressure on manufacturers to reduce the use of single use plastics in packaging which may lead to a reduction of microplastic pollution [20].

Application of paper products for food product packaging gains increasing interest due to its recyclability and feasibility of replacing plastic packaging material [21].

However, for food packaging a major requirement is the preservation and shelf life of the packed food product, which is influenced by the packaging material to serves as a moisture barrier [22].
The following research project investigates different properties of commercial produced papers to gather information of properties needed for further developing food grade packaging papers.

2. MATERIALS

For this research project commercially, available material was used to perform the research project.

2.1 Materials

Seven commercially available paper used for food packaging were collected in department stores. The first three papers with nomenclature P1, P2, and P3 are used to pack a variety of baked products and are manufactured from the same base paper material. Paper P1 is used for packaging bread products and has no coating applied with a basis weight of 60 g/m². Paper P2 contains a thin polymer film on the inside and is used is used for packaging baked goods such as doughnuts, cakes, and other sweet baked products with a basis weight of 80 g/m². The third paper P3 has a waxy coating applied on the side that is exposed to the packaged goods and used for rolls, bagels, etc., that might have a slightly oily or fatty outside with a basis weight of 80 g/m². The fourth paper with nomenclature P4, is a regular commercially available 80 g/m² copy paper used for reference. The fifth and sixth paper is parchment like paper with and without coating applied with a with a basis weight of 56 g/m² 76 g/m² respectively. Paper with nomenclature P7, is a wax paper for packaging sandwiches with a basis weight of 34 g/m². Paper with nomenclature P8, is a wax paper for high temperature applications such as baking cookies and other products in an oven above 300°F (148.8ºC) with a basis weight of 47 g/m².
A glass test jar as shown in Figure 1 with a weight of 95 g was used. The used glass jar has an outside diameter of 90 mm and inside diameter of 85 mm with a height of 37 mm. The wall thickness is 2.5 mm. At 9 mm from the top the jar has a recess, which allows the fixation of the paper test specimen.
For fixing the paper sample with an airtight seal to the test glass jar candles made out of red and white paraffin wax were used. The candles were purchased from an art supply store.
To achieve a constant surface area, an O-ring made out of Ethylene Propylene (EPDM Rubber) was used to form a round circumference.
As desiccant, to absorb water, reusable silica gel beads, purchased from Fisher Scientific, were used.

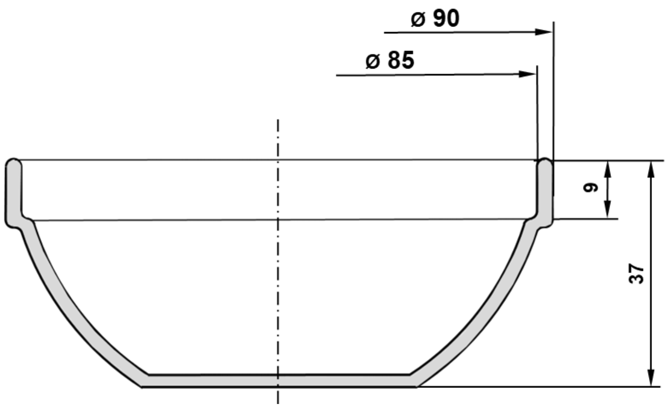


Fig. 1 Glass Test Jar [23]

2.1. Testing Methods

For this research project the following testing methods of the Technical Association of the Pulp and Paper Industry (TAPPI) were used:

Physical testing of handsheets was performed in accordance to T 220 sp-06, “Physical testing of pulp handsheets” [24].

Zero-Span (ZS) data measured with T 231 cm-07 [25] and normalized to a 60 g/m² basis weight.

Conditioning of the paper samples was done according to T 402 sp-08, “Standard conditioning and testing atmospheres for paper, board, pulp handsheets, and related products” [26]. Burst Index was measured in accordance with T 403 om-02 :Bursting strength of paper” [27]. Basis weight was measured with T 410 om-08. “Grammage of Paper and Paperboard (weight per unit area)” [28]. Moisture content of the paper samples was determined by T412 om-06 “Moisture in pulp, paper and paperboard” [29]. Tear resistance was measured according to T 414 om-04 “Internal tearing resistance of paper (Elmendorf-type method)” [30]. Water vapor transmission of the paper product was measured according to T 448 0m-04 “Water vapor transmission rate of paper and paperboard at 23°C and 50% relative humidity (RH) [31]. Tensile strength was performed following T494 om-06, “Tensile properties of paper and paperboard (using constant rate of elongation apparatus)” [32].

2.3. Water Vapor Transmission

Water Vapor Transmission (WVT) of the tested paper products was done according to TAPPI Testing method to T 448 0m-04 “Water vapor transmission rate of paper and paperboard at 23°C and 50% RH [31]. The testing method was modified due to the unavailability of testing jars described in the testing method. For this research project we used a testing jar made out of glass shown in Figure 2. The testing jar had a weight of 95 g, which allowed weighting on an analytical balance with a maximum allowable weight of 220 g and accuracy of 0.0001 g. The used glass jar has an outside diameter of 90 mm and inside diameter of 85 mm with a height of 37 mm. The wall thickness is 2.5 mm. At 9 mm from the top the jar has a recess, allowing the fixation of the paper test specimen.

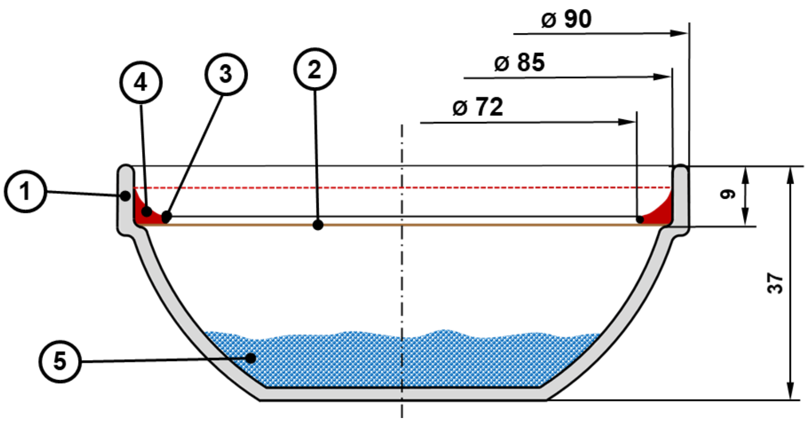


Fig.2.: Water Vapor Transmission Assembly, 1) Test Jar, 2) Paper Test Specimen, 3) O-Ring, 4) Wax Seal, 5) Water absorbent [33]

To prepare a water vapor paper absorbency test assembly for measurement the following preparation steps were done. First, a disc (2) with a diameter of 84 mm was cut out of the paper specimen and weighted. Second, 30 g of Silica Gel (5) were placed in the test jar (1). Third the cut-out paper specimen (2) was sealed with EPDM O-ring (3) and paraffin wax (4) to the glass jar. The assembled test assembly was weighted and placed in a humidity-controlled room with a temperature of 23°C and 50% RH.
To perform the test, it is important to prepare a few test assemblies for training purpose prior to preparing the actual assembly. It takes some skill level to assemble the test assembly as well as pour the molten wax in place to achieve a good seal. Figure 3 shows prepared test assemblies with red and white paraffin wax. All WVT tests were done in triplicate for each paper test specimen.

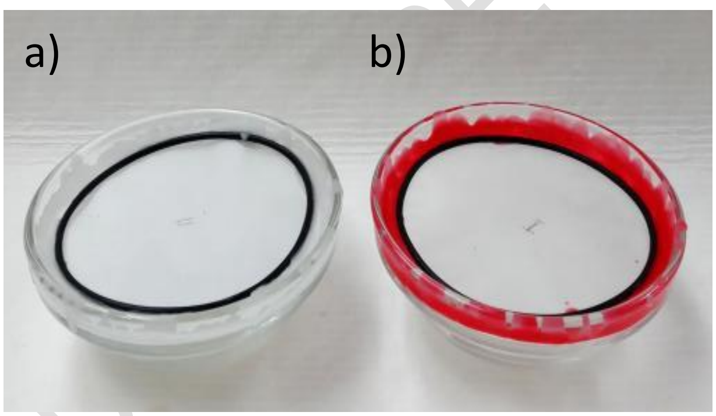


Fig.3: Picture of Water Vapor Transmission Test Assembly a) White Paraffin Wax b) Red Paraffin Wax [33].

3. RESULTS AND DISCUSSION

All tests for this research were performed in accordance with Section 2.1 referenced TAPPI methods. All results stayed in the precision statements for the referenced TAPPI methods.

3.1. Water Absorption

Prior to measuring the WVT according to TAPPI Testing method T 448 0m-04 [24], the moisture uptake for the Paper samples P1 to P9 as well as the red and white paraffin Wax W1 and W2, and the EDPM O-Ring (OR) was tested using the same testing time of 240 hours as for the WVT test period.
For testing the paraffin Wax W1 and W2 10 g were used as test specimen. The OR with a weight of 0.99 g was tested as a whole. For Paper Samples P1 to P9 100 cm^2 paper samples were prepared from each paper P1 to P9. The paper samples were dried in a drying oven for 24 hours at 105°C prior to testing. After drying each sample was weight and put in a humidity and temperature-controlled room with 23°C and 50% RH and the moisture uptake was measured during a 240-hour period.
Figure 4 shows the water absorption for the nine paper samples (P1 to P9), the red and white paraffin wax W1 and W2, and the EDPM O-Ring OR for a period of 240 h.
Paper sample P1 and P2 absorbed 1.1 g, paper samples P3, P4, P5, and P6 absorbed 1.6, 1.7 g, 1.4 g, and 2.1 g respectively. Paper sample P7 and P8 absorbed 0.2 and 0.3 g respectively. The paraffin wax samples W1 and W2 including the OR did not absorb any water.

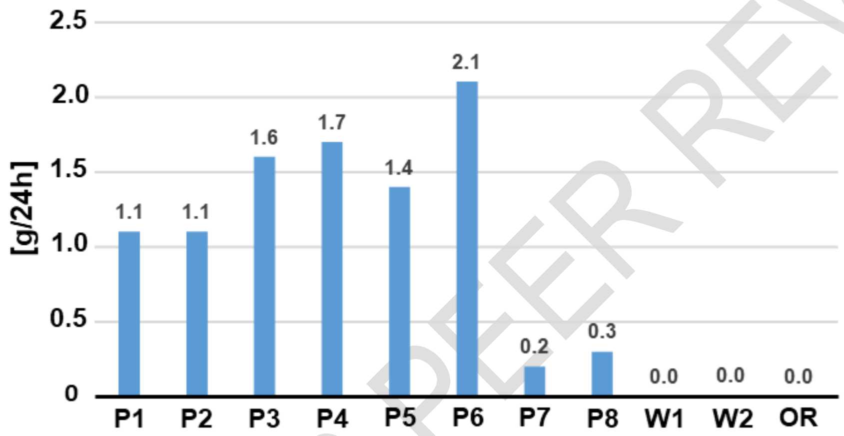


Fig. 4: Water Absorption

3.2. Water Vapor Transmission

The WVT was measured according to TAPPI Testing method T 448 0m-04 [31] which was modified as described in section 2.3 above. The testing was conducted at 23°C and 50% RH for 240 hours and measuring the WVT every 24 hours.
As shown in Figure 5, paper sample P5 had the highest accumulated WVT with 5.16 g, while paper sample P2 a plastic-coated version of paper sample P1 (packaging paper for baked goods) had the lowest accumulated WVT of 0.32 g.
Paper sample P7 (wax paper for packaging sandwiches), P1 (packing paper for baked goods with no coating applied), and P4 (commercially available copy paper) had a similar accumulated WVT of 3.38 g, 3.33 g, and 2.96 g respectively.
Paper sample P8 (wax paper for high temperature applications) had an accumulated WVT of 1.35 g, followed by Paper sample P3 (baked goods packaging paper with wax coating) and P6 with an accumulated WVT of 1.06 g and 0.67 g respectively.
As shown, the WVT can be influenced by coating packaging paper. Paper with a plastic film coating showed to result into the lowest WVT, while packaging papers with coatings applied show a lower WVT than papers that do not have a coating applied.

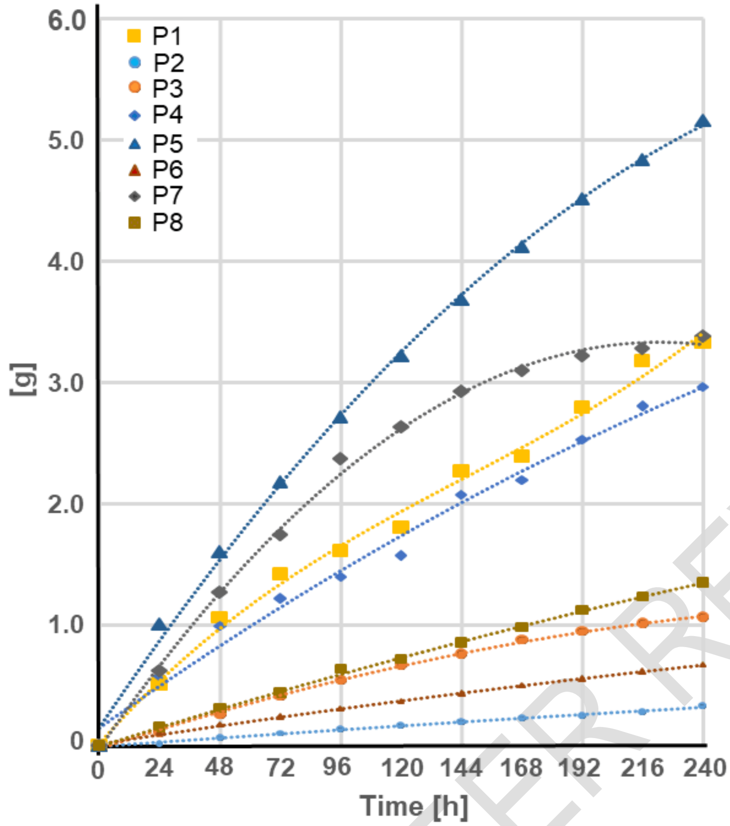


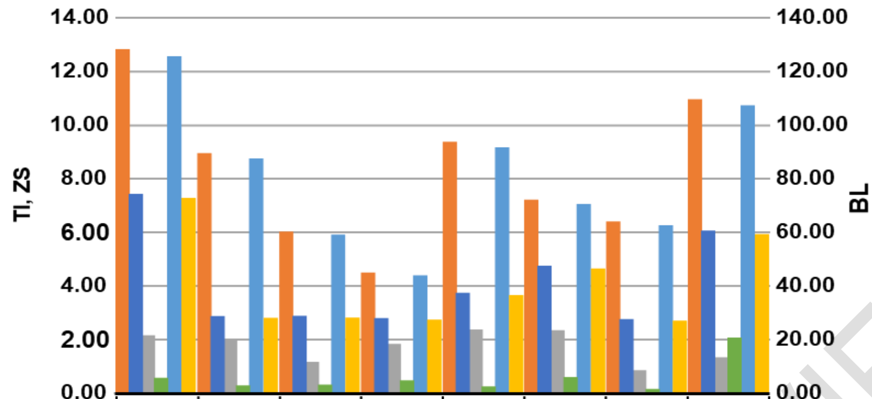
Fig. 5: Water Vapor Transmission

3.3. Mechanical Paper Properties

Figures 6 and 7 show the mechanical properties of the tested paper samples P1 to P8 according to TAPPI testing methods. Results show that each paper test specimen has different paper properties regarding Tensile Index (TI), Breaking Length (BL), Tear Index (TEI), Zero Span (ZS) and Elongation (E) for the Machine Direction (MD) and Cross machine Direction (CD) as well as Burst Index (BI) which is not dependent on MD and CD.

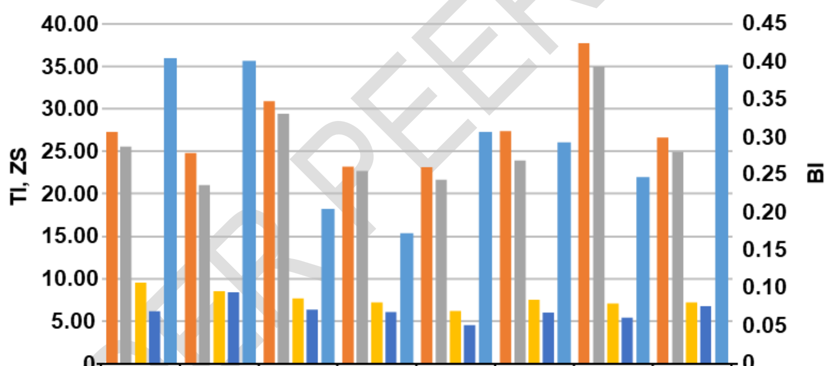
Paper sample P4 (80 g/m² basis weight commercial copy paper) has the lowest paper properties and paper sample P1 (60 g/m² basis weight packing paper for baked goods with no coating applied) had the highest paper properties of all tested paper samples. Paper sample P8 (47 g/m² basis weight wax paper for high temperature applications) and paper P5 (56 g/m² basis weight parchment like packaging paper without coating) had the second highest and third highest paper properties respectively. Paper P2 (80 g/m² basis weight packing paper for baked goods with polymer film coating) had the fourth highest paper properties. Paper P6 with a basis weight of 56 g/m² and Paper P3 with a basis weight of 80 g/m² are a polymer coated version of paper P5 (56 g/m² basis weight parchment like packaging paper) and paper P1 (60 g/m² basis weight packing paper for baked goods) showed lower over all paper properties as their uncoated counter parts. Paper P7 (34 g/m² basis weight wax paper for packaging sandwiches), showed similar properties to paper P3 (80 g/m² basis weight packing paper for baked goods with polymer coating applied).

Based on the results mechanical paper properties values cannot be directly related and compared between the different packaging paper due to their different basis weight and intended use. Therefore, packaging paper is specifically designed for their intended use and application including the application of a coating as necessary which, on the other hand, might affect paper properties negatively as show for paper samples P2, P3 and P6.



	P1	P2	P3	P4	P5	P6	P7	P8
TI-MD [Nm/g]	125.73	87.71	59.15	44.02	91.89	70.68	62.74	107.44
BL-MD[km]	12.82	8.95	6.03	4.49	9.37	7.21	6.40	10.96
E-MD [%]	2.17	2.00	1.18	1.85	2.40	2.37	0.87	1.35
TI-CD [Nm/g]	72.91	28.10	28.25	27.48	36.75	46.61	27.14	59.52
BL-CD[km]	7.44	2.87	2.88	2.80	3.75	4.75	2.77	6.07
E-CD [%]	5.72	2.89	3.27	4.77	2.57	6.01	1.64	20.72

Fig. 6: MD & CD Paper Properties: Breaking Length, Elongation, Tensile Index



	P1	P2	P3	P4	P5	P6	P7	P8
TI-MD [mNm²/g]	27.40	24.86	30.98	23.24	23.20	27.46	37.82	26.71
TI-CD [mNm²/g]	25.62	21.07	29.54	22.74	21.72	24.01	35.03	24.95
ZS-CD [kg/15 mm]	9.56	8.55	7.74	7.29	6.27	7.54	7.09	7.29
ZS-CD [kg/15 mm]	6.14	8.39	6.40	6.09	4.55	6.00	5.44	6.78
BI [kPa*m²/g]	0.41	0.40	0.21	0.17	0.31	0.29	0.25	0.40

Fig. 7: MD & CD Paper Properties: Tear Index, Zero Span, and Burst Index

4. CONCLUSION

Based on the research results mechanical paper properties values cannot be directly related and compared between the different packaging paper due to their different basis weight and intended use. Therefore, packaging paper are specifically designed for their intended use and application including the application of coating as necessary which might affect paper properties negatively as show for paper P2 (80 g/m² basis weight packing paper for baked goods with polymer film coating), P3 (80 g/m² basis weight packing paper for baked goods with polymer film coating), and P6 (56 g/m² basis weight parchment like packaging paper with polymer film coating).

As shown in this research, WVT can be influenced by applying a coating onto the packaging paper. Packaging paper with a plastic film coating or wax coating applied resulted into the lowest WVT.

Further research should focus on light weight packaging paper products that might be enhanced with polymer or wax coating if moisture transfer levels required by the packaged good cannot be achieved with the paper packing material alone.

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