SINAYA
Philippine Journal for Senior High School Teachers and Students

"Utilization of *Daucus carota subsp. sativus* (Carrot) Peels and *Oryza sativa* (Rice) as Alternative Materials for Paper Production"

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ABSTRACT: The problem of pollution and deforestation have continuously contributed to the mass deterioration of the environment. This study aimed to create paper from rice and carrot wastes tested in a laboratory. The study followed an experimental research design, utilizing TAPPI T-220 test methods and ISO standard procedures. The paper sheets were tested under four quality tests: paper tear index, folding endurance, grammage, and paper burst strength. Data gathered from laboratory tests were statistically analyzed via the independent t-test. It was found that rice papers had a higher paper tear index (4.99 mN.m^2/g), folding endurance (3.81 folds), and paper burst strength (1.47 kPa.m^2/g) than carrot papers (2.56 mN.m^2/g, 0.77, and 1.10 kPa.m^2/g). Carrot papers, however, had higher grammage than rice papers (152.76 g/m^2 and 132.90 g/m^2, respectively). There was no significant difference found in data for paper tear index ($p = 0.072$) and paper burst strength ($p = 0.13$), while there was a substantial difference in terms of folding endurance ($p = 0.033$). Previous studies have supported each result and findings. In conclusion, cooked rice can be considered a promising raw material for the paper industry. Although carrot papers were significantly weaker, they still provided average values compared to normal papers. Future research should consider exploring other interventions such as soda pulping and kraft pulping.

KEYWORDS: paper production; recycled paper; paper quality; rice paper; carrot paper

INTRODUCTION

Human factors have caused the decline of forest population through acts of deforestation. The issue of climate change is directly linked to the continued prevalence of global deforestation (Bologna & Aquino, 2020). A past study by Munesue et al. (2015) emphasizes that if food waste in countries decreases by 50%, the impoverished population will decrease by up to 9%. In relation to deforestation, waste management strategies can be used to reduce food waste pollution and the overuse of wood resources for demand in markets (Environmental Paper Network, 2007; Yilmaz & Gumuskaya, 2015). Using non-wood raw materials, such as food waste, in paper making can decrease deforestation and pollution.

There are only a few considerable agricultural food wastes that could be used as pulp in paper-making due to the amount of fiber and cellulose needed to create successful paper material, according to Daud et al. (2013). A single piece of paper from wood mainly contains the following cellulosic raw materials: cellulose fibers (for paper flexibility), hemicellulose (for paper strength in fiber bonding), and lignin (for increasing the pulp yield). Carrot peels or *Daucus carota subsp. sativus* contains 9.14% hemicellulose content, 80,94% cellulose content, and 2.48% lignin content (Sharma et al., 2012).

The Concept of Lignocellulosic Biorefinery states that lignocellulosic raw materials, such as vegetables, have potential to become alternative source for wood pulp through the separation of lignocellulosic components to obtain paper products and other chemical products in pulp and paper industries (Eugenio et al., 2019; Rodriguez et al., 2010). To support this, surface morphological studies indicated that vegetable wastes would yield comparable pulp similar to wood resources (Eugenio et al., 2019). On the other hand, wheat, grains, or any raw material with enough cellulose fiber content can be used in producing decent quality papers (Daud et al., 2013; Talebizadeh & Rezayati-Charani, 2010). This solidifies that cooked rice or *Oryza sativa* also has the potential to become a wood pulp alternative. Theory of Fiber-Reinforced Materials states that composite materials such as paper can be physically

improved by adding fiber content (Hashin, 1972). With this, cooked rice waste could increase the strength of the recycled papers.

Studies suggest that non-wood fiber was the basis of papermaking even before 1870, with its properties and components needed for paper seen in some agricultural residues (consumed or pre-consumed wastes) from households and factories (Bowyer et al., 2014; Main et al., 2014). Reich (2021) reasons that handmade paper production is needed to expand the paper product market. Its potential is measured using four paper quality tests: paper tear index, paper folding endurance, paper grammage and paper burst strength. Paper tear index is used to identify the tensile strength properties of both wood and non-wood pulp paper. It serves as one of the leading considerations in determining a paper's quality using either an Elmendorf tear test or the "TAPPI T 414" (Technical Association of Pulp and Paper Industry) method (Tutuş et al., 2015; Yusof et al., 2012). Similar to this study, other studies have used this method to compare different food waste group products' tensile strength properties (Daud et al., 2013; de Assis et al., 2019; Enayati et al., 2009). Folding endurance refers to the durability or the number of folds a paper can withstand that is defined by the logarithm of the number of folds or the amount of "double folds", measured using a BS ISO 5626 method or MIT (Mechanical Integrity Test) method (Olsen, 2018; Talebizadeh & Rezayati-Charani, 2010). Similar to other studies, this study uses folding endurance to measure the durability of the paper and its fiber strength (Karlsson, 2010; Prajapati, 2005; Talebizadeh & Rezayati-Charani, 2010). The grammage test measures the average paperweight per unit area expressed in grams per meter squared using the Digital GSM (grams per square meter) Tester (SGS IPS Testing, 2018). Other research papers regarding the creation of paper with alternative materials have also used this method as the basis for the claims of their paper strength (Saad & Ibrahim, 2016). Lastly, paper burst strength is the range of how well the paper can withstand forces that may cause rupture to the paper using the TAPPI 403 bursting test (SGS IPS Testing, 2018). Testing this variable would allow this study to improve the paper's durability as this material may be used for products that require strong paper durability. This test was also found to be highly applicable in other studies (Saad & Ibrahim, 2016). These paper quality tests were used to validate the quality of each food waste paper group. Multiple

studies have proven that recycled papers provide the environment with several benefits. However, none have focused on making the papers using a ratio of household food waste and recycled papers. The purpose of this study is to create a potential alternative paper pulp source using a ratio of household food wastes: vegetable wastes (carrot peels), carbohydrate wastes (cooked rice), and recycled papers that would be proven using multiple paper test qualities.

Several studies in the past have proven that recycled papers can provide several environmental benefits, such as decreasing deforestation and pollution. However, little to none have used household food wastes as alternative raw materials in papermaking. This is the research gap that the study addresses. The main problems in focus are deforestation and food waste pollution; the study's objectives are to create handmade papers using household food wastes, test these handmade papers in accordance with TAPPI and ISO parameters, and determine the feasibility of such raw materials in general papermaking. In the making of this research paper, the COVID-19 pandemic has given the study difficulty in producing a higher sample size for the testing. Hence the tests conducted have been done with only ten papers. Moreover, this study will not discuss the paper's chemical properties but only its physical properties. Sustainable development can be done through the use of food waste as an alternative source of paper-making, providing for not only one benefactor group but multiple benefactor groups. This study benefits the agricultural sector and food industries as it is anchored to solving pollution such as excess unwanted crops. This study can help provide a feasible solution to people in poverty and the environment by recycling food waste products into paper products instead of allowing both food and paper wastes to accumulate in landfills. This benefits all living organisms because all can be protected and survive deforestation and pollution.

METHODOLOGY

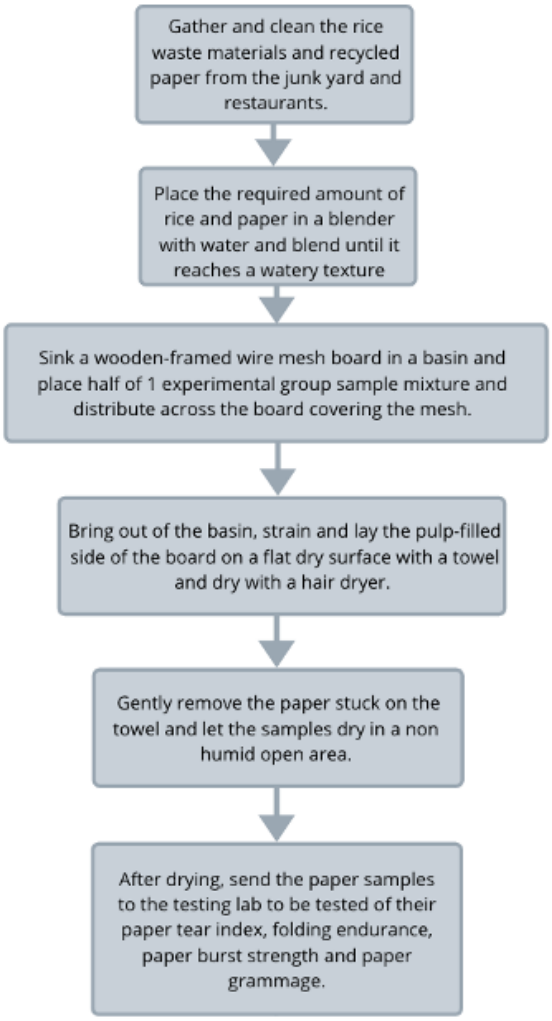
Research Design

The experiments conducted in this study aimed to create paper sheets from two experimental groups (carrot peels and cooked rice wastes) by using TAPPI test methods

(Technical Association of Pulp and Paper Industry) and ISO methods (International Organization for Standardization). Hence, the appropriate research design was experimental because of the inclusion of interventions and the presence of two experimental groups under the independent variable. This study used a posttest design because the two experimental groups underwent the same process and quality testing. Not only were the results of these experimental groups differentiated from each other, but they were also compared to other similar research studies that utilized the use of food wastes and wood for paper-making. Please refer to Figure 1 for the step-by-step procedure.

Figure 1

Handmade Paper Making Procedure Flowchart



Research Locale

The handmade paper production was done at home. In contrast, the paper quality testing was conducted through the Department of Science and Technology (DOST) Forest Products Research and Development Institute Laboratory in Laguna. Due to choosing this laboratory for paper testing, the controlled environment was followed based on the laboratory's standards (dry bulb temperature 23 ±, 1 °C). The study did not involve any human participants.

Preparation of Paper Samples

Paper samples were prepared using the method reported by Picciutio (2015). The process started with gathering the raw food waste materials and recycled papers from each member's household. The samples were prepared by peeling the vegetables and cleaning the rice thoroughly. Samples were then separated into two experimental groups: vegetables and carbohydrate wastes. Each experimental group sample and paper wastes were processed with enough water using a blender until they reached a watery texture. A wooden-framed wire mesh board was sunk in a basin, and half the amount of one experimental group sample mixture was distributed across the board to cover the mesh. A basin was used to strain the board; the pulp-filled side of the board was laid on a flat surface with a towel underneath, which was further dried using a hair dryer. The remaining paper on the towel was gently removed and the samples were dried further in a non-humid open area. The paper's qualities: tearing resistance, folding endurance, grammage, and paper burst were tested after drying.

Paper Tear Index

Paper tear index is the resistance to tear through physical force. The ISO 2758 method was conducted to test this factor. This value is expressed with the unit mNm^2/g, where Nm = millinewtons, m = meter, and g = grams. The paper underwent testing through the Elmendorf test using a pendulum cutter machine. The sample is placed in the machine's work area, to which the machine a portion of the paper from end to end. The loss of energy was measured

by dividing the distance the blade ran through the sample. This energy is then expressed as millinewtons (Nm). The paper's grammage (g/m^2) was divided into the energy loss to find the paper's tear strength. Similar to past studies, this variable was used to test the strength properties of the paper product. It contributes to creating a comparison between the qualities of paper made by each experimental group (Yusof et al., 2012).

Folding Endurance

Paper folding endurance is the paper's maximum amount of paper folds until the sample is damaged. An MIT tester machine was used during this test. As instructed from the ISO 2656 method, an exhaust fan was used to maintain the room temperature throughout the process as the paper is subjected to being folded at an angle of 135° at a rate of 175 folds per minute. The folding stopped as soon as the paper shows visible damage due to folding. The paper's folding endurance is expressed by the average number of folds the paper can withstand before failure. Multiple studies have shown and used this variable to measure physical qualities, durability, the permanence of a paper, and fiber strength of paper material (Karlsson, 2010; Prajapati, 2005; Talebizadeh & Rezayati-Charani, 2010).

Paper Burst Strength

Paper burst strength is the paper's resiliency towards horizontal force and pressure until the paper is ruptured. The ISO 2758 method was used in this study to test this factor. The paper sample is held between annular clamps in a controlled setting. A diaphragm was used to exert pressure to the paper until the paper reached failure. The highest pressure reading was then recorded in kilopascals (kPa) and was labeled as the paper's bursting strength. The paper's burst strength index was measured by dividing the average paper bursting strength (kPa) by the paper's grammage (g/m^2), with the final expression in $kPam^2/g$. A similar study done by Mohamad Jani Saad (2016) used this variable to indicate the strength of his paper made out of rice. The results received from the test were then used as the basis for his handmade paper's strength (Saad & Ibrahim, 2016). Due to this test being highly applicable in knowing the strength of our paper, this test is used for the study.

Paper Grammage

Paper grammage is the general basis weight of the paper. The paper's grammage was measured using the TAPPI 220 method with the GSM tester. First, the paper's weight was measured using a GSM tester. Then, the area of the paper was measured. The paper's grammage was based on the weight-to-area ratio; hence, the expression of the paper's basis weight was in g/m^2. Other studies have used this method as the basis for the claims of their paper strength (Saad & Ibrahim, 2016). Furthermore, this test is needed due to the variable being required for the burst strength test, and paper tear index are part of their equations.

Statistical Treatment

Since these results will utilize numerical data, these two independent variables were compared through the independent t-test. The four dependent variables were presented. The independent sample t-test, the two independent groups based on the displayed dependent variable results. The results gathered from the statistical evidence determined whether there is a significant difference between the independent groups. The graphs and statistical evidence depict the conclusion of this study. Furthermore, the statistical analysis application Jamovi was used in analyzing the data. The data distributed applies the mean and standard deviation or SD. The significance was determined based on the p-value. If the p-value > 0.05, the result is significant.

RESULTS AND DISCUSSION

The results provided data that allowed the researchers to obtain conclusions and other expected and unexpected outcomes from the paper samples. The paper tear index means of rice papers is 663.0 while carrot papers are 391.0. The folding endurance mean of rice papers is 7.80 while carrot papers are 1.8. The paper burst strength mean of rice papers are 30.4 while carrot papers are 26.0. With these, and the other additional data provided in the further section of this chapter, the research was able to provide concrete results.

Paper Tear Index

Table 1

Statistical Data found in Rice and Carrot paper in terms of Paper Index

	Group	***N***	***Mean***	***Median***	***SD***	***SE***
Paper Tear	Rice	5	663	610	254	113
Index	Carrot	5	391	391	148	66.2

Figure 2

Graph of Comparison for Paper Tear Index

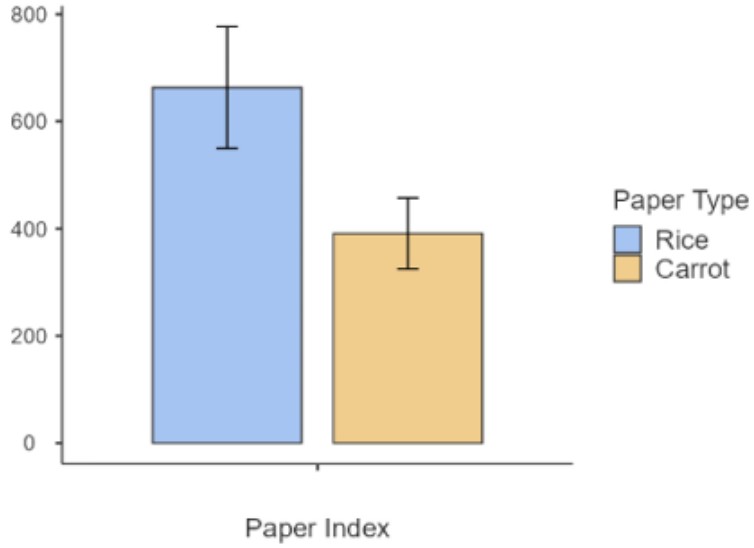


Table 2

Independent t-test for Paper Tear Index

							95% Confidence Interval				***95% Confidence Interval***	
		Statistic	***df***	***p***	***Mean Difference***	***SE Difference***	***Lower***	***Upper***		***Effect Size***	***Lower***	***Upper***
Paper Index	Student's t	1.67	8.00	0.072	272	131	-30.6	575	Cohen's	1.31	-0.257	2.78

The significant difference in paper tear index for each dependent variable is examined in Tables 1 and 2. As seen in Table 1 and Figure 2, among the five samples, the descriptive statistics and comparison graph demonstrated that the paper tear index was significantly higher for rice paper (M = 663, SD = 254) than for carrot paper (M = 391, SD = 148). Based on the standard deviation (SD), minimum and maximum values, rice paper samples have a range of 391 mN - 1007 mN (SD = 254; 95 % confidence interval), whereas carrot paper samples have a range of 173 mN - 566 mN (SD = 148; 95 % confidence interval).

Furthermore, the Shapiro-Wilk test revealed that the data for the paper tear index is normal, with W(8) = 0.966 and p = 0.849. The data for the paper tear index exhibits equal variance (F = 2.43, p = 0.16), according to Levene's test. This means that the *p*-value from the Student's t-test can be used.

The difference in data for both variables is insignificant since the p-value (p = 0.072) is more than 0.05 using the independent sample t-test. There is no significant statistical difference in the paper tear index between rice paper and carrot paper (t(8.00) = 2.07, p = 0.072). (Table 2). Furthermore, even though the student's t statistics (t(8.00) = 2.07) is larger than Cohen's d effect size (effect size = 1.31), it is insufficient to demonstrate a significant difference between rice and carrot paper (Table 2).

Folding Endurance

Table 3

Descriptive statistics of rice and carrot paper in terms of folding endurance

	Group	***N***	***Mean***	***Median***	***SD***	***SE***
Paper Tear	Rice	5	7.80	7.00	4.66	2.08
Index	Carrot	5	7.80	2.00	0.837	0.374

Figure 3

Graph of Comparison for Folding Endurance

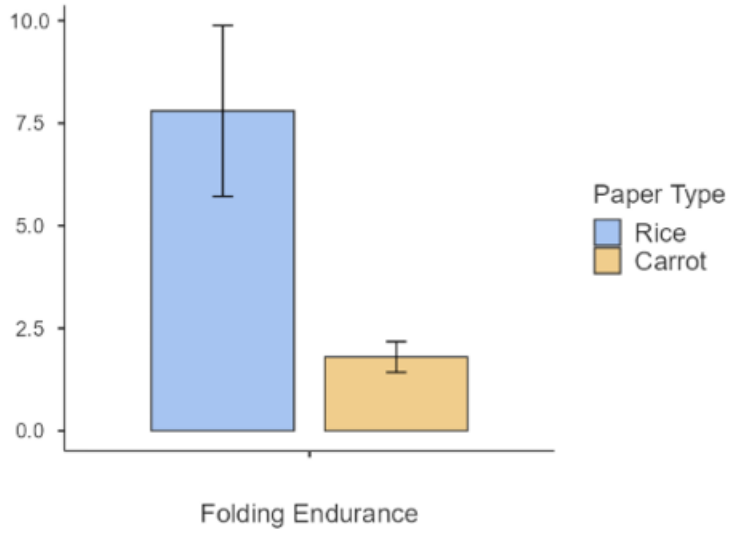


Table 4

Independent t-test values for folding endurance

							95% Confidence Interval			
		Statistic	***df***	***p***	***Mean Difference***	***SE Difference***	***Lower***	***Upper***		***Effect Size***
Folding Endurance	Mann-Whitney U	1.67	8.00	0.072	272	131	-30.6	575	Rank biserial correlation	0.840

The folding endurance of carrot peel sheets and rice waste papers was noticeably different. According to the descriptive statistics and comparison graph, rice paper (M = 7.80, SD = 4.66) considerably has better folding endurance than carrot paper (M = 1.80, SD = 0.84). (Table 3, Figure 3). Rice paper samples have a standard deviation, minimum, and maximum value range of two folds to 15 folds (SD = 4.66; 95 % confidence interval), whereas carrot paper samples have a range of one fold to three folds (SD = 0.84; 95 % confidence interval).

Furthermore, the folding endurance data was shown to be abnormal by the Shapiro-Wilk tests, W(8) = 0.805, p = 0.02. However, Levene's test shows that the data for folding endurance have equal variance (F = 2.46, p = 0.16), indicating that the Mann-Whitney U test p-value may be utilized due to its non-parametric (not following a normal distribution). The Mann-Whitney test revealed that rice paper (Mdn = 7.00) had better folding endurance than carrot paper (Mdn = 2.00), U(N rice = 5, N carrot = 5) = 2.00, p = 0.033. The result is also significant since the Mann-Whitney U p-value (p = 0.033) is smaller than the effect size (effect size = 0.84) in Table 4. This is sufficient to show a significant difference in the folding endurance between carrot peel and rice papers.

Paper Burst Strength

Table 5

Descriptive statistics of Rice and Carrot paper in terms of Paper Burst Strength

	Group	***N***	***Mean***	***Median***	***SD***	***SE***
Paper Tear	Rice	5	30.4	30.0	2.97	1.33
Index	Carrot	5	26.0	28.0	5.10	2.28

Figure 4

Graph of Comparison for Paper Burst Strength

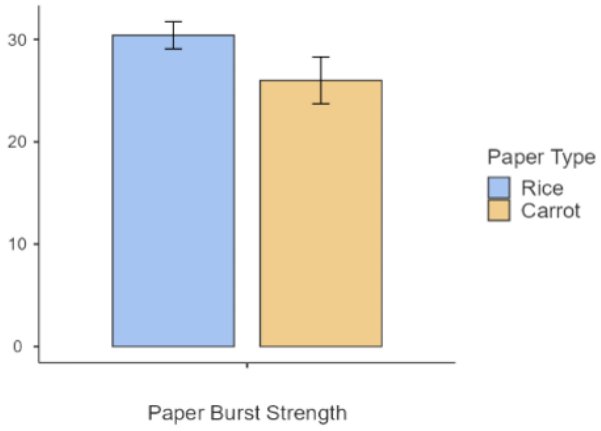


Table 6

Independent t-test for Paper Burst Strength

							95% Confidence Interval				95% Confidence Interval	
		Statistic	df	p	Mean Difference	SE Difference	Lower	Upper		Effect Size	Lower	Upper
Paper Index	Student's t	1.67	8.00	0.134	4.40	2.64	-1.68	10.5	Cohen's	1.05	-0.418	2.43

The descriptive statistics and comparison graph revealed that the paper burst strength of rice paper (M = 30.4, SD = 2.97) was significantly higher than carrot paper (M = 26.0, SD = 5.10) among the five samples (Table 5, Figure 4). According to the standard deviation, minimum and maximum values, rice paper samples have a range of 26 psi - 34 psi (SD = 2.97; 95 % confidence interval), whereas carrot paper samples have a range of 18 psi - 30 psi (SD = 5.10; 95 % confidence interval) (Table 5).

In addition, the Shapiro-Wilk tests indicated that the data for paper burst strength is normal, $W(8) = 0.905$, $p = 0.25$. Furthermore, the data for the paper burst strength shows identical variance ($F = 1.96$, $p = 0.199$), according to Levene's test. This means that the p-value from the Student's t-test can be utilized. The types of paper (rice paper and carrot paper) have an insignificant impact on the paper burst index, $t(8) = 1.67$, $p = 0.13$ (Table 6) since the p-value ($p = 0.13$) is more than 0.05, according to the Student's t-test (Table 6). Given that the Student's t statistic ($t(8) = 1.67$) is greater than the effect size (effect size = 1.05), the effect size is insufficient to demonstrate a significant difference in paper burst strength between rice paper and carrot paper, even though it is high (Table 6).

Discussion

Paper Tear Index

Tearing strength is one of the properties of paper that would indicate how much vertical stress the material could take before rupture. Regarding the results on the paper tear index, rice paper samples provided higher values than carrot paper samples. This suggests that papers made partially from rice can resist more tearing force than carrot papers. The result is possibly due to the fiber amount in rice being significantly higher than those found in carrots. Previous literature regarding alternative papermaking stated similar results when carbohydrate papers were compared to vegetable papers (Jimenez et al., 2001; Petroudy et al., 2014; Requejo et al., 2012). Furthermore, paper tear index values of rice papers are also within the range of office papers (Goyal et al., 2015). The similarities between previous and current studies' results imply a fitting and reasonable conclusion that carbohydrate waste papers have higher paper tear index values.

Folding Endurance

In terms of folding endurance, carrot paper samples provided higher values than rice paper samples. This suggests that papers made partially from rice can withstand more folds than carrot papers. Rice papers would less likely deteriorate upon aging than carrot paper. Previous literature also stated similar results when carbohydrate papers were compared to vegetable papers (Behera et al., 2015; Fiscal & Dandan, 2016; Hassan et al., 2016). Furthermore, folding endurance is important in manufacturing high-quality commercial papers (Goyal et al., 2015). The similarities between previous and current studies' results imply a fitting and reasonable conclusion that vegetable waste papers have higher folding endurance values.

Paper Burst Strength

Paper burst strength evaluates the horizontal strength of the material. In terms of the paper tear index, rice paper samples provided higher values than carrot paper samples. This suggests that papers made partially from rice can tolerate higher pressure levels than

papers made partially from carrots. This notion is supported by previous literature, which also states similar results (Ates et al., 2015; Enayati et al., 2009; Rahman et al., 2014). Furthermore, rice papers had similar mean burst index values to normal coated paper (Goyal et al., 2015; Kasmani et al., 2013). The similarities between previous and current studies' results imply a fitting and reasonable conclusion that carbohydrate waste papers have higher paper burst strength values.

Grammage

Grammage is the base measurement ratio of the paper. In terms of paper grammage, carrot paper samples provided higher values than rice paper samples. This suggests that papers made partially from carrots are heavier than papers made partially from rice. This is supported by previous literature that states close value to this study's results (Ates et al., 2015; Farahin Syed et al., 2016; Nascimento et al., 2011; Saad & Ibrahim, 2016). Furthermore, it is important to note that office-quality papers have lower grammage values than rice and carrot papers in this study (Tutuş et al., 2015). However, grammage values from rice and carrot papers are within the range of folded leaflets and paperboards (Goyal et al., 2015; PrintSimple, 2021). The similarities between previous and current studies' results imply a fitting and reasonable conclusion that vegetable waste papers have higher grammage values.

Paper tear index and paper burst strength show that rice paper samples provided higher values than carrot paper. It indicates that rice resists more tearing force and tolerates higher pressure levels than carrot paper. As for folding endurance and Grammage, carrot paper has higher values than rice paper, which indicates that it can withstand numerous folds and is heavier than rice paper.

CONCLUSIONS

In conclusion, rice paper has better qualities than carrot paper in terms of paper tear index and paper burst strength. In contrast, carrot paper has better quality in terms of folding endurance. Combining alternative raw materials with recycled paper can strengthen the

ending product such that it can surpass normal paper quality in terms of physical properties. Both rice and carrot papers had good properties, but it was discovered that carbohydrate wastes (sugars, grains, and starches) provide better paper quality than vegetable waste, and it was unexpected that the use of vegetable waste was less likely to function as a paper product. Exploring other dependent variables such as brightness, kappa number, ink absorption, and chemical composition is suggested for further researchers that may want to expound on this paper. Future studies should consider professionals making the paper in a laboratory or a paper factory.

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ACKNOWLEDGMENTS

We would like to acknowledge the help of our school in making this research paper. They have provided us with immense support and guidance through our teachers. We are thankful for the accessibility to a research database (EBSCO and Proquest); these have greatly reduced our initial problems and have provided us with quality sources and references to ensure a well-built research paper. We would like to thank the Department of Science and Technology Forest Products Research and Development Institute for processing our experimentation process and for providing us with highly accurate results. Last but not least, we would like to acknowledge the help of Kean Arkin S. De Guzman, who helped with the experimentation procedure despite being an unofficial member of the group this year.

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