PA-BI-BOARD - PLANTABLE BIODEGRADABLE CARDBOARD: SEED INTEGRATION IN CARDBOARD TO REDUCE PAPER AND SEED WASTE

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ABSTRACT

During this COVID-19 pandemic, the growth in packaging production has been fueled by the online shopping boom and with the rise of the E-commerce industry. There is a growing need for corrugated cardboard as a packaging material for parcel delivery. However, there has also been a rise of deforestation, a steady increase of the amount of packaging material waste, and increasing rate of improper waste disposal. The Philippines has been plagued by inefficient waste collection, lack of disposal facilities, and poor policy implementation which further makes the initial problem much more severe. This research study aims to provide an eco-friendly alternative by the utilization of excess seeds and recycled office papers. Plantable Biodegradable Cardboard (Pa-Bi-Board) is developed to aid and lessen the growing waste pollution by providing incentives to its consumers. The new developed packaging material will be tested in terms of Tensile Strength, Water Contact Angle, and Germination tests against the respective control groups using a comparative left-tailed statistical test for numerical analysis. Results show that Pa-Bi-Board performed equally or better in the Strength (P-Value = 0.5069) and Water (P-Value = 0.9979) test. However, the Pa-Bi-Board did not perform equally or better in the Germination (P-Value = 0.0031) test. The researchers recommend increase in sample sizes, machinery for production, and exploration of other biodegradable materials.

Keywords: *Cardboard, Solid Waste Management, Sustainable Packaging, Seed Paper, Paper Pollution*

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Chapter I

INTRODUCTION

Background of the Study

While the major economies slid into recession and industries suffered great losses to the COVID-19 pandemic, E-commerce sales saw explosive growth. In this rapid movement of consumers to online purchasing and delivery services, there has been a significant increase in the demand for packaging materials, such as cardboard boxes. Supporting this, Parcel Shipping Index by Pitney Bowes Inc. (2020) finds global parcel volume exceeding 131 billion, a 27% increase from 2019, with a 9% increase of corrugated-box shipments. Corrugated cardboards are widely used for secondary packaging of goods, as well as tertiary packaging of large packs into mass cargo (Saxon Packaging, 2020). In addition to its relatively low cost, its strength and durability are remarkable in protecting a variety of products from damage, notably during the shipment process. Given this, businesses have been largely reliant on cardboards as a more practical, secure, and sustainable means of transporting their products from production centers to consumers (Kaushal et al., 2010).

However, with the surge in the production of cardboard, so has its environmental impact (Yilan et al., 2020). While the industry of Philippine E-commerce grew, a significant shift in local package volume occurred, generating more waste from packaging materials. Notably, cardboard was already a significant contributor, accounting for roughly 31% of the local municipal solid waste (Philippine Environmental Management Bureau, 2018). The environmental damages include deforestation, air pollution, and water pollution. Cutting trees and making pulp for the production of the likes of cardboard cause rising carbon dioxide and sulfur dioxide concentration levels. Discharges from pulp and paper mills pollute the surrounding bodies of water, further impacting biodiversity. Moreover, the decomposition of the disposed boxes and containers in open landfills releases methane in the atmosphere; Thus, the worsened effect of greenhouse gasses and the induction of global warming (Chua, 2021; Matthews, 2016).

On a different note, pomace remains another source of environmental pollution. For major crop vegetables in the Philippines, the processing generates mass by-product wastage. Since their seeds are tasteless and indigestible, they are usually meticulously removed before consumption. In a commercial setting, deseeding also occurs, in which it is an automated process for numerous food companies into producing puree, juices, sauces, and dried powders; And so, a bulk of pomace is produced but is commonly disposed of (Kumar, et al., 2021).

Furthermore, the Philippines has been plagued by inefficient waste collection and a lack of disposal facilities, while other countries have developed systematic means of managing waste, such as the United States of America and Japan with designated recycling centers. In 2001, the Philippines pursued its programs of solid waste management and related protection of public health and environment through the passage of Republic Act 9003 or the Ecological Solid Waste Management. However, data exhibits that the local government units (LGUs) have struggled with the implementation of the legislation even two decades after its passage. In 2030, annual solid waste production is expected to increase by five (5) kilograms, resulting in a total of 20 million metric tons. Comparing this with the annual solid waste production in the Philippines in 2014, it is alarmingly an estimated 40% increase (Gatchalian, 2020).

Despite the rising solid waste production, Filipino citizens continue to fail in practicing proper waste disposal. Statistical data by Parayno & Busmente (2006) shows that an estimated 5,980 tons of domestic wastes in Metro Manila alone are not being composted nor recycled out of 6,700 tons of wastes. In addition, the Philippines does not have government-owned centralized or designated recycling centers for recyclable wastes, and instead, the LGUs rely on landfills to dump all of the wastes (Castillo & Otoma, 2013). Out of a thousand LGUs, more or less than 300 are serviced by operational sanitary landfills, whereas there are still 400 operational illegal dumpsites. Cardboard then loses its potentiality to be mass recycled for sustainable production since there are inadequate facilities and inefficient implementation for solid waste management.

Statement of the Problem

Noting that the increased production volume of cardboard contributes much to the environmental problems including deforestation, paper pollution, and seed wastage, the study aims to innovate cardboards into a more sustainable eco-conscious packaging product by the utilization of excess seeds and recyclable paper materials. The integration of seed and the cardboard's recyclable materials present an opportunity to decrease a large amount of cardboard left for landfill decomposition and mass seed wastage, as well as to aid in the replanting of barren areas.

This study specifically aims to answer the following research questions:

1. Is Pa-Bi-Board an effective alternative to standard cardboard in terms of tensile strength?
2. Is Pa-Bi-Board an effective alternative to standard cardboard in terms of water resistance?
3. Will the disposed Pa-Bi-Board successfully allow growth of the embedded seeds, and how will it compare to conventionally planted seeds?

Conceptual Framework

The conceptual framework of the study was described using the system approach (Input-Process-Output System). The variables considered in the research and the methods used to achieve the output are depicted in the diagram below.

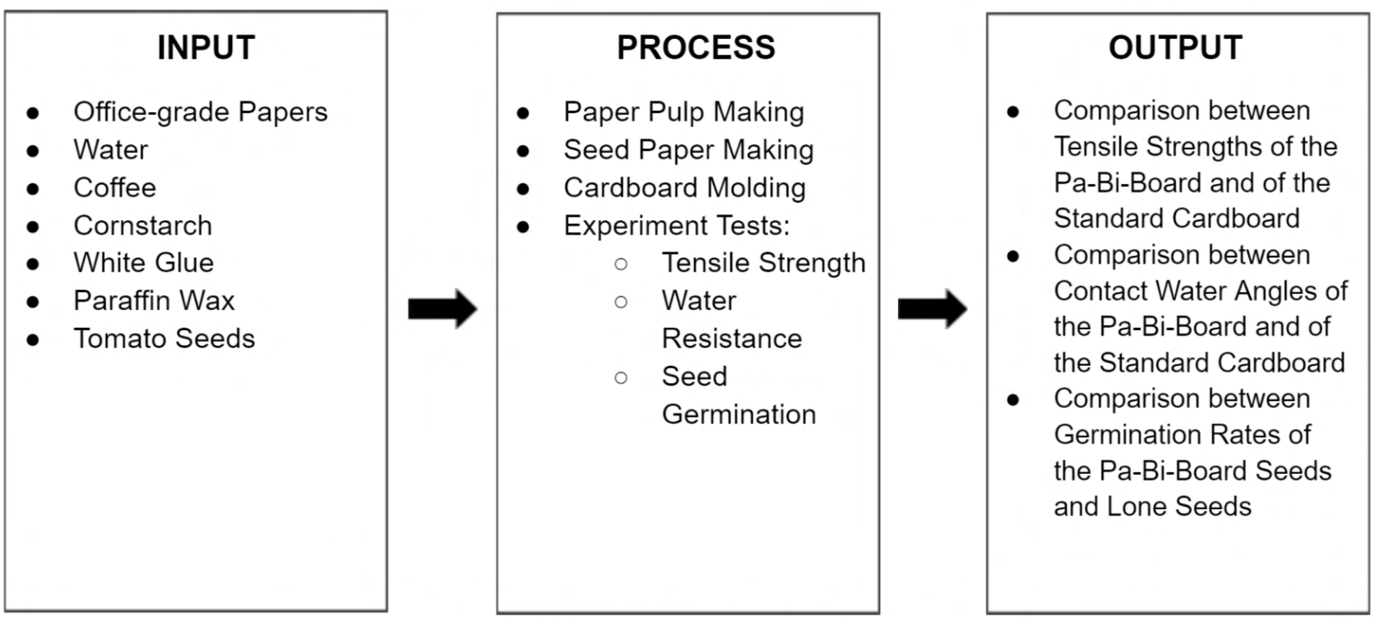

Figure 1. *Conceptual Paradigm*

The Input will include the materials or ingredients for the development of a prototype of the Pa-Bi-Board. The Process portion will consist of the creation in each phase, beginning with paper pulp making, followed by seed paper making, then the cardboard molding or structuring using the sheets altogether, and finally, the experimental integrity and viability testing. The Output will consist of each of the experimental test results, along with a comparison of the strength and water resistance of the Pa-Bi-Boards to Standard Cardboards, as well as differences in Pa-Bi-Board Seeds germination rates to the Lone Seeds.

Research Hypotheses

- *Strength*

Question: Is there a significant difference between standard cardboard and Pa-Bi-Board, taking into account the tensile strength test, which will show the effectiveness of the Pa-Bi-Board as a viable alternative?

Null Hypothesis: Pa-Bi-Board performed equally or better than standard cardboard in the specific experimental test. (PBB >= SC)

Alternative Hypothesis: Pa-Bi-Board did not perform equally or better than standard cardboard in the specific experimental test. (PBB < SC).

- *Water Resistance*

Question: Is there a significant difference between standard cardboard and Pa-Bi-Board, taking into account the water resistance test, which will show the effectiveness of the Pa-Bi-Board as a viable alternative?

Null Hypothesis: Pa-Bi-Board performed equally or better than standard cardboard in the specific experimental test. (PBB >= SC)

Alternative Hypothesis: Pa-Bi-Board did not perform equally or better than standard cardboard in the specific experimental test. (PBB < SC).

- *Seed Germination*

Question: Is there a significant difference between the successful seed germination of Pa-Bi-Board and the control group of separate seeds, taking into account the germination test?

Null Hypothesis: Pa-Bi-Board has statistically germinated the same amount of seeds or more compared to the control group. (PBB >= S)

Alternative Hypothesis: Pa-Bi-Board has statistically germinated less amount of seeds compared to the control group. (PBB < S)

Significance of the Study

The findings of this study would contribute to a general awareness of the environmental issues and further expanded research on greener alternatives that could help mitigate the harmful effect of mass cardboard production.

This data will be beneficial for:

- *Government*. This research will help the Philippine government in developing products or methods that may aid in managing waste or addressing issues such as inefficient waste collection, improper waste disposal, and a lack of disposal facilities. They may be able to incorporate the concepts described in this study into current programs aimed at improving and utilizing related innovative recyclable and biodegradable products, as well as to generally endorse creating a greener environment nationwide.
- *Communities*. This research will inform local communities on the advantages and disadvantages of an environment-friendly alternative to cardboards and recycling in general. Along with this, it may foster awareness on the ever-growing pollution in their community, in which they may realize potential contributions to partake in pollution reduction. As a result, it may improve air and land quality and overall, promote community health. Further, the fruits of the planted cardboards may prove valuable as an added food source to the community.
- *Environment*. This research will help improve present environmental conditions through the increased understanding and utilization of biodegradable products. The cardboard is a sustainable product due to its ability to return to the earth without posing any harm to ecosystems. It may also contribute to increasing the number of plants and decreasing paper pollution because of its disposal process; Hence, locally mitigating greenhouse gas emissions.
- *Researchers*. The findings of the study will benefit future academics studying cardboard and paper pollution reduction. The background review of the research and related anti-pollution measures may aid researchers in finding or synthesizing better biodegradable components for integration into the major

sources of solid waste. Notwithstanding, they may utilize this study supposing that they conduct similar environmental research subjects.

Scope and Delimitation

The study aims to aid in the reduction of solid pollution and improve waste disposal conditions at a local level. It proposes an alternative product to reduce seed wastage and mass-produced corrugated cardboard that is increasingly being used and yet relatively unregulated despite the prominent environmental impacts. The researchers are limited to the results of a specific seed paper cardboard by only incorporating tomato seeds, office-grade papers, and household ingredients (e.g. school grade glue for adhesive and cornstarch for the sizing instead of the standard industrial components). The researchers only performed manual manufacturing and molding procedures. The research also only aimed to test at least 10 prototypes each in the three domains or properties: water, strength, and germination.

The research is further limited in the creating and testing of the prototypical item with restrictions brought upon by the pandemic, hindering collaborative in-person work. Moreover, there is a lack of access for sourcing and to a larger scale or scope to multiple types of standard cardboard and seed paper products for comparative analysis.

Chapter II

REVIEW OF RELATED LITERATURE AND STUDIES

History of Cardboard Packaging

Flexible packaging materials were used in ancient China as early as the first or second century B.C. (Berger, 2002). The Chinese wrapped food in mulberry bark sheets and invented paper-making techniques, ushering in the first use of paper for packaging items such as medicine and tea parcels, as well as the invention of cardboard and paperboard. In 1817, the first paperboard carton was made in England (Berger, 2002). Then by 1871, corrugated cardboard boxes were invented, when they began to replace wooden crates and boxes (Heimlich & Hook, 2017). However, there came a surge in plastic production for packaging in the 1970s, hence the phase-out of paper and its related products (Berger, 2002).

The global consumption of paper and cardboard is now estimated to be around 400 million metric tons per year (Tiseo, 2021), and the demand continues to increase annually. The online shopping boom has fueled growth in packaging production, with a growing demand for containerboard — a material used in the manufacture of cardboards. The COVID-19 pandemic has also further increased online shopping (Kim, 2020), with 131 billion parcels shipped globally in 2020 — more than tripled in the last six (6) years (Buchholz, 2021). Locally, the Philippines presently has 24 non-integrated paper mills, totaling an annual production capacity of 1.3 million tons of paper and paperboard. Waste paper would account for 19% of total municipal solid waste. After kitchen garbage, it is considered the second most commonly produced solid waste. (Government of the Philippines, 2015).

Composition and Characteristics of Cardboard

Corrugated cardboard consists of paper pulp material, mainly of cellulose, hemicellulose, and lignin, which account for 52%, 6% and 10% of the total composition, respectively. A standard panel of a corrugated board comprises two liners (sheets of paper) joined with an adhesive to a fluting (corrugated inner medium) (Kaushal et al., 2010). Generally, cardboards have a high strength-to-weight ratio, are rigid, light in weight, and thin (Park, 2018). The series of connected fluted arches provide support to heavy loads and its shape permits air circulation, acting as an insulator, protecting against temperature changes (Belmont Packaging, 2017).

The corrugated boards are generally reusable and recyclable. The recycling process includes the reprocessing and reuse of thick sheets or hard multilayer paper. The majority are recycled into new cardboard, while the rest are downcycled into other paper products. During the process, biodegradable waste is generated, which may be further processed in both mechanical (material) and biological treatment processes (Nowińska, et al., 2019). However, most cardboards have been subject to chemical coatings to increase qualities such as wet-strength, and this makes recycling more difficult (Park, 2018).

Paper Pollution

The production of pulps from trees used for cardboard increases the production of sulfur dioxide, potentially contributing to sulfur dioxide pollution. Another factor that adds to paper pollution is the wastewater from pulp and paper mills; different types of wastewater are generated from various industrial processes (Ince, et al., 2011). Paper and pulp mills in Pakistan are an example of these processes, where most of their wastewaters containing bleach and black liquor are directly discharged into their bodies of water (Thompson et al., 2001). The main problems with wastewaters are their high organic content (20-110 kg COD/air dried ton paper), dark brown coloration, and adsorbable organic halides, which lead to the accumulation of toxic pollutants in large quantities (Ince et al., 2011). Every year, to meet the demand for paper materials and goods, an estimated 4.4 million hectares of forest lands are extracted, contributing to 14% deforestation, and 23% release of carbon dioxide gasses, outweighing 14% of carbon dioxide emissions by cars, as measured by the World Car-Free Network (2018).

- *Improper solid waste management*

In the Philippines, according to the Environment Management Bureau (2018), paper and cardboard account for 31% of total solid waste produced by municipalities. Wastes are accounted the highest from commercial sources at 27%. The enacted Republic Act No. 9003 then seeks to address the environmental issue on local wastes, inclusive of paper and cardboard disposals. The Act initiates the adoption of a systematic, comprehensive, and ecological Solid Waste Management (SWM) program with the LGUs as the policy's implementing bodies. It also calls for the creation of new SWM Boards, the establishment of Material Recovery Facilities in all barangays, the prohibition of open waste dumping, and the conversion of dumpsites to sanitary landfills.

Packaging Alternatives

Reusable eco-bags for plastic bags with smaller and less amount of products are presented to consumers as alternative packaging material. There are presently a number of developed alternatives to standard cardboard, but only of which primarily improve product safety, such as air pillows packaging and seaweed packaging. These alternatives function similarly to air bubble packing but do not serve as external structural support for cardboard (“Alternatives to Cardboard Boxes”, 2018). It is recognized too that these products either similarly add pollutants and are cost-intensive: air pillows are made of non-biodegradable plastic, and seaweed packaging’s manual processing is expensive.

Seed paper, also known as plantable paper, is made from post-consumer and post-industrial paper waste rather than trees. It is observed to have been produced since 1941 by American papermakers (Fogler, 2013). Small seeds are embedded within the paper and when the seed paper is planted in the soil and watered, the seeds sprout and the paper remains in the soil until it degrades completely. This could be a material for product packaging as well such as paper bags, belly bands, inserts, and box fillers (Botanical Paperworks, 2017). Few businesses have already turned this idea into a viable business model:

- *Botanical PaperWorks* is a company that manufactures and distributes environmentally friendly seed paper products. They have made seed paper goods for wedding invitation cards, paper packaging for small goods, memorial cards, and a variety of other things.
- *Bluecat Paper* is another company that promotes the use of post-consumer products and claims that its products are tree-free. Mulberry, banana peels, corn husks, linen rags, and cotton rags are used to make their seed papers and palatable products. It should be noted that their papers are free of chemicals.
- *Thaely*, a shoe brand producing shoes from single-use plastic, has featured the cardboard box in which they store the pair of shoes. According to an Insider

video (Business Insider, 2021), the cardboard box of paperboard packaging is made of recycled paper and can be planted similarly to seed paper.

Seed Wastage

In the fresh and processing industries, byproducts pose major nutritional, economic, and environmental concerns worldwide. Particularly, fruit and vegetable losses and waste are estimated to be the highest of any type of food, reaching up to 60% according to the United Nations Food and Agriculture Organization (FAO, 2018, as cited in Sagar et al., 2018). The processing operations generate significant wastes of byproducts, which account for approximately 25% to 30% of the total commodity group. The wastes consist of seed, skin, and rind, which are rich in potentially valuable bioactive compounds (Sagar et al., 2018). Pomace introduces a variety of components that can be further exploited. It could be used as a potential feedstock because it is non-edible and has a high lipid content; a good potential feedstock for biodiesel production (Puangsri et al., 2005, as cited in Sultana et al., 2020). In newer studies, it may also provide the food industry with a new source of edible oils (Sultana, et al., 2020).

- *Tomato (Solanum lycopersicum)*

  In terms of area and production volume, the tomato is the Philippines' second most important fruit vegetable, extensively cultivated as a secondary crop in the country (Department of Agriculture, 2019). Tomato along with garlic and onion are grown after rice in rainfed lowland areas with zero or minimal tillage. As well as with soybeans, mustard, *pechay*, carrots, cowpeas, bush *sitao*, and sweet corn, tomatoes are planted in one section, which will mature in two to four months (Altoveros & Borromeo, 2007). In 2001, the crop was planted on 17,700 hectares, yielding 174,000 metric tons worth 1.8 billion Philippine pesos. And in 2020, the value produced has increased to around 4.7 billion Philippine pesos (Statista Research Department, 2021). The fruit, varying in size, shape, and color has become an integral part of the cuisine of all of the country's cultural groups as well. (Altoveros & Borromeo, 2007).

- *Tomato Pomace*

Tomato pomace is about 25%-35% of tomato seed waste. It includes seeds (60%) and skin or peel (40%), and is produced as a result of the fruit processing into puree, juices, ketchup, sauces, and dried powders (Celma et al., 2009 as cited by Kumar et al., 2021). Consequently, a high tomato production equals a high amount of waste generated, contributing to the large masses for waste management and utilization, and therefore impeding with significant environmental recovery. Although some of the waste is already used as animal feed or biodegraded, there is still a need for more tomato waste, including its seeds, to be exploited. (Celma et al., 2009). This is further backed up by the Environmental, Social, and Governance Report (ESG Report) in 2018 by Syngenta Group, which states that plant and seed waste from seed sites amount to 68% of the total non-hazardous waste generated in the agricultural operations based in Chicago, USA.

Seed Germination

Seed germination is a fundamental process which denotes the sprouting of a plant or its parts from the seed; this process typically occurs post-seed dormancy or a temporary standstill of a seed. A germination test is commonly conducted to determine the plant's potential field performance. Common seed germination testing methods include: regular seed germination method, rock wool method, greenhouse method, and paper towel method. As the seeds age, the average rate of germination of the seeds changes. Seeds packaged in the present year would have a favorable 80% rate of germination. However, time and the age of the seed is inversely proportional to its germination rate; therefore, if the seed ages, the rate of its germination will probably decrease, as well as its viability. (Pothour, Brady, Vierria, Vaughan, & McClure, 2017)

- *Tomato Seed Germination*

Tomato seeds can be concluded to have a high germination rate (Brown, 2017). The plant is estimated to begin its germination after 5 to 8 days. The optimal conditions described for tomato germination include temperatures of tomato germination is 65°F to 85°F, relative humidity 30-90%, and concentration 200–1500 μmol mol^{-1}. Tomatoes also require at least 6 hours in direct sunlight per day, but can also thrive in 50% light exposure or in the shade. A multi-purpose compost can be a viable option for germinating or growing the tomato seeds, but they can be cultivated in soil, on substrates, or aeroponically. The container holding the seeds should also be stored in a warm place, still following conventional planting standards. (Lin, Luther, & Hanson, 2015)

Chapter III

METHODOLOGY

Research Design

This study is quantitative in nature with regard to examining the relationship between two separate entities through numerical data analysis (Carr, 1994). This research particularly adopted a true experimental research design where a set of variables are held constant as the control group and the other variables are randomly assigned test units and treatments as the experimental groups (Salkind, 2010). Random assignment refers to the units in the study population group having an equivalent and independent chance of being assigned to any given group, which allows the researchers to compare and contrast hard figures and precise representation of the entire process accurately (Chiang, Jhangiani, & Price, 2015).

In this study, the control group in the integrity testing of the board is the standard cardboard and the experimental group is the Pa-Bi-Board. For the seed viability testing, the control group is the lone seeds and the experimental group is the seeds integrated into the Pa-Bi-Board.

Materials

The materials for the experiment were chosen according to accessibility and practicality, if replaced with alternative materials. The required items for the prototypes were sheets of recycled paper, tomato seeds, cornstarch (internal sizing agent), water (solvent), glue (porosity reducing and adhesive agent), black coffee powder (colorant), and paraffin wax (external sizing agent). Papers were purposely selected to be thin colorless sheets with minimal damages, such as used office-grade papers, bond papers, and Oslo papers. For the tomatoes, the seeds selected were small and flat in size and shape for easier integration and mix in the paper pulp. The required equipments were blender, mold and deckle, sponge, large containers, and strainer or screen.

Procedure

The study applied and improved existing approaches of different seed paper production and separate cardboard construction methods, such as Lindsey Wasnak's Homemade Seed Paper study (2021) and Ayesha Firoz's Homemade Corrugated Cardboard study (2020). The researchers target to produce at least 10 prototypes for each experimental test, the two (2) physical integrity tests and the seed viability test. The liners measure 4-inches by 5.5-inches, while the fluting medium measures 0.5-centimeter in height. These components are structured into a single wall (double-faced) board with reeded corrugation.

The procedure was conducted into two main parts: seed paper making and the Pa-Bi-Board molding: (1) For the seed paper, recycled papers were first made into pulp using a blender. Then, the pulp was combined with water and converted into new paper sheets using a mold and deckle (measured into 8" by 5.5"). Next, the 10 seeds were embedded in the wet paper, with an estimated 5-centimeter distancing; which were left to dry in a cloth or rice sack for a minimum of 9 hours. (2) For the cardboard, the seed paper was cut into 4" by 5.5" (into half crosswise). This was set aside as the two pieces for the outer liners. Then, the new 8" by 5.5" seed paper was divided into 4 pieces of 2" by 5.5". These are rolled with the help of sticks (i.e. barbecue skewer) into a long cigar shape. Once enough 4” by 5.5” paper filling cigar-shaped rolls are made, glue was used to stick the tubes one by one on the inner liner as the fluting medium. After one side is completely dried, the outer liner is glued atop (the other 4” by 5.5” paper), or on the exposed fluting. Until dried, application of glaze, the candle wax, was lastly commenced.

To measure and examine the overall condition of the Pa-Bi-Board and compare it to standard models, two (2) integrity tests were performed on Pa-Bi-Board prototypes and Standard Cardboard samples — 13 boards per group for strength test and 16 divided boards for water resistance, and a (1) seed germination test on Pa-Bi-Board Seeds and the Lone Tomato Seeds — 13 sets of 10 seeds per group. All gathered numerical data have been recorded and arranged in a Google Sheets file, to be used for comparative analysis.

1. Strength Test

The study adapted the Three-point Bend Test or Flexural Stiffness Test of Scărlătescu, Modrea, and Stanciu (2019), which was created and evaluated for the determination of the strength and deformability of mechanical engineering products.

The span and height of the two pillars of stacked books was arranged and prepared for the experiment. The original bending tests are done by laying a length of material across a span and pushing it down, bending the material until failure (Farhat, 2021). The modified strength test consisted of placing the cardboards across a span to be supported by two pillars on the end sides of the board, placing the weights in the center of the span, placed atop of plastic medium and wooden flat-surfaced board;

Then, adding weight load every 15-second interval to bend the board until breakage. The measured maximum load, minus the 150-gram weight of the medium, of each sample from both groups were recorded.

2. Water Resistance Test

The study adopted the Contact Angle Test from the works of Thomas Young in 1805, developed into a smartphone software, ImageJ, by Durham University (2015). The software is used for obtaining an on-the-spot analysis of the droplet pictures captured by a smartphone. The study utilized this technology to examine the interaction between the surface of the cardboards and water droplets, particularly for comparison of the hydrophobic capabilities of Standard Cardboard and Pa-Bi-Board.

This procedure consisted of three parts:

1. *Obtaining the pictures of the samples.* The board was placed in front of the camera set-up. With the use of a pipet, a 20-30-millimeter droplet of distilled water was placed in the middle of the board. A picture of the droplet with the sample cardboard was taken and it is labeled for analysis.
2. *B-Spline Snake Analysis (DropSnake Approach)*. Using a novel model, derived from B-spline snakes' elasticity and guidance provided by global drop contour, the whole drop shape was used to provide global information of contact angles. The ImageJ Plugins then yielded the contact angle values.
    - The ImageJ software sketches the shape of the droplet together with the tangent lines. The interior angles (contact angles) are shown in the upper left of the shell for both the left and right side

angles of the droplet. Both the left and right contact angles were recorded.

3. Germination Test

The study adapted a simple seed germination test version by Abram Bicksler, with the International Sustainable Development Studies Institute (2017). Testing is common to determine the germination potential of seeds and planting rates under different conditions. The study employs this approach to confirm seed viabilities and to compare the germination rate of the lone tomato seeds and the tomato seeds embedded in the Pa-Bi-Board.

The study made use of basic planting requirements including: soil, plant pot, water, and the seed. The level of the hole is dependent on the type of seed for the experiment, but the study utilizing the same tomato seeds meant planting uniform hole heights. Soil germination tests for tomato seeds required a 1 to 1.5 cm height of a hole for the seed to grow; the watering process required 30 to 40-mL of water each day; the environment should at least be exposed partially in sunlight for the water to take proper effect in the seeds germination. The number of seeds germinated per day were recorded and observed within seven (7) days. To compute the rate of germination, the total number of seeds germinated must be divided by the total number of seeds planted; the quotient should be multiplied by 100 to express the rate in percentage.

Data Analysis

The descriptive and inferential statistics approach are used in this study, as the experiment compared the information gathered to the variables as well as hypothesized and generalized the outcomes (Sutanapong & Louangrath, 2015). The collected data from the strength, water resistance, and germination experimental tests were systematically analyzed using two-sample independent t-Tests in the evaluation of the hypotheses. The T-Test statistics family was favored, given being the most appropriate substantive tests for smaller sample sizes ($n<30$) and data variables for the study (Ugoni & Walker, 1995). The standard alpha value of 5% ($a=0.05$) was used and embedded in the statistical program for the one-tailed test. The type of data gathered from each test contains categorical data — control cardboard and seeds group and the experimental Pa-Bi-Board group, and continuous data — respective numerical values. Such analyses target to determine whether one group did better than the other or statistically performed equally to the specific experimental tests.

1. *Testing for Normality*

The study first utilized the Shapiro-Wilk statistic for normality testing of the data values. The Shapiro-Wilk statistic is known to work well with small sample sizes ($n < 50$) and is considered best for asymmetric and symmetric non-normal distributions throughout varying sample sizes (Keskin, 2006; Mendes & Pala, 2003).

2. *Testing for Homoscedasticity*

Following the normality testing, Levene's test was utilized for equality of variance testing. The Levene test verifies the assumption that the variances are equal across the two samples, and different versions provide the best power depending upon the normality and distribution behavior of the data. (Zaionts, 2015).

The comparative numerical analysis were conducted using parametric or non-parametric tests depending on the normality and homoscedasticity results. Such statistical tests were selected under the t-Test family provided that all specific experimental tests comprise two independent groups.

- Parametric Test

  If the output from both data sets is normally distributed, the t-Test statistical family to use will be Student t-Test or Welch t-Test. The Student t-Test will be for results indicating both data sets have equal variances while the Welch t-Test will be for unequal variances. (Kim, 2015; Delacre, et al., 2017)

- Non-parametric Test

  If at least one data set is not normally distributed, the analogous t-Test statistical family to use will be Mann-Whitney U Test or Brunner-Munzel Test. The Mann-Whitney U Test will be for equal variances and the Brunner-Munzel Test is for unequal variances. (Hart, 2001; Neuhauser, 2011)

Statistical Tests		Shapiro-Wilk Test	
		Normal	Non-Normal
Levene's Test	Equal Variance	Student's t-Test	Mann-Whitney U Test
	Unequal Variance	Welch's t-Test	Brunner-Munzel Test

Table 1. *Statistical Tests Summary*

Chapter IV

PRESENTATION, ANALYSIS, AND INTERPRETATION OF DATA

I. Comparison of Cardboard Tensile Strength

The two groups have been tested for the tensile strength, quantified as the maximum load values of each board in their respective groups.

Table 2.1: *Descriptive Statistics for Strength Test*

Samples	Number	Mean	Standard Deviation	Standard Error	Lower 95%	Upper 95%
PBB	13	2.93385	0.626146	0.173662	2.55547	3.31222
SC	13	2.42692	0.725895	0.201327	1.98827	2.86558

In Table 2.1, it is noticeable that the mean of the Pa-Bi-Board (PBB) group, at 2.9339, is higher than the mean of the Standard Cardboard (SC) group, only at 2.4269. This implies that the tensile strength values of Pa-Bi-Board, on average, are higher than those of the Standard Cardboard group. With regard to the standard deviation, the Standard Cardboard has a higher standard deviation of 0.7259 than the Pa-Bi-Board, which has a standard deviation of only 0.6261. This indicates that the values of Pa-Bi-Board are more clustered around the mean, implying that they are more reliable.

The chosen normality test and ANOVA test are the Shapiro-Wilks test and Levene's test respectively, and the results were printed in the same program.

Table 2.2: *Shapiro-Wilks Normality Test Results for Strength Test*

Groups	Test Statistics	P-Value	Behavior	Verdict
PBB	0.868994	0.0397847	Non-Normal Distribution (reject H_0)	Non-Parametric Route
SC	0.749515	0.00182031	Non-Normal Distribution	

			(reject H_0)	

Table 2.3: *Levene Equal Variance Test Result for Strength Test*

Groups	Test Statistics	P-Value	Behavior	Verdict
Two	0.0323571	0.858756	Have equal variances (fail to reject H_0)	Equal Route

In table 2.2, both groups' P-Values of 0.8690 and 0.7495 are below 0.05. This result validates that the variables follow a non-normal distribution and the test rejects the null hypothesis of the Shapiro-Wilks normality test. In table 2.3, since the P-Value 0.8587 is greater than 0.05, the variances are equal for all samples and it cannot reject the null hypothesis of the Levene's equal variance test.

Since the two groups have statistically equal variances but a non-normal distribution, a Heteroscedastic version of an independent comparative statistical test for the two groups is undertaken, which would be the Mann-Whitney U-Test.

Figure 2.1: *Histogram of Pa-Bi-Board Group*

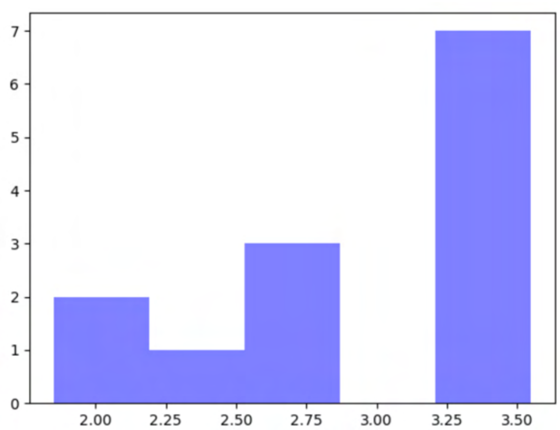

Figure 2.2: *Histogram of Standard Cardboard Group*

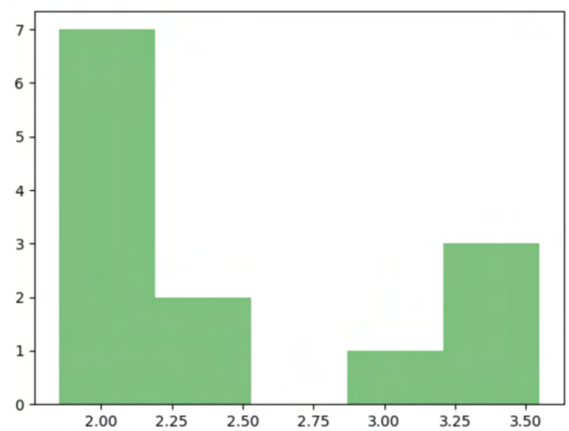

Table 2.4: *Mann-Whitney U-Test Results for Strength Test*

Mann-Whitney U-test	
Mean Difference	0.506923
T-Score	121.5

P-Value (One-Tailed)	0.974387

The left-tailed Mann-Whitney U Test results indicate that the Pa-Bi-Board group statistically performed equally or better than the Standard Cardboard group. The null hypothesis of the research is accepted, given that the sample sets have a positive large mean difference of 0.5069 and a P-value of 0.9743, which is higher than the significance level ($P>0.05$). It is worth noting that the P-value is very near to the value of 1, thus implying that there is a noticeable difference in performance between the two groups. With regard to the cardboard tensile strength, results show that the restructuring of the flutes to rolls is similarly effective in withstanding increasing weight loads. This can be attributed to the Pa-Bi-Board production process, including adding bonding agent and altering structural design. Particularly, cornstarch was added into the seed paper pulp mixtures, which contributed to the board's stiffness and bonding of the sheet with others (Shen, Zhou, Wu, & Ma, 2012). It also utilized circular rolls (reeding shape) rather than the standard wavy medium (fluting shape). The architectural element, arc/circle or reeding, is considered to be the stronger structural design because the stress is distributed equally in the rounded convex ridges, as opposed to the wavy concave grooves found in fluting (Kosmala & Kemmis, 2015).

II. Comparison of Cardboard Water Resistance

The two groups have been tested for the contact angle of each droplet in their respective groups. The DropSnake plugin in the ImageJ software was able to detect up to the thousandths place for both left contact angle and right contact angle values.

Table 3.1: *Descriptive Statistics for Water Resistance*

Samples	Number	Mean	Standard Dev	Standard Error	Lower 95%	Upper 95%
PBB	18	94.3896	6.58754	1.5527	91.1137	97.6655
SC	18	85.8868	9.7155	2.28996	81.0554	90.7182

In Table 3.1, it is apparent that the mean of the Pa-Bi-Board (PBB) group, at 94.3896, is higher than the mean of the Standard Cardboard (SC) group, only at 85.8868. Which means that the values of Pa-Bi-Board, on average, are higher than those of the Standard Cardboard group. With regard to the standard deviation, the Standard Cardboard has a higher standard deviation of 9.7155 than the Pa-Bi-Board, which has a standard deviation of only 6.5875.

Table 3.2. *Shapiro-Wilks Normality Test Results for Water Resistance*

Groups	Test Statistics	P-Value	Behavior	Verdict
PBB	0.959408	0.590234	Normally Distribution (fail to reject H_0)	Parametric Route
SC	0.974962	0.884012	Normally Distribution (fail to reject H_0)	

Table 3.3. *Levene Equal Variance Test Result for Water Resistance*

Groups	Test Statistics	P-Value	Behavior	Verdict
Two	1.54673	0.222126	Have equal variances (fail to reject H_0)	Equal Route

In table 3.2, both groups' P-Values of 0.5902 and 0.8840 are above 0.05. This result means that the variables follow a normal distribution and the test fails to reject the null hypothesis of the Shapiro-Wilks normality test. In table 3.3, since the P-Value 0.2221 is greater than 0.05, the variances are equal for all samples and it cannot reject the null hypothesis of the Levene's equal variance test.

Since the two groups have statistically equal variances and a normal distribution, a Homoscedastic version of an independent comparative statistical test for the two groups is undertaken, which would be the Student's t-Test.

Figure 3.1: *Histogram of Pa-Bi-Board Group*

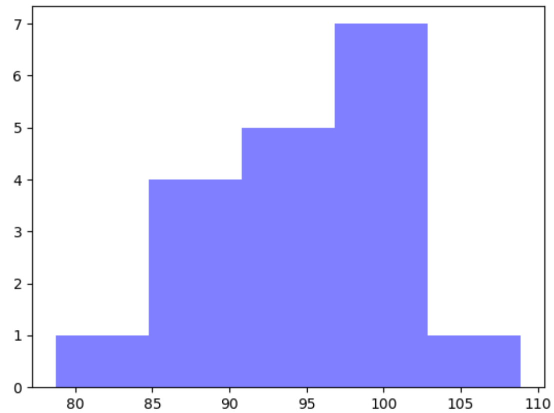

Figure 3.2: *Histogram of Standard Cardboard Group*

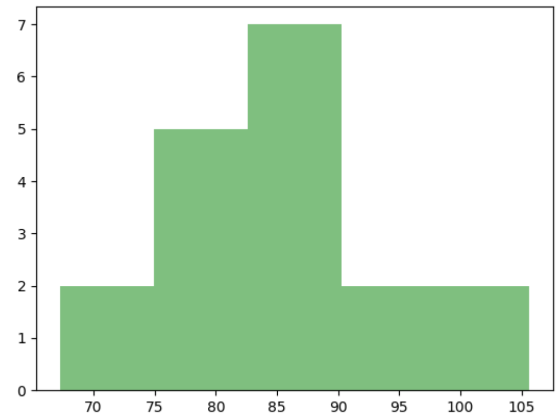

Table 3.4. *Student's T-Test Results for Water Resistance*

Student's T-test	
Mean Difference	8.50283
T-Score	3.07324
P-Value (One-Tailed)	0.997923

The left-tailed Student's T-test results indicate that the Pa-Bi-Board group statistically performed equally or better than the Standard Cardboard group. The null hypothesis of the research is accepted, given that the sample sets have a positive large mean difference of 8.5028 and a P-value of 0.9979, which is higher than the significance level ($P>0.05$). It is worth noting that the P-value is very near to the value of 1, thus implying that there is a noticeable difference in performance between the two groups. The gathered data implies that the Pa-Bi-Board is more efficient in resisting absorption of tap water droplets. This is assumed to be because of the process and materials utilized for the Pa-Bi-Board prototype, specifically as to how the researchers manually coated melted wax onto the surface. While standard cardboard boxes also utilize several chemical and semi-chemical additives in coating such as polyurethane, acrylic paint, and lacquer spray, they are less water resistant than the likes of wax oil (Boonstra, 2020; Marinelli et.al., 2021). In addition, research by Van Dooren and Van Iersel (2008) discovered that standard cardboard has a low overall moisture tolerance of 7-8%. This is further supported by the industry standard of water repelling ability of materials, according to which The Journal of Physical Chemistry Letters (2014) concludes that a material is hydrophobic if the contact angle is greater than 90°, and a material is hydrophilic if the contact angle is less than 90°; Thus, the Pa-Bi-Board is hydrophobic with a mean contact angle value of 94.3896°, whereas the Standard Cardboard is hydrophilic with only a mean contact angle value of 85.8868°.

III. Comparison of Seed Germination

The two groups have been tested for the seed viability values of each group of seeds. The data values were collected at exactly Day 7.

Table 4.1: *Descriptive Statistics for Strength Test*

Samples	Number	Mean	Standard Dev	Standard Error	Lower 95%	Upper 95%
PBB Seeds	13	0.276923	0.224179	0.0621762	0.141453	0.412393
Lone Seeds	13	0.676923	0.34194	0.0948371	0.470291	0.883555

In Table 4.1, it is noticeable that the mean of the Pa-Bi-Board (PBB) group, at 0.6769, is lower than the mean of the Lone Seeds (LS) group. This indicates that the Pa-Bi-Board seeds, on average, sprouted less seeds than the regularly planted or lone seeds at Day 7. Analyzing the standard deviations, the Lone Seeds group has a higher standard deviation of 0.3419 than the Pa-Bi-Board group, which has a standard deviation of only 0.2242.

Table 4.2: *Shapiro-Wilks Normality Test Results for Germination Test*

Groups	Test Statistics	P-Value	Behavior	Verdict
PBB Seeds	0.88819	0.0921516	Normal Distribution	Non-Parametric Route
Lone Seeds	0.862409	0.0414516	Non-Normal Distribution (reject H_0)	

Table 4.3: *Levene Equal Variance Test Result for Germination Test*

Groups	Test Statistics	P-Value	Behavior	Verdict
Two	1.22222	0.279885	Have equal variances (fail to reject H_0)	Equal Route

In Table 4.2, the Pa-Bi-Board Seeds group's P-value of 0.0921 is above 0.05, the variables follow a normal distribution. However, the Lone Seeds group's P-value of 0.0415 is below 0.05, thus a non-normal distribution. Since one of the groups is not normally distributed, it fails the requirements to conduct a Parametric Route. In table 4.3, since the P-Value of 0.2799 is greater than 0.05, the variances are equal for all samples and it cannot reject the null hypothesis of the Levene's equal variance test.

Since the two groups have statistically equal variances and a non-normal distribution, a Heteroscedastic version of an independent comparative statistical test for the two groups is undertaken, which would be the Mann-Whitney U-test.

Figure 4.1. *Histogram of Pa-Bi-Board Group*

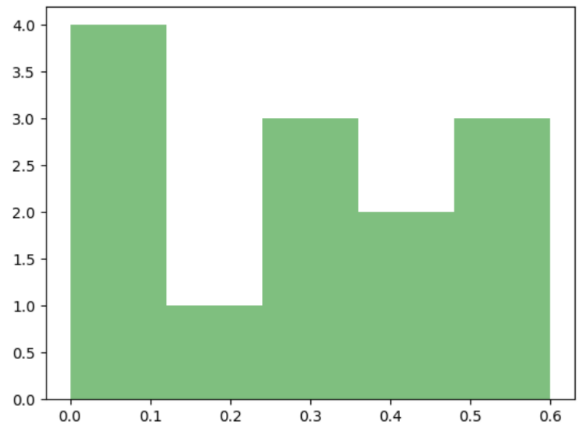

Figure 4.2. *Histogram of Lone Seeds Group*

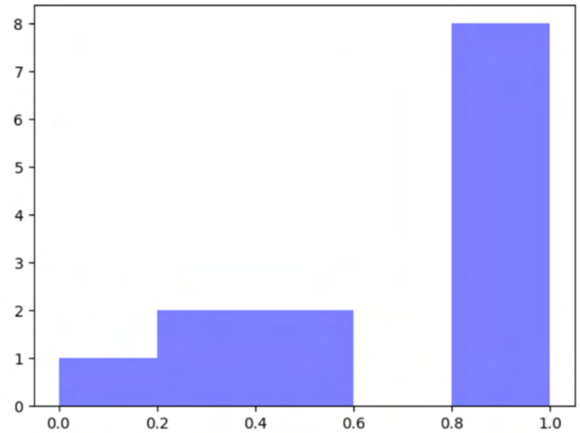

Table 4.5. *Mann-Whitney U-test Results for Seed Germination*

Mann-Whitney U-test	
Mean Difference	-0.4
Statistics	31
P-Value (One-Tailed)	0.00305371

The left-tailed Mann-Whitney U-test results indicate that the Pa-Bi-Board Seeds group did not statistically perform equally or better than the Lone Seeds group. The null hypothesis is rejected, given that the sample sets have a negative mean difference of -0.4 and a P-value of 0.0031, which is lower than the significance level ($P>0.05$). With regard to seed viability, data results exhibit positive results for both groups, with multiple samples from each group sprouting seeds. As for germination rate, data shows that Pa-Bi-Board Seeds are inferior to the Lone Seeds. The Lone Seeds had germinated faster and sprouted a greater number of seeds. The probable explanation to this lies with the creation of seed paper and Pa-Bi-Board, particularly with the seeds' early exposure to water due to integration along with drying, and to chemicals of the wax across the liners, as compared to the Lone Seeds with no physical alterations. Studies state that environmental factors affecting seed quality and development include moisture, humidity, and nutrition (chemical application) (Fernández, & Velasco, 2017).

Chapter V

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Summary

The study determined the Pa-Bi-Board samples to be statistically equal to or better than the Standard Cardboard samples in terms of strength, with P-Value of 0.9743 ($P>0.05$). It was found that the highest tensile strength value, at 2700-grams or the maximum load, was exhibited by both Pa-Bi-Board and the Standard Cardboard samples. Similarly, the Pa-Bi-Boards performed statistically equal to or better than the Standard Cardboards in terms of water resistance, with P-Value 0.9979 ($P>0.05$). The highest water resistance value obtained by the Pa-Bi-Board group was 108.9185°, whereas the Standard Cardboard only had 105.6525°. Other than the integrity testing, a seed germination test was also conducted and found that the Pa-Bi-Board Seeds were viable but were inferior to Lone Seeds in germination rate, with P-Value of 0.0031 ($P<0.05$). Assessing the germination rates, the highest germination rate of the Pa-Bi-Board group was at 60%, whereas the Lone Seeds was at 100%.

Conclusions

1. With regard to the cardboard tensile strength, Pa-Bi-Board samples performed equally or better in holding higher maximal loads than standard cardboards. Results show that the restructuring of the flutes to rolls allowed withstanding different weight capacities.
2. For the cardboard water resistance, Pa-Bi-Board samples performed equally or better than standard cardboards. Data indicates that the Pa-Bi-Board is similarly

efficient in resisting absorption of tap water droplets due to the wax-coated surface.

3. During the seven-day tomato seed germination, Pa-Bi-Board seeds statistically germinated a lesser amount of seeds compared to the Lone Seeds due to its integration to the board as well as additives. Data showed that the Pa-Bi-Board seeds are less efficient than lone seeds but are nonetheless viable.

Recommendations

Based on the results of the study, the researchers suggest the following:

1. The use of appropriate papermaking materials and natural additives. Given that the majority of the materials used in the study were common household items, the researchers recommend using more eco-friendly and non-toxic components (e.g., PVA/starch-based glues, plant-based hydrophobic coating, etc.) to produce seed cardboards or a comparable invention that may prolong its decomposition lifespan with the possibility of improving its mechanical properties as well. As a case, reproducing the standard corrugated fluting shape may also be considered in making Pa-Bi-Boards for more accurate comparative data.
2. The integration of the tomato seeds and other seeds with various sizes and shapes, higher and lower germination rates (e.g. Pechay, Pepper, and ornamental flower seeds) in different environmental conditions — a variable of the study. Given the limited time and materials available for this study, other common plants that generate abundant seed waste may

discover a more compatible integration of their seed to the paper sheet, allowing for the development of a more diverse array of plant species.

3. The use of more efficient experimental procedures, particularly the sample size and structuring and testing equipment. Increased sample sizes may provide more accurate data results for the statistical analyses. Whereas, standard laboratory and machinery works may reduce errors in comparison to the manual papermaking production and assembly of the cardboard components, as it demands more labor and time. Nevertheless, it is also considered that combining the seeds and switching from fluting to reeding may be possible without replacing present equipment (corrugator), making it a cost-effective and productive operation.
4. The exploration and experimentation on the topic of integrating biodegradable components to main sources of solid waste (e.g. seaweed paper packaging, food waste as plastic material, silk electronics). Relevant to this paper, physical properties other than tensile strength and water resistance should be examined for seed paper packaging, such as biodegradability, compressive strength, puncture resistance, insulation qualities and air permeability; these key qualities are among the most commonly tested for to ensure packaging quality in standard cardboard and paperboard packaging (Fadiji et al., 2018).
5. The improving of and stricter implementation of solid waste management policies that may promote creation and widespread use of bigger and greener inventions and innovations alike to the study's seed paper

packaging, with the aid of monitoring disposal sites and recycling facilities for significantly reducing paper waste concentration in landfills.

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Appendix 1: Definition of Terms

The terminologies used in the study are listed below that readers may better understand what is being discussed.

- *Cellulose* - it is a structural protein which gives plants and algae strength and structure. It is the principal structural component of paper-based products.
- *Compostability* - it refers to the characteristic or ability of the product if it can biodegrade in the soil given normal conditions to the surrounding.
- *Corrugated Cardboard* - it is fresh cardboard that was made from tree pulp and consists of a fluted inner middle layer and outer smooth layer/s.
- *Fluting* - it is also referred to as corrugation. It is the structure in between two liners that provides strength to the cardboard.
- *Liner/Linerboard* - it is the flat or smooth outer surface which is attached to the fluted medium of the cardboard.
- *Paperboard* - it is a type of packaging that is made out of pulp. It is thicker and stronger than standard paper but does not have any fluting like cardboard.
- *Plantable Biodegradable Cardboard (‘Pa-Bi-Board’)* - it is a cardboard innovated by integrating seeds and utilizing entirely recycled paper products. It has enhanced decomposability and can be cultivated in its disposal.
- *Plantable/Seed Paper* - it is a product that resembles standard paper and has the ability to be planted in the ground where seeds can potentially sprout.
- *Pomace* - the residual mass of a fruit or vegetable after it has been processed by machine or by human. The residual mass contains the fruit or vegetable’s skin, flesh, meat, and seeds.

- *Pulp* - it refers to the shredded and mashed paper cellulose with an ample amount of water present.
- *Sizing* - it refers to an organic or inorganic chemical agent which is used during the paper-making process. It makes the paper less susceptible to water damage.
- *Water Test* - it refers to the test whether the product can maintain its physical composition even after water submersion.
- *Strength Test* - it refers to the test whether the product can hold a certain amount of weight without major bending and breakage.
- *Germination Test* - it refers to the test whether the product can successfully sprout the seeds given the adequate needs of a plant.

Appendix 2: Experiment Procedure

Figure 5. Seed Paper Pulp

Figure 6. *Uncut Seed Paper Sheet*

Figure 7. *Seed Paper Rolls*

Figure 8. *Raw Pa-Bi-Board*

Figure 9. *Final Pa-Bi-Board*

Figure 10.1 *Pa-Bi-Board Strength Test*

Figure 10.2 *Standard Cardboard Strength Test*

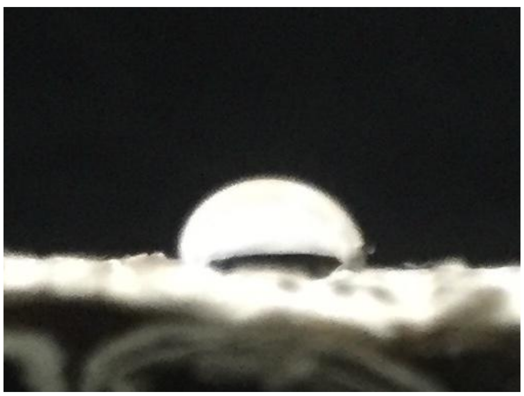

Figure 11.1 *Pa-Bi-Board Water Resistance Test*

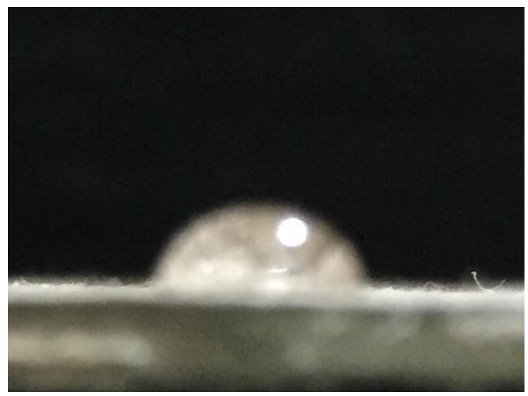

Figure 11.2 *Standard Cardboard Water Resistance Test*

Figure 12.1 *Pa-Bi-Board Germination Test*

Figure 12.2 *Lone Seed Germination Test*

Table 2.5. *Raw Data of Strength Test*

Standard Cardboard (SC)	Pa-Bi-Board (PBB)
2000	2000
2000	2800
2000	3700
3700	3700
3300	2800
2000	2700
3600	3400
2100	3700
2500	3690
2600	2400
3700	3400
2000	3600
2000	2200
2000	2000
2000	2800
2000	3700
3700	3700
3300	2800

Table 3.5: *Raw Data of Water Resistance Test*

Standard Cardboard (SC)	Pa-Bi-Board (PBB)
79.8095	90.0580
78.2340	99.9185
102.8195	99.0550
67.2340	94.5145
83.5155	98.0090
96.2910	91.8355
81.2870	108.9185
86.1660	88.8765
93.1235	93.4445
89.4690	91.6695
86.5380	85.8235
85.1160	78.7045
82.4900	96.8540

79.4375	97.7050
87.5650	98.6565
105.6525	90.2295
71.3660	95.4380
89.8480	99.3025

Table 4.5: *Raw Data of Seed Germination Test*

	Total Seeds Germinated per Day						
Sample	DAY 1	DAY 2	DAY 3	DAY 4	DAY 5	DAY 6	DAY 7
PBB	0	0	0	0	3	4	4
PBB	0	0	0	0	2	3	3
PBB	0	0	0	0	3	3	3
PBB	0	0	0	0	0	0	0
PBB	0	0	0	0	0	0	0
PBB	0	0	0	0	1	2	2
PBB	0	0	0	0	0	3	3
PBB	0	0	0	0	0	0	0
PBB	0	0	0	0	3	5	6
PBB	0	0	0	0	0	1	4
PBB	0	0	0	0	1	4	6
PBB	0	0	0	0	0	0	0
PBB	0	0	0	0	0	1	5
LS	0	0	0	0	4	3	5
LS	0	0	0	0	3	10	10
LS	0	0	0	0	5	5	5
LS	0	0	0	0	8	10	10
LS	0	0	0	0	7	7	8
LS	0	0	0	0	5	5	10
LS	0	0	0	0	2	10	10
LS	0	0	0	0	2	3	3
LS	0	0	0	0	0	2	2
LS	0	0	0	0	0	0	0
LS	0	0	0	0	2	8	9
LS	0	0	0	0	4	6	8
LS	0	0	0	0	1	7	8