International Journal of Sustainable Development and Planning
Vol. 19, No. 11, November, 2024, pp. 4281-4289
Journal homepage: http://iieta.org/journals/ijsdp

Paperboard Production from Waste Rice Husk for Sustainable Development in Packaging

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https://doi.org/10.18280/ijsdp.191117

Received: 19 September 2024
Revised: 21 October 2024
Accepted: 28 October 2024
Available online: 28 November 2024

Keywords:
rice husk, paperboard, packaging, sustainability, agricultural waste, renewable material

ABSTRACT

Rice husk (RH), an agricultural waste, was transformed into a paperboard using a chemical maceration process with maceration liquid ($H_2O_2/H_2O/CH_3COOH$ mixture) to eliminate lignin via acid hydrolysis. The optimal production conditions of paperboard included mixing RH pulp with recycled pulp at a 60:40 ratio and adding 1.0% cornstarch adhesive. The RH-based paperboard demonstrated a standard mass of 357 grams per square meter, tear resistance of 673 millinewtons, tensile strength of 776 kilopascals, and stiffness of 189 millinewtons, matching the properties of box or corrugated paper. Its water absorption rate was low at 4.91 seconds due to non-surface modification. Laboratory tests revealed that RH-paperboard sleeves for drink cups effectively retained temperature better than cups without sleeves. Cold drinks stayed up to 7°C cooler, and hot drinks stayed up to 6°C warmer for 60 minutes. In collaboration with Ban Nong Ling Community Enterprise in Suphan Buri Province, Thailand, the project successfully combined handwoven fabrics with RH-based paperboard to fabricate various packaging forms, including a fabric bag for yeti cups and lunch boxes. Consumer attitudes toward the material, figure, size, and color of the RH-thermal bags were high, with an average score of 4.67, indicating a positive reception of environmental packaging. We successfully converted rice husk waste to paperboard using maceration. The RH-based paperboard was comparable to corrugated paper and its applications can be varied based on objectives for sustainable development in packaging.

1. INTRODUCTION

Rice husk (RH) is a primary agricultural waste produced in countries of Asia and Africa where rice cultivation is prevalent, such as India, China, Vietnam, the Philippines, and Thailand [1, 2]. Grain processing generates RH as a by-product [3], and rice milling often disposes of it through open burning, leading to environmental concerns and landfill waste [4]. RH is therefore one of the primary agricultural waste produced in rice cultivation countries. In Thailand alone, rice production yielded approximately 22.2 million tons in 2023, as reported by Walderich [5], resulting in 3-5 million tons of agricultural waste, with RH content ranging from 16-25% of paddy [6]. RH is usually burned to free up land space for the next agricultural cycle [7]. Traditionally, RH has been utilized domestically as animal feed, fertilizer, and fuel [2], with agricultural applications including soil treatment, animal husbandry, and medium for mushroom production cultivation highlighted in previous reviews [1, 3]. However, RH is increasingly recognized for its elemental composition, comprising 37.05wt.% C, 8.80wt./% H, 11.06% N, 9.01wt.% Si, 35.03wt.% O and 0.36-1.66wt.% P [1, 6, 8]. Untreated RH fibers consist of 35% cellulose, 33% hemicellulose, 23% lignin, 20% silica ash, and trace amounts of 15% pentosans [1, 8], making RH a valuable resource for diverse industrial applications [1, 2, 7]. It has been utilized as a fuel source with boiler efficiency comparable to coal [6], synthesized into silica and silicon-based material for wastewater treatment [9-11], and used as a porous, thermally-insulating alternative in products like bricks [12-14]. RH has applications in environmental sustainability by removing all kinds of dyes [15-17] and organic or inorganic pollutants [18, 19]. Recent advancements have focused on surface modifications of RH to enhance filler-matrix interactions in composite materials [20] or to functionalize cellulose of RH as a component in epoxy thermosets [21].

Cellulose is the primary ingredient in paper and textiles made from plant fibers. Alkalizing of RH to eliminate hemicellulose can enhance the cellulose content of the materials; for example, papermaking from RH, banana peel, and recycled paper for paper plates [22], RH and bagasse [23], RH-paper for making Arabic calligraphy art [24]. With additional bleaching, hemicellulose and lignin can be efficiently removed, leaving nearly pure cellulose. Cellulose is the most basic and main component used for paper production. “Paper” refers to writing-purpose, low-absorption-rate sheets composed primarily of cellulose derived from wood fiber. On the other hand, a strong material made from wood pulp called paperboard is used to make boxes and other packaging items. Because of its increased strength, thickness, and resilience, it can support heavier loads and is suitable for shipping. It is easily recyclable. Paperboard can be made from leftover RH residues, bagasse, and waste paper since RH is resistant to environmental changes [25], and few works used the maceration process for papermaking. Paper and paperboard are frequently made from virgin wood pulp and are used in packing; however, cardboard that may be used in packaging as an insulating board, wrapping material, and corrugating medium can be produced by combining rick husk, bagasse, and waste paper [3]. Because of this, the product is resilient to the environment and appropriate for heavy-duty packaging.

Since cellulose can be recycled and composted, it is a viable substitute for conventional packaging materials. On the other hand, customer packaging is a colorful, adaptable, and environmentally friendly choice that can be used in almost any sector. Fabric packaging can fit a product's appearance to increase customer appeal and provide value by using various materials and customizing them. Natural cotton woven by hand has several advantages for packaging uses. It is a great option for sustainable packaging because it is a renewable material that can be reused endlessly. Cotton that has been meticulously handwoven at nearly every step by craftsmen is known as handwoven cotton. Cotton is spun into yarn and then woven, creating eye-catching patterns and hues that capture the allure and quirkiness of the regional way of life. In Thailand, manufacturers spin more than 800,000 tons of cotton and man-made yarns each year, 70% of which are consumed domestically [26], and cotton is produced annually in the country's northeast and north, for example, in Suphanburi Province. The cost, production capacity, and consumer demand all affect the price of imported cotton. Handwoven cotton typically costs more because of labor expenses and stylistic differences. That cotton is imported to make textiles and apparel to a tune of over 90% [26]. A range of goods, including key rings, slippers, handwoven pads, scarves, travel cosmetics bags, and pillows, have been developed to enhance the value of handwoven cotton and cater to consumer demands. However, Thailand is one of the few countries in the world that provides the whole value chain of the textile industry, from upstream, midstream, to downstream [26].

The local textile producer, the "Ban Nong Ling Weaving Group" in Suphanburi Province's Song Phi Nong District creates woven products with unique handwoven designs. This group, which produces fabrics under the Roi Lai Dee trademark with distinctive motifs like the "Trawadee" pattern and the eggplant flower embroidery pattern, both in natural hues, comprises members of the Mon-Descence Thai population. The shawls in question, which come in two styles, bring in about 675,000 Baht, or about 19,000 US dollars, per year [27]. According to research, using technology and experience, it is conceivable to grow the product range to include scarves, shirts, purses, key rings, and pillows under the same brand. Despite its unique pattern and client needs, the organization faces competition and continues to seek ways to add value. They worked together to design and present their items in 2020 with Suan Sunandha Rajabhat University's faculty of fine and applied arts students. The project, which is a component of the Creative Young Designer Project: Local Loincloth Thai Handcrafts, was put together by Thai Beverage Public Co. Ltd., Suan Sunandha Rajabhat University, and Pracharath Pak Samakhi (Thailand) CO. Ltd. The project goal was to use loincloths to create souvenir items that would highlight the value-added possibilities of handwoven fabrics [28]. The programming of Thai handwoven fabric for export has been made possible by this partnership with educational institutions.

Our objective was to increase the value of this agricultural waste by turning rice husk (RH) into paperboard using the maceration process. There hasn't been much use of materials from renewable sources in community products. Using renewable materials in fabric goods produced by the "Ban Nong Ling Weaving Group" was another goal. Our product concept combined community-made fabric products with RH-agricultural waste as an alternative resource, reducing the environmental impact, and making a partnership between community and educational institutions to promote social sustainability and community products.

2. MATERIALS AND METHODS

2.1 Materials

The rice husk (RH), a raw material, was sourced near my hometown from the local paddy of Kamphaeng-Phet Province in upper central Thailand's local agricultural area. For subsequent usage, the RH that had undergone oven drying at 105°C for 24h was stored for later use. The wastepaper from our office was cut into small pieces, each measuring 1 to 2cm. We used all commercial-grade chemicals without any additional purification for the maceration.

2.2 Methods

2.2.1 Pulping by cold maceration

Jeetah et al. [25] produced the cardboard from waste rice husk using the maceration process, and the obtained cardboard is suitable for packaging as a corrugating medium, wrapping, and insulating board. To perform the pulping of waste RH via maceration, the maceration solution then followed the method described in the study [25]. This involved combining 1 part of 30% hydrogen peroxide solution, 4 parts of distilled water, and 5 parts of glacial acetic acid as the maceration liquid. The RH sample was weighed and soaked in the maceration solution was prepared following the method described in the study [25]. This involved combining 1 part of 30% hydrogen peroxide solution, 4 parts of distilled water, and 5 parts of glacial acetic acid as the maceration liquid. The RH sample was weighted and soaked in the maceration mixture for the required number of days at an average room temperature of approximately 30°C until complete digestion occurred. The mixture was thoroughly stirred daily. Complete digestion was indicated by the formation of pulp and the softening of the RH pulp. The pulp was then washed with water and subsequently blended. The blended pulp was screened using a sieve for the paperboard preparation maceration mixture for the required number of days at an average room temperature of approximately 30°C until complete digestion occurred. The mixture was thoroughly stirred daily. Complete digestion was indicated by the formation of pulp and the softening of the RH pulp. The pulp was then washed with water and subsequently blended. The blended pulp was screened using a sieve for the paperboard preparation.

2.2.2 Determination of optimum maceration conditions

1) Effect of the maceration period

A 10.0g RH sample was weighed. The samples were soaked in 100.0ml of the maceration liquor and allowed to macerate for 7, 14, 21, and 30 days. The softness and color of the pulp samples were observed and screened at different times.

2) Effect of the ratio between RH and wastepaper

RH and wastepaper samples, weighing 10.0g, were soaked in 100.0ml of the maceration liquor. The ratios of RH to wastepaper studied were the ratio of 100:0, 80:20, and 60:40. The samples were allowed to be macerated for the desired days. The softness and color of the pulp samples were observed and screened at different conditions.

3) Effect of starch modifier

To study the modifier's effect, we mainly addressed the use of organic modifiers. The native and modified starch were first selected. RH and wastepaper samples with optimal ratio, in total weighing 10.0g, were soaked in 100.0ml of the maceration liquor. The corn starch and starch modifiers were each used for 1.0%. Under the optimal conditions, the attachment of the pulp samples was observed and screened using different modifiers. However, inorganic fillers, for example ($CaCO_3$ or TiO_2) are an interesting choice further.

2.2.3 Characterization of paperboard from RH

1) The mechanical properties testing

Under the optimal conditions of the maceration, the RH-based paperboard was prepared for the mechanical properties testing. According to Thai Industrial Standard (TIS) No. 170 for packaging paper [29], the paperboard samples were tested by the Department of Science Service (DSS), a government unit that provides science and technology services for standards and material characterizations. The mechanical properties of the paperboard, including grammage, tear resistance, tensile, stiffness, and water absorption, were measured according to standard methods. The results obtained served as guidelines for designing packaging.

2) Laboratory testing of temperature

Because RH has insulating properties, the temperature retentions of RH-based paperboard were investigated for packaging fabrication. Initially, the RH-based paperboard was tested as cup sleeves by cutting to the desired size. Cups with and without cup sleeves were filled with hot and cold drinks, and the initial water temperatures were recorded. The temperature changes were measured every 5 minutes for 60 minutes. A plot of temperature versus time was created to visualize the results.

2.2.4 Design for packaging incorporated between paperboard and handwoven cotton

The aims of the work were not only to add value to waste rice husk to RH-based paperboard but also to collaborate with the community in product fabrication. The Ban Nong Ling Weaving Community Group is known for its handmade products made from traditional woven textiles and designed thermal bags. RH-based paperboard was designed and used as the padding material for fabricating thermal bags. Consequently, the focus was on combining RH-based paperboard with naturally dyed woven cotton for the community's product. The prototypes of thermal bags were fabricated, including a fabric bag for Yeti cups and a zippered lunch box.

2.2.5 Evaluation of the attitude toward the thermal bag

The prototype of the thermal bag was used to evaluate consumer attitudes towards environmental packaging. A survey was conducted with 200 Gen Y respondents in Bangkok, who were randomly selected to participate through a questionnaire. The results provided valuable insights for further improving commercial products. Respondent analysis was conducted using preliminary statistics (average and standard deviation) on a 5-point Likert scale to evaluate their attitudes.

Part 1 of the survey collected demographic information, including personal characteristics, gender, age, education level, occupation, and income.

Part 2 evaluated the static data based on the following Likert scale criteria:

Mean 4.51-5.00: strongly agree/ very satisfied
Mean 3.51-4.50: agree/ satisfied
Mean 2.51-3.50: neutral / neither satisfied nor dissatisfied
Mean 1.51-2.50: disagree/dissatisfied
Mean 1.00-1.50: strongly disagree / very dissatisfied

3. RESULTS AND DISCUSSIONS

3.1 Effect of the maceration period

The RH has the potential to be used for converting agricultural wastes into renewable sources, the hydrolysis of RH through hydrogen peroxide can eliminate an amount of lignin from biomass. Hydrogen peroxide-acetic acid (HPAA) was used as a green solvent in pretreatment and exhibits excellent selective lignification capacity at low reaction temperatures (80°C) so that acetic acid can react with hydrogen peroxide and form peracetic, which can be used for lignin removal [30, 31]. To find out how long maceration lasts on pulp, researchers looked at cold maceration-that is, macerating pulp at room temperature (30°C) for 7, 14, 21, and 30 days. When the pulp formed and the RH softened, complete digestion was seen. In these circumstances, the pulp's bright yellow color and suppleness were a result of the prolonged period. After 7 days of maceration, the 100% RH sample's color changed from brown to yellow, and after 14 days, it fully recovered to a brilliant yellow hue. The color changes are due to the removal of non-cellulosic materials and other impurities such as lignin, hemicellulose, pectin, and wax upon chemical treatment of the RH [25]. Furthermore, after 14 days, the pulp's softness and flatness were noted, as depicted in Figure 1. A 21-day maceration period was chosen to obtain full maceration and the desired pulp; because of scheduling constraints, a 30-day timeframe was rejected. The obtained pulp from the 21-day maceration was blended and later screened on a sieve. The sifting of the pulp was obtained, but the paperboard was ineffective due to the unattached pulp. Moreover, in the previous report, 94.1% of lignin from poplar can be removed by 75% HPAA pretreatment at 80% [32]. To increase the extraction capacity and decrease the maceration period, hot maceration at 80°C was also experimented with; however, the liquid maceration had a strong odor when heated. The strong maceration conditions were better avoided for health and environmental reasons, as well as the risk of explosion.

The purpose of starch, a natural adhesive, was to alter the RH pulp's adhesion. In the process of manufacturing paper, starch is considered one of the most promising natural adhesives due to its wide availability, low cost, renewability, and biodegradability [33], which can enhance the smoothness of the paper. Different amounts of starch (1.0, 3.0, 5.0, and 10.0%) were added during the blending process. The pulp's sifting decreased as the starch content was lost, and it was discovered that the pulp adhered better than it was without the starch. Even with the starch level increased to 10.0%, an inefficient paperboard was still formed, as shown in Figure 2. Additionally, levels higher than 10.0% were eliminated due to the pulp's sticky screening. Moreover, RH's pulp's texture hardened and stiffened. Wastepaper was selected as a solution to this since it is easily collected readily and is available in our office, and natural fibers were altered and combined with RH pulp to increase their softness.

Goodman [3] mentioned the blending of RH, bagasse, and wastepaper can produce cardboard suitable for packaging as a corrugating medium, wrapping, and insulating board. The office generates a large amount of wastepaper, which is typically returned to paper production to reduce costs. We also decided to utilize the wastepaper within our office to minimize this waste. The mixture of RH and wastepaper was macerated at room temperature with different ratios of RH to wastepaper (100:0, 80:20, and 60:40). The amount of wastepaper affected the color and texture of the obtained pulp. The white color and smoothness of the paperboard increased with the amount of wastepaper, as seen in Figure 3. The 100% RH was rejected, as previously mentioned of unattached pulp, while the 80% RH produced a good white color of pulp but still showed unattached pulp in the paperboard. Therefore, 60% RH to 40% wastepaper was selected. However, the obtained paperboard was quite thick and partly rigid, breaking when folded. Its physical properties made it difficult to sew for packaging purposes. To solve this, the total weight of the original content (RH and waste paper) was reduced from 15.0g to 10.0g to decrease the thickness and create unbroken paper. The resulting paperboard can be easier to fold, making it better for sewing as packaging. Using a total weight of 10.0g of RH and wastepaper, the desired ratio of RH to wastepaper was 60:40.

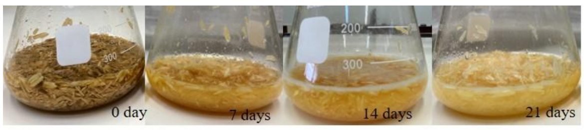


Figure 1. The feature of the pulp at different maceration periods

Figure 2. RH-based paperboard with different amounts of starch (3.0 and 10.0% starch)

Figure 3. RH-based paperboard with different ratios of RH to wastepaper

To observe the effect of fillers on improving the smoothness of paperboard, we studied starch adhesives (corn starch and modified starch) using 1.0% adhesive concentration. Starch is added at several stages of the paper-making process, and is generally used as an adhesive, flocculant, and bonding agent to improve the properties of paper. Water absorption was tested and physically observed. Adding starch filler affected water absorption due to the hydrophilic nature of starch. Starch is not a true thermoplastic polymer, due to its strong inter-molecule and intra-molecule hydrogen bonds. Still, in the presence of a plasticizer (water, glycerol, sorbitol, etc.), high-temperature value (90 to 180°C), and shearing, it melts and fluidizes, enabling its processing like that of synthetic polymers [34]. Bodîrlău et al. [34] also found the water absorption of cellulose fillers was lower than without filler. Moreover, Lin et al. [35] concluded that starch's enhanced film-forming performance is the prerequisite to preparing starch-coated paper with excellent moisture resistance. However, we observed a small water adsorption rate in RH-based paperboard with starch filler. This may be due to the formation of lipophilic layers that shield the surface from water, delaying water absorption and increasing rigidity. The adhesion of the RH-based paperboard, made from wastepaper, was evaluated with only 1.0% adhesive to observe its physical properties. Bending wastepaper and RH with starch filler made the sticky pulp difficult to screen, blocking the sieve and flexibility of the paperboard, especially with modified starch addition. No significant difference was observed between corn and modified starch, as shown in Figure 4. Therefore, corn starch was preferred in paperboard making as an adhesive due to its abundance, low cost, and renewability compared to modified starch, and it gave better brightness, hardness, and fineness properties of paperboard, according to the study [36].

Under optimal cold maceration conditions, a screening around the size of an A4 piece of paper was employed in the paperboard manufacturing process; the "Ban Nong Ling Weaving Group" may also use this screening. The group's packaging board was successfully assembled, as shown in Figure 5, and the RH-based paperboard was handmade from agricultural waste. Consequently, there were differences in the cellulose distribution. However, a sample of the obtained paperboard was employed for mechanical testing.

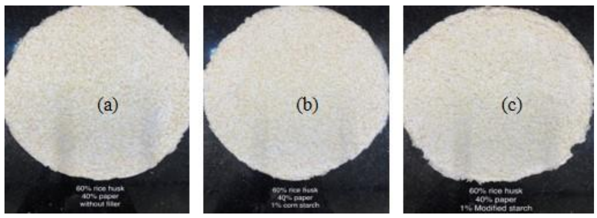


Figure 4. Paperboard of RH and wastepaper (60:40) (a) without starch filler, (b) with 1.0% corn starch, and (c) with 1.0% modified starch

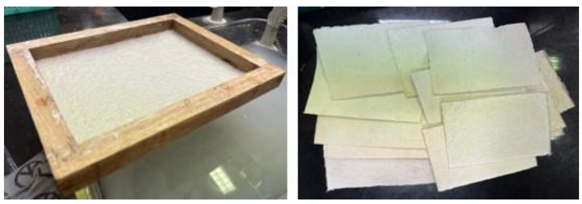


Figure 5. Hand-making of RH-based paperboard for packaging

3.2 Characterization of the paperboard

3.2.1 The mechanical properties testing

According to the Thai Industrial Standard (TIS) No. 170, paper and paperboard materials are frequently used for packaging folding boxes and plates. The RH-based paperboard was also intended to be used as a thermal bag. The mechanical properties of the RH-based paperboard are presented in Table 1. Packaging paper principles require high resistance to tearing and bursting. The mechanical properties of the RH-based paperboard exceeded the TIS index. The paper properties were tested using the ISO standard methods to evaluate its suitability for packaging applications. The preliminary characteristics revealed that it has a standard mass of 357 grams per square meter, tear resistance of 673 millinewtons, tensile strength of 776 kilopascals, and stiffness of 189 millinewtons. The RH-based paperboard's grammage value, which was tested according to the standard ISO 236: 2019, is higher than the box or corrugated paper. Referring to the standard of paperboard, requiring 250g/m^2 grammage and 150 plus Nm/g tensile index [37], the grammage and tensile strength of RH-based paperboard are in the scope of the standard of paperboard. Therefore, RH-based paperboard is suitable for packaging, compared to the grammage of corn husk (73.44g/m^2) [38], while corn husk paper is suitable for newsprint. The measurements of tear resistance (ISO 1974: 2012), tensile strength (ISO 1924-2: 2008), and stiffness (ISO 2493-1: 2012) indicate the strength of the paperboard, presented in the packaging for transit, storage, or distribution. However, its water absorption by droplet test was low at 4.91 seconds. It is likely due to the short fibers of the rice husk, which may create more internal gaps, resulting in poorer water absorption, compared to box or corrugated paper. Compared to the paper plate from RH, banana peel, and recycled paper, RH-based paperboard provided a lower tensile index and water absorptiveness than paper plates [22]. However, these results confirm that RH-based paperboard has mechanical properties that are comparable to and even higher than Kraft paper since Kraft paper is the most used in packaging. Although the RH-based paperboard exhibited low water resistance with 1.0% corn starch, this can be further improved through surface sizing to enhance its water resistance further. Based on the study [25], RH-based paperboard cannot be used for shipping containers or for stacking one on top of the other. It should be used for other purposes, and the additives and filler should be further investigated. We addressed applying the RH-based paper board to the thermal bag with handwoven cotton.

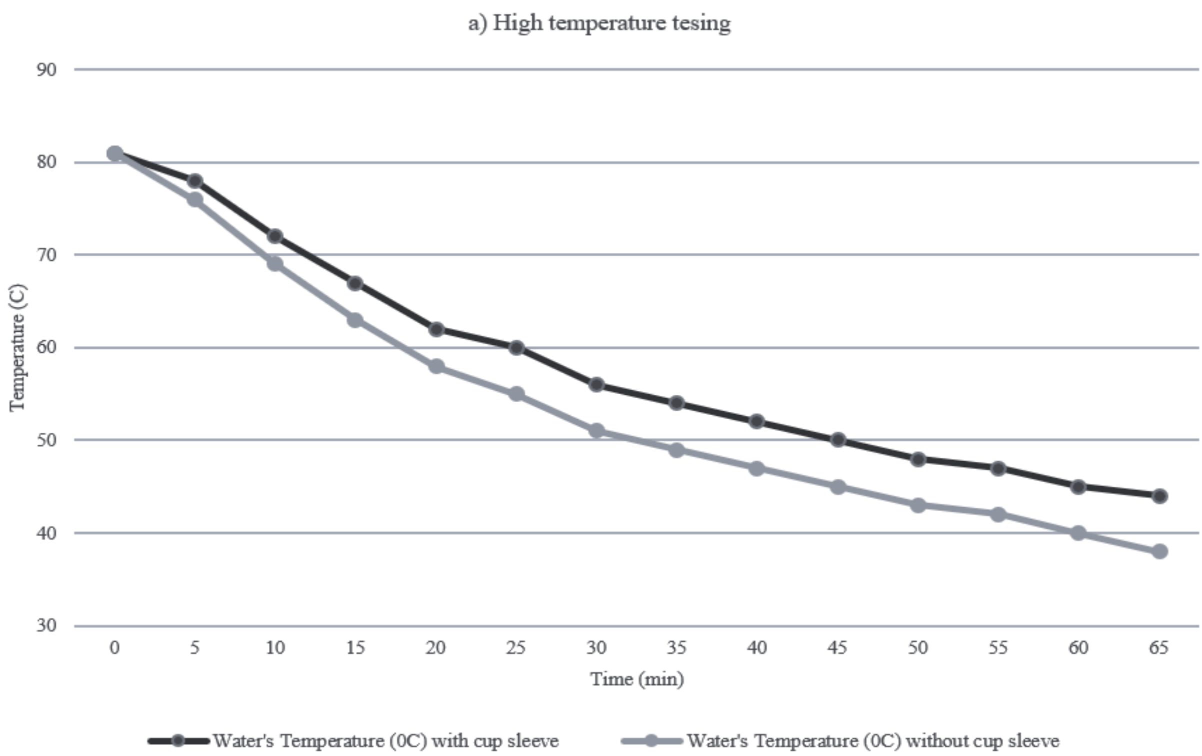
3.2.2 Laboratory testing of temperature

Due to its properties, the RH-based paperboard was primarily used to fabricate a prototype of a thermal bag. The paperboard's temperature-control properties were tested in the laboratory by cutting it to the desired size to cover a cup containing hot and cool water and assuming a cup sleeve, as shown in Figure 6.

Table 1. The mechanical properties of RH-based paperboard

No.	Testing Parameter	Result	Testing Method
1	Grammage (g/m^2)	357	ISO 236: 2019
2	Tear resistance (mN)	673	ISO 1974: 2012
3	Tensile (kPa)	776	ISO 1924-2: 2008
4	Stiffness (mN)	189	ISO 2493-1: 2012
5	Water absorption (sec)	4.91	TAPPI T835

Figure 6. Cup sleeve from RH-based paperboard in the laboratory for temperature test



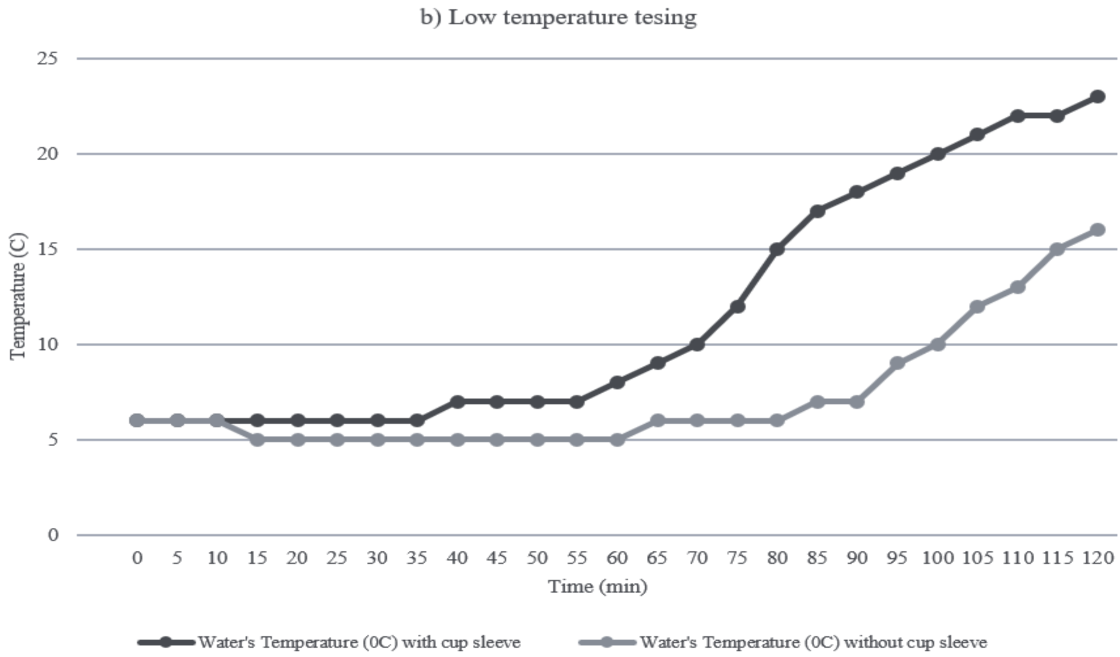


Figure 7. The plots of temperature tests (a) high-temperature (b) low-temperature versus time

For temperature testing, the temperature changes were recorded during the testing period (60 min), and the results are shown in Figure 7. In high-temperature testing as in Figure 7 (a), assuming the cup contained a hot drink, the temperature with RH-based paperboard sleeve slowly decreased from 78°C to 41°C over 65 minutes. Without the paperboard sleeve, the temperature dropped to 36°C. The temperature difference was noticeable within the first 5 minutes. In low-temperature testing, assuming the cup contained a cold drink, the initial temperature inside the cup was 6°C. The temperature in the cup without a RH-based paperboard sleeve rapidly increased, while the temperature in the cup with a paperboard sleeve remained more stable, as shown in Figure 7 (b). The temperature difference was noticeable within the first 10 minutes. The temperature in the cup with the paperboard sleeve increased from 6°C to 18°C while in the cup without paperboard, it slightly increased to 7°C. These tests demonstrate that a paperboard cup sleeve helps maintain the drink's temperature inside the cup, with no decomposition of the paperboard during testing, making it easier to hold and suitable for commercial use. The insulation property of the RH-based paperboard was applied for further application.

3.3 The application of RH-based paperboard for thermal bag

From research to the community application, collaboration with the community group was ideal for sustainability development in both environmental and social sections. We discussed combining RH-based paperboard and handwoven fabrics to produce community products. The group's handwoven fabrics are unique and natural-looking, as shown in Figure 8 (a). We designed patterns for thermal bags using paperboard made from RH and the group's handwoven fabric, as shown in Figure 8 (b). Three types of lunch box packaging and one type of drink packaging were designed. The paperboard was used as the base material for sewing the packaging instead of paper or rubber sheets. The thermal bags were handcrafted according to the designed pattern, as shown in Figure 8 (c), resulting in the prototype of the thermal bags as shown in Figure 9.

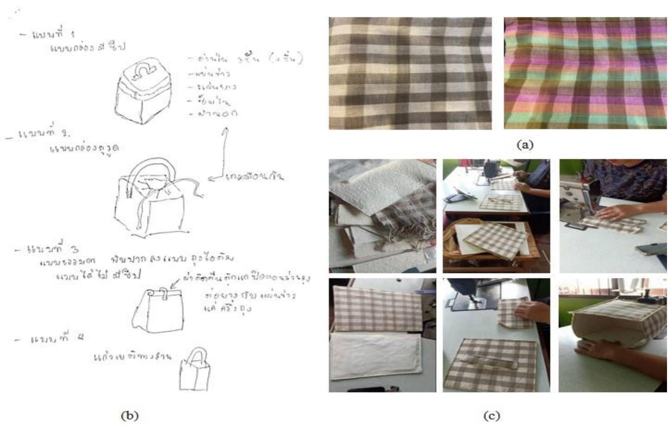


Figure 8. Making of the thermal bags with handwoven cotton; (a) fabric style, (b) hand-design step, and (c) hand-making step

Figure 9. The 4 prototypes of the thermal bag

3.4 Evaluation of customer attitudes toward a thermal bag from RH-based paper board

Consumer attitude refers to the beliefs, evaluations, and perceptions that individuals have towards a particular product, brand, or service. Understanding consumer attitudes is essential for marketers as it provides valuable insights into how consumers perceive and interact with their offerings. Consumer attitude consists of three components: cognitive (beliefs and knowledge), affective (feelings and emotions), and behavioral (actions and intentions). To achieve sustainable design, understanding customers' attitudes towards packaging is crucial for reducing waste and designing packaging for commercial use. The concept of creating thermal bags was introduced to the community, and a prototype was used in an online questionnaire survey with 200 samples to assess attitudes. Our focus was on Generation Y, born from the early 1980s to the late 1990s. This group grew up in the age of computers, enabling rapid access to information updates. They generally prioritize health and have an interest in politics and government, while also valuing honesty expressing their opinions and practices [25] and demonstrating a mature perspective in responsible packaging for ecological preservation. The demographic profiles of the respondents are 80% aged more than 25 years with a university education.

In the first part, we collected the behavior of the respondents toward environmental packaging. From the results, the behavior towards packaging revealed that 74.9% of respondents frequently use it 2-12 times per month when purchasing convenience and food products at convenience stores. This trend reflects their awareness and concern for the environment through their choices in daily life products.

The second part evaluation focused on consumers' purchasing of environmental packaging. A total of 40.7% of respondents expressed a high level of preference for choosing products with such packaging, indicating a moderate overall attitude towards the use of environmental packaging. Despite good awareness of store policies on packaging, actual usage remains low, potentially due to the additional costs associated with purchasing this type of packaging. However, a significant portion of respondents (73.4%) recognize the benefits of environmentally friendly products and their positive impact on health. Furthermore, 81.9% of respondents show a willingness to change their behavior towards using environmental packaging. Overall, the survey indicates that consumer purchasing decisions regarding environmental packaging are at a very high level, with an average score of 4.41, representing the high value of purchasing environmental packaging.

The third part assessed the perception regarding the RH-thermal bag. The survey is divided into usage, emotional, social, and environmental perspectives. According to the result, a significant majority of consumers (87.4%), rating it as 4 or 5, were suitable in terms of pattern and size for practical use. Retention temperature received a minimum satisfaction rating from 72.3% of respondents. In conclusion, the perception of the usage value of the thermal bag averaged 4.63 points, indicating a very high level of satisfaction. All package types generated favorable sentiments about utilizing environmental packaging, according to the statistics about the emotional value that it helped them contribute to environmental conservation. Customers' average emotional assessment of the thermal bag was 4.27 overall, which shows satisfaction with the emotional criterion of perception regarding the prototype of the RH-thermal bag.

The last evaluation is the question with four categories of material, design, size, and color of the thermal bag used to assess customer opinions regarding the prototype, as shown in Figure 10.

According to study responses about the material composed of RH, respondents view RH as an environmentally friendly material. It is stronger and more resilient than plastic packaging, is natural, and does not react with the product it holds. With an average score of 4.61, the survey results show that the material aspect of the RH-thermal bag is considered excellent, visually appealing, creatively designed, manageable, and suitable for the products it holds. The design of the RH-thermal bag receives an overall excellent rating of 4.70 on average. The size of the RH-thermal bag is adequate for the type and quantity of items they carry, have a reasonable weight, and come in a range of sizes. With an average score of 4.67, the survey's overall findings show that the packaging design's size is regarded as excellent. The colors of the products evoke a sense of nature and align with the eco-friendly concept, complement the packaging's shape, and harmonize with the materials used, according to survey results. With an average score of 4.69, the survey's findings show that the color usage element is great. The results show high satisfaction with the prototype of the RH-thermal bags which can be further produced for commercial products of the community enterprise group.

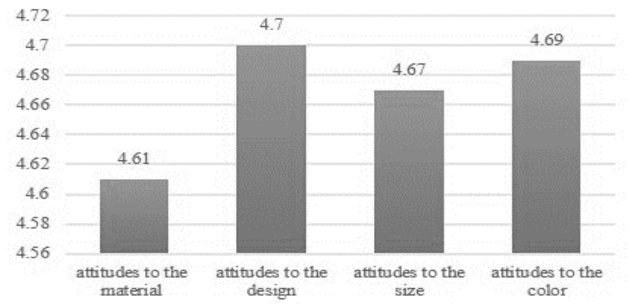


Figure 10. The attitude study regarding the RH-thermal bag

4. CONCLUSION

Rice husk, a renewable material, has been repurposed using a cold maceration process to convert it into RH-based paperboard for fabricating the prototypes of the thermal bags. The study found that the optimal conditions for preparing RH-based paperboard involve mixing rice husk pulp with wastepaper at a ratio of 60 to 40 for 21 days of maceration via acid hydrolysis to increase cellulose. The paper-making step used a 1.0% corn starch modifier as an adhesive. The mechanical properties were tested to evaluate their suitability for packaging according to standard methods. Tear resistance, which depends on fiber length and bonding, is a crucial characteristic of packaging paper. The properties of RH-based paperboard were higher than the standard A4 printing and comparable to corrugated paper. However, its water absorption by droplet test was low, resulting in poorer water absorption, compared to corrugated paper. Under the studied condition the water resistance should be improved, and the use of fillers to improve the surface should be discussed. In laboratory experiments, RH-based paperboard was applied as a sleeve for hot and cold beverage cups to assess the paper's ability to retain the temperature. The findings demonstrated that cups with sleeves made of RH-based paperboard maintained their temperatures better than those without. Apart from helping the cups retain their temperature, the decomposition of the RH-paper sleeve was not observed during temperature testing. The RH-paper sleeves are also made safer and easier to handle.

The development of the prototype RH thermal bag was a collaborative effort with the Ban Nong Ling Community

Enterprise in Suphan Buri Province. The project involved using handwoven fabrics to fabricate the packaging along with an RH-based paper board. Despite its hardness and brittleness, rice husk paper can still be sewn into packaging forms. The prototype packaging designs included a fabric bag for Yeti cups, a zippered lunch box, a drawstring lunch box, and a foldable lunch box with a mouth similar to an ice cream bag. Consumer satisfaction data indicated that the prototype RH-thermal bag received a good level of satisfaction, with an average score of 4.41. This reflects positive consumer purchasing behavior toward environmentally friendly packaging and provides a basis for improving the prototypes for commercial use. Additionally, the survey on consumer value perception and purchasing decisions regarding prototype RH-thermal bags showed that the emotional value of the prototype designs scored the highest, with an average of 4.71. In terms of design, consumers rated the size aspect of the rice husk prototype RH-thermal bag as excellent, with an average score of 4.67.

ACKNOWLEDGMENT

The work reported in this paper was funded (No. P202-ST-1027-202220127-164715) by the Rajamangala University of Technology Krungthep (RMUTK), Bangkok, Thailand. We would extend our sincere thanks to the staff of the Chemistry program and the Marketing program for their support throughout the project.

REFERENCES

[1] Kordi, M., Farrokhi, N., Pech-Canul, M.I., Ahmadikhah, A. (2024). Rice husk at a glance: From agro-industrial to modern applications. Rice Science, 31(1): 14-32. https://doi.org/10.1016/j.rsci.2023.08.005

[2] Laftah, W.A., Wan Abdul Rahman, W.A. (2021). Rice waste-based polymer composites for packaging applications: A review. Polymers and Polymer Composites, 29(9_suppl): S1621-S1629. https://doi.org/10.1177/09673911211046775

[3] Goodman, B.A. (2020). Utilization of waste straw and husks from rice production: A review. Journal of Bioresources and Bioproducts, 5(3): 143-162. https://doi.org/10.1016/j.jobab.2020.07.001

[4] Johar, N., Ahmad, I., Dufresne, A. (2012). Extraction, preparation and characterization of cellulose fibres and nanocrystals from rice husk. Industrial Crops and Products, 37(1): 93-99. https://doi.org/10.1016/j.indcrop.2011.12.016

[5] Walderich, A. (2024). Production volume of rice Thailand 2012-2023. https://www.statista.com/statistics/1108648/thailand-rice-production-volume/, accessed on Aug. 12, 2024.

[6] Patil, N.B., Sharanagouda H. (2017). Rice husk and its application: Review. Internal Journal of Current Microbiology and Applied Sciences. 6(10): 1144-1156. https://doi.org/10.20546/ijcmas.2017.610.138

[7] Rajamani, S., Kolla, S.S.N., Gudivada, R., Raghunath, R., Ramesh, K., Jadhav, S.A. (2023). Valorization of rice husk to value-added chemicals and functional materials. International Journal of Environmental Research, 17(1): 22. https://doi.org/10.1007/s41742-023-00512-2

[8] Anamika. Syed, A.R. Ahmad, Suresh Jatawa, V.A. Selvi, Archana, T. (2022). Value-added products of rice husk in various disciplines. International Journal for Research in Applied Science and Engineering Technology, 10(IX Sep 2022): 594-608. https://doi.org/10.22214/ijraset.2022.46661

[9] Masoud, M.S., El-Saraf, W.M., Abdel-Halim, A.M., Ali, A.E., Mohamed, E.A., Hasan, H.M. (2016). Rice husk and activated carbon for waste water treatment of El-Mex Bay, Alexandria Coast, Egypt. Arabian Journal of Chemistry, 9: S1590-S1596. https://doi.org/10.1016/j.arabjc.2012.04.028

[10] Mane, S.J., Kumbhare, P., Pandav, A. (2024). Experimental study of treatment of kitchen waste water using rice husk ash. Materials Today: Proceedings. https://doi.org/10.1016/j.matpr.2024.01.056

[11] Uddin, M.K., Rahaman, P.F. (2017). A study on the potential applications of rice husk derivatives as useful adsorptive material. Inorg. Pollut. Wastewater Methods Anal. Remov. Treat, 16: 149-186. https://doi.org/10.21741/9781945291357-4

[12] Ani, F.M., Nahid, A.M. (2023). Development of brick by utilizing rice husk ash as the partial replacement for clay. Multidisciplinary Science Journal, 5(1): 2023004-2023004. https://doi.org/10.31893/multiscience.2023004

[13] Cigarruista Solís, L., Chen Austin, M., Deago, E., López, G., Marin-Calvo, N. (2024). Rice husk-based insulators: Manufacturing process and thermal potential assessment. Materials, 17(11): 2589. https://doi.org/10.3390/ma17112589

[14] Kerber, F., Zienert, T., Neumann, M., Malczyk, P., Schemmel, T., Jansen, H., Aneziris, C.G. (2024). Insulating refractories based on rice husk ashes functionalized by flame-sprayed alumina coatings for steel ingot casting. Journal of the European Ceramic Society, 44(12): 7296-7309. https://doi.org/10.1016/j.jeurceramsoc.2024.04.075

[15] Sonu, K., Sogani, M., Syed, Z., Rajvanshi, J., Sengupta, N. (2022). Effectiveness of rice husk in the removal of methyl orange dye in Constructed Wetland-Microbial Fuel Cell. Bioresource Technology Reports, 20: 101223. https://doi.org/10.1016/j.biteb.2022.101223

[16] Mladenovic, N., Makreski, P., Tarbuk, A., Grgic, K., Boev, B., Mirakovski, D., Toshikj, E., Dimova, V., Dimitrovski, D., Jordanov, I. (2020). Improved dye removal ability of modified rice husk with effluent from alkaline scouring based on the circular economy concept. Processes, 8(6): 653. https://doi.org/10.3390/pr8060653

[17] Homagai, P.L., Poudel, R., Poudel, S., Bhattarai, A. (2022). Adsorption and removal of crystal violet dye from aqueous solution by modified rice husk. Heliyon, 8(4): e09261, https://doi.org/10.1016/j.heliyon.2022.e09261

[18] Chuah, T.G., Jumasiah, A., Azni, I., Katayon, S., Thomas, C.S.Y. (2005). Rice husk as a potentially low-cost biosorbent for heavy metal and dye removal: An overview. Desalination, 175(3): 305-316. https://doi.org/10.1016/j.desal.2004.10.014

[19] Xu, M., Yin, P., Liu, X., Tang, Q., Qu, R., Xu, Q. (2013). Utilization of rice husks modified by organo-multiphosphonic acids as low-cost biosorbents for enhanced adsorption of heavy metal ions. Bioresource

Technology, 149: 420-424. https://doi.org/10.1016/j.biortech.2013.09.075
[20] Suhot, M.A., Hassan, M.Z., Aziz, S.A., Md Daud, M.Y. (2012). Recent progress of rice husk reinforced polymer composites: A review. Polymers, 13(15): 2391. https://doi.org/10.3390/polym13152391
[21] Yiga, V.A., Subramaniyan, S., Kalita, N.K., Lubwama, M., Hakkarainen, M. (2024). Modified rice husk as component in recyclable and biodegradable epoxy thermosets. Discover Applied Sciences, 6(4): 175. https://doi.org/10.1007/s42452-024-05834-0
[22] Armamento, M.D., Barairo, F.V.P., Canales, J.M.Y., Iranzo, P.J.C., Magmanlac, G.T.H., Rosento, A.A.A., Saldua, P.R.J., Tuzon, T.P., Bagui, J.C. (2024). From waste to resource: Transforming rice husk and banana peel into eco-friendly paper plate. International Journal of Development Research, 14(4). https://doi.org/10.37118/ijdr.27845.04.2024
[23] Kusumawati, Y.A., Wijaya, J.C. (2024). EQO: Designing eco-friendly packaging using bagasse and rice husk waste. In Environmental Issues and Social Inclusion in a Sustainable Era. Routledge. In Proceedings of the 2nd International Conference on Humanities and Social Sciences (ICHSOS 2022), Malang, Indonesia, pp. 152-159. https://doi.org/10.1201/9781003360483
[24] Zarnuju, A., Amrulloh, H., Azizah, I.N. (2019). Utilization of rice husk waste for paper raw materials as an Arabic Calligraphy media. Engagement: Jurnal Pengabdian Kepada Masyarakat, 3(1): 43-54. https://doi.org/10.29062/engagement.v3i1.49
[25] Jeetah, P., Golaup, N., Buddynauth, K. (2015). Production of cardboard from waste rice husk. Journal of Environmental Chemical Engineering, 3(1): 52-59. https://doi.org/10.1016/j.jece.2014.11.013
[26] The Board of Investment of Thailand (BOI). Thailand: Textile industry. https://www.boi.go.th/index.php?page=business_opportunities_detail&topic_id=117531, accessed on Jul. 5, 2024.
[27] Community Enterprise Promotion Division. Department of Agricultural Extension. Ban Nong Ling Weaving Group (In Thai). https://smce2023.doae.go.th/product_detail.php?smce_id=272071410001&ps_id=3321, accessed on Jul. 5, 2024.
[28] Showcases products made from “Loincloth” of Ban Nong Ling Weaving Group, Suphanburi Province. https://far.ssru.ac.th/en/news/view/showtheproduct-vcd-loincloth-291020, accessed on Jul. 5, 2024.
[29] Udomphoch, P., Pormsila, W. (2023). Communicating corporate social responsibility through green packaging: A case study in Thailand. TEM Journal, 12(1): 241-252. https://doi.org/10.18421/TEM121-31
[30] Wen, P., Chu, J., Zhu, J., Xu, Y., Zhang, J. (2022). Highly selective delignification of poplar by hydrogen peroxide-ethyl acetate pretreatment at room temperature. Renewable Energy, 188: 1022-1028. https://doi.org/10.1016/j.renene.2022.02.094
[31] Novia, N., Hasanudin, H., Hermansyah, H., Fudholi, A. (2022). Kinetics of lignin removal from rice husk using hydrogen peroxide and combined hydrogen peroxide-aqueous ammonia pretreatments. Fermentation, 8(4): 157. https://doi.org/10.3390/fermentation8040157
[32] Liao, H., You, J., Wen, P., Ying, W., Yang, Q., Xu, Y., Zhang, J. (2021). Production of monosaccharides from poplar by a two-step hydrogen peroxide-acetic acid and sodium hydroxide pretreatment. Industrial Crops and Products, 170: 113820. https://doi.org/10.1016/j.indcrop.2021.113820
[33] Ma, Y., Kou, Z., Hu, Y., Zhou, J., Bei, Y., Hu, L., Huang, Q., Jia, P., Zhou, Y. (2023). Research advances in bio-based adhesives. International Journal of Adhesion and Adhesives, 103444. https://doi.org/10.1016/j.ijadhadh.2023.103444
[34] Bodîrlău, R., Teacă, C.A., Spiridon, I. (2014). A green composite comprising thermoplastic corn starch and various cellulose-based fillers. Bioresource, 9(1): 39-53. https://doi.org/10.15376/biores.9.1.39-53
[35] Lin, D., Kuang, Y., Chen, G., Kuang, Q., Wang, C., Zhu, P., Peng, C., Fang, Z. (2017). Enhancing moisture resistance of starch-coated paper by improving the film forming capability of starch film. Industrial Crops and Products, 100: 12-18. https://doi.org/10.1016/j.indcrop.2017.02.013
[36] Udomphoch, P., Wongsiri, C., Maneedang, W., Pormsila, W. (2022). Knowledge distribution of business and science for development of packaging from water hyacinth. Journal of Distribution Science, 20(80): 81-91. https://doi.org/10.15722/jds.20.08.202208.81
[37] Alam, M., Rikta, S., Bahauddin, K., Hasnine, M.T., Ibne Kamal, A.K. (2018). Production of eco-friendly handmade paper from wastepaper and other local biomass material. Academia Journal of Environmental Science, 6(7): 147-155. https://doi.org/10.15413/ajes.2018.0128
[38] Rahmayanti, H., Asma, A. (2022). Development and characterization of paper from corn husks as a new material for newsprint. In Proceedings of the First Jakarta International Conference on Multidisciplinary Studies Towards Creative Industries, JICOMS 2022, Jakarta, Indonesia. https://doi.org/10.4108/eai.16-11-2022.226122