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BAMBOO AS A SOLUTION FOR FOOD PACKAGING

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Abstract:

Food packaging has become a ubiquitous industry that is growing in quantities playing a vital role in circular economy of the country. Virgin fiber is preferred for food packaging to overlook contention of inks from recycled paper and cardboard fiber to food. Bamboo is very fast growing cellulosic raw material. This paper is communicated juvenile bamboo and mature bamboo as a solution for food packaging grade products by applying the chemithermo mechanical pulping (CTMP) process. The aim was to produce material that could be used for moulded paper crockery, secondary packaging & board. The CTMP pulp was required to have properties that match existing food packaging norms in terms of physical strength characteristics and barrier to gas, oil and moisture.. Green chemicals applied i.e. alkene ketene dimer (AKD) for internal sizing and poly vinyl alcohol (PVA) for surface coating which successfully used to provide water and oil resistance without affecting other characteristics. Various characteristics i.e. Cobb, grease proofing, breaking length, burst factor, tensile index, & tensile energy absorption (TEA) related to food grade (moulded products) & packaging were determined. The effects of surface treatment of PVA on pulp sheet was analyzed. The breaking length, burst factor, tensile energy absorption (TEA) was found increasing up to 30%, 20%, 48% respectively after surface treatment of PVA. To measure the grease proof characteristic i.e. KIT test value was observed. There was increment observed in KIT value in control pulp sheet 0 to coated pulp sheet 12 after applying sizing and coating agent. These findings substantiate the efficacy of the process and the suitability of bamboo pulp for production of good quality food packaging-grade products.

1. INTRODUCTION:

The development of high performance renewable materials is one important factor for sustainable growth of packaging industry. In order to facilitate safe transportation and protection of the integrity of the product packaging of liquid items, glass & plastic are the first choice. However Jelse et al. (2011) [1] and Johansson et al. (2012) [2] found in study that paper board packaging is more compatible over glass or plastic bottles for liquid packaging, in addition to these are bio compostable. Consumers looking for fiber based packaging as it considered environment friendly and final products can be recycled [2]. Packaging product manufacturing from renewable raw materials currently represents huge market of distributed as primary and secondary [3].

There are numerous packaging options in the market & the most used is flexible plastic films like polyolefins (polyethylene), waxes, ethylene vinyl alcohol (EVOH), polyvinyldene chloride (PVDC) which ensures the protection from oil and moisture for many products but causes severe environment issues due to their non-biodegradability [4]. Sustainability of packaging material is trending right now with that sustainability of raw material is also important. In present scenario biobased packaging and moulded paper board packaging is used for the purpose of cushioning properties [6]. Liquid and semi liquid items are being packed in recycled paper and cardboard fibre, although in some cases, such as food contact this is not deemed viable. Contamination from inks in recycle pulp have some toxic chemicals like printing inks, phthalates, surfactants, bleaching agents hydrocarbons etc. which can leached into food chain during packaging. Most of the developed countries have already impose ban on using recycled fiber for food packaging [6]. Virgin pulp has been used for packaging of food which fulfilling health safety norms. India is fibre deficit country, there is fast growing demand which of virgin pulp for food packaging application has compelled authors to search for alternate source of industrial crops which can be utilized for the end uses related to food packaging.

Bamboo is green alternative raw material, which is potentially viable alternative of wood and agrobased raw materials. Bamboo known as green gold is a woody perennial grass belongs to true grass family Poaceae. Properties of bamboo have an advantage of having longer fibres, making it suitable for the production of pulp for paper and board as well as mechanical pulp with high yield [7,8].

Various food packaging products prepared from bamboo. *Source: Internet*

In present work authors has selected CTMP pulping process which provides high pulp yield and sufficient strength properties of pulp for various packaging end product. To improve strength and barrier properties, lamination with polyethylene are commonly used in packaging materials. The most commonly used surface coating chemicals for paper are oxidized starch, cationic starch, acrylamide polymer, polyvinyl alcohol, latex etc. Polyvinyl alcohol (PVA) is a polymer that possesses film-forming properties and is known for its biodegradability. PVOH synthetic polymer shows resistance to solvent and grease and oxygen makes it suitable for coating application as barrier material [9].

The present work aims to promote cultivation of bamboo by plantation through social forestry and farm forestry. It recommends farmers to cultivate bamboo as annual /biennial crops as bamboo straw for a sustainable supply for pulp manufacturers.

Material and method:

Material: - Dendro calamus strictus bamboo was collected from the CPPRI (Central Pulp and Paper Research Institute) nursery, where it was specifically planted for the purpose of the study. The bamboo clumps were chipped using a lab chipper to obtain smaller pieces suitable for further processing and analysis.

Proximate chemical analysis

To determine the chemical composition of juvenile and mature bamboo chips sample was converted to powder by using laboratory Wiley Mill (Thomas) as per Tappi T 257 sp-14, and collected by passing through the 40 mesh size. The chemical compositions were determined according to the respective standard procedures, holocellulose content by Wise's chloride method (Wise, 1946), acid insoluble lignin by (TAPPI T 222 om-02), ash content by (TAPPI-211 om-02) and alcohol benzene solubility by (TAPPI T 204 cm-97).

Fiber morphology

Detailed morphological features of the CTMP pulp were examined to assess its fiber characteristics. This evaluation involved parameters such as fiber length, fiber width, cell wall thickness, and lumen diameter. From these parameters the fundamental properties factors were derived i.e. runkel ratio, slenderness ratio, lucas factor, rigidity coefficient, solid factor, flexibility coefficient were measured. To perform these measurements, a Hi-Resolution Fiber Quality Analyzer, specifically the Optest Equipment Inc. model LDA 2002 was used, following IS5285:1998 standard method.

Chemithermo mechanical pulping of bamboo chips

Pretreatment of chips

For the pre treatment, bamboo chips were fed into reactor bombs. These bombs were placed in an electrically heated polyethylene glycol bath in a digester (STALSVETS, Alfa Laval Group, Sweden). The pre-treatment process was carried out using a specific time and temperature schedule. The chips were subjected to 140°C for 60 minutes.

Refining of Pretreated chips

Refining of pre-treated chips was performed in laboratory using Sprout Waldron single disc refiner maintaining 3-4% consistency with hot water. Chips were fed maintaining gap sizes of 35, 15, and 5thou in each stage respectively. After refining in order to remove rejects, the pulp was screened using a Somerville vibrator screening apparatus with a mesh size of 0.25mm. The screened rejects were collected and dried in an oven to determine the percentage of rejects and the screen pulp yield. Screen pulp was collected and subjected to various parameter measurements, such as the freeness of the pulp (using the Canadian Standard Method), brightness etc,.

Internal sizing and pulp sheet preparation

2% AKD were added in pulp slurry. The targeted grammage of paper sheet was 70 g/m^2. After addition of AKD pulp stock was stirred and disintegrated at 1200 RPM for 15 min. Hand sheets were prepared with British sheet former machine following the ISO 5269.1:2005 standard to measure apparent density (ISO 534:1988E).

Surface sizing

5% PVA solution was prepared for surface sizing at 60^0C temperature. The PVA solution was applied on hand sheets using brush. The amount of sizing agent applied to each sheet is controlled by measuring the sheet weights. The target sizing agent amount is 3.5 ± 0.5 g/m^2. This means that the weight of the sizing agent on the sheet should fall within the range of 3.0 to 4.0 g/m^2. After the sizing application, the hand sheets are conditioned in a controlled environment. The sheets are placed in an environment with a temperature of 27 ± 2°C and a relative humidity of 65 ± 5%. The conditioning period is 24 hours, as per the ISO:187 standard. This step allows the sheets to equilibrate and stabilize under the specified conditions before further testing or evaluation.

Pulp sheets properties

The grammage of paper sheet before and after internal sizing and surface coating was determined by cutting circular disc of area 100 cm^2 and weighing on weight balance multiplied the value with 100 reported as grammage for the measurement of strength and surface properties of control, AKD sizing and surface coated, hand sheet of 70 GSM were prepared and burst factor (ISO 2758), tensile index (ISO 1924), tear index (ISO 1974), breaking length, tensile energy absorption (TEA) (L&W Tensile Tester, Code: 60) were determined standard methods.

Water absorbency

In Cobb60 method 100 ml water exposed to paper sheet of known weight to know the behavior of paper towards water. The weight diffrence of sheet before and after exposure to water is noted in gm/m^2.

KIT test (Grease Proof)

The KIT method (TAPPI T559) is used to observe the oil resistance of coated paper. Castor oil, toluene heptanes, and their mixture were used to measure the KIT test. A higher solvent proportion provided a higher degree of aggressiveness. To evaluate the KIT number, a drop of test liquid was put on the coated surface above 25mm and wiped off with tissue paper after 15 seconds. The highest number which remained on the surface without causing failure was recorded.

Results and Discussion

Initial characteristics of bamboo and their impact on pulp properties

Table 1 depicted the results of chemical composition analysis of juvenile bamboo and mature bamboo for assessing their suitability for pulp and paper making. The chemical composition analysis included the contents of ash, lignin, holocellulose and alcohol benzene extractives. Results reveal significant influence of stem age on ash content. The juvenile bamboo tended to have high extractives contents than that in matured bamboo. Klason lignin content reflects and increasing trend with increasing stem age [11]. High lignin content influences the pulpability, bleach ability, hardness and stiffness. Stiffness of pulp fiber due to lignin i.e. natural plastic gives hardness to fiber which normally interfere in fiber networking process but also good for economical viability provide high yield of CTMP pulp.

Table 1:- Chemical composition and Fiber Morphology of bamboo of juvenile and mature bamboo.

Parameters	Juvenile Bamboo	Mature Bamboo
Proximate chemical analysis		
Lignin Content %	20.3	23.2
Holocellulose Content %	64.4	68.2
Ash %	3.7	3.2
Extractives %	5.34	3.55
Fiber Morphology		
Average fibre length (L), mm	1.62	1.83
Average fibre width (D), µm	13.8	16.1
Average Lumen diameter (d), µm	3.52	4.00
Average Cell wall thickness (w), µm	5.14	6.05
Runkel ratio (2w/d)	2.92	3.45
Slenderness ratio (L/D)	117.4	113.7
Flexibility coefficient, d/D*100	25.5	24.8
Rigidity coefficient, 2w/D	0.745	0.752
Solid factor, $(D^2-d^2)*L$	109.9	132.4
Lucas factor, $(D^2-d^2)/(D^2+d^2)*$	0.877	0.878

Fiber length generally influences tearing strength of paper which means higher the fiber length higher will be the tearing resistance. The fiber length is slightly higher in mature bamboo than juvenile bamboo. Lumen diameter and cell wall thickness show variation from 3.52µm to 4.00µm and 5.14µm to 6.05µm of juvenile and mature bamboo respectively. Cell wall thickness governs the fiber flexibility which affects the bursting strength, tensile strength and folding endurance. The greater the length to width ratio (L/w) greater the fiber flexibility and better the chance of forming well bonded paper [12]. Mature bamboo stem tended greater degree of significance and fiber cell walls tended to increase in thickness with increasing age [13]. The fiber of juvenile bamboo is more slender that is 117.6 compared to mature bamboo i.e. 113.7 which results higher degree of collapsibility and comfortability with in the paper sheet and tends to produce less opaque and less bulky sheet with low air permeability as compare to mature bamboo [14]. Morphology of the bamboo pulp fiber of both the types is shown in Fig. 1.

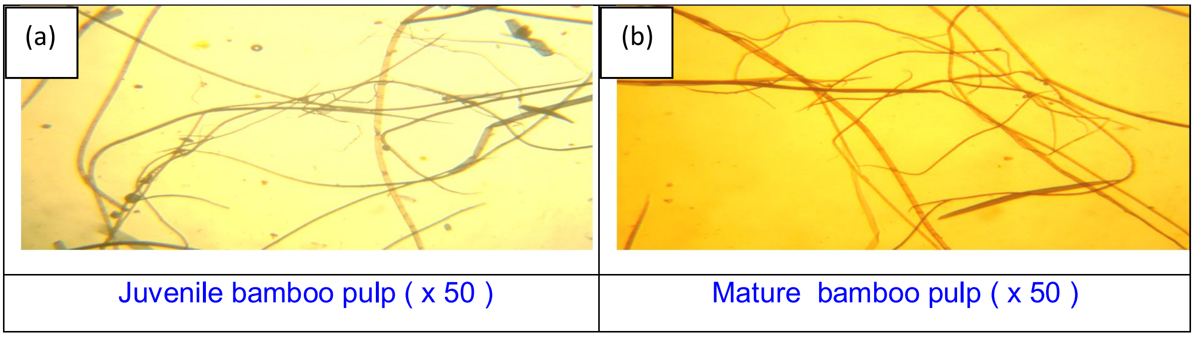

Figure 1:- (a) Photomicrographs of juvenile bamboo fiber at a magnification of x50, (b) photomicrographs of mature bamboo pulp fiber at a magnification of x50

Chemithermo mechanical pulping

The conventional method of CTMP process is based on the pre impregnation of wood chips with chemical before mild cooking and pressurized refining. In this study NaOH has been added as chemical which promote fiber swelling and softening as well as to improve fiber quality during refining. The short duration impregnation at high temperature and pressure promotes lignin softening which results in high yield and excellent paper properties.

Table 2:- Chemithermo mechanical pulping experiment results and pulp characteristics.

Particulars	Juvenile		Matured	
NaOH %	4	6	4	6
Refining gap (thou)	35,15, 8	35,15,8	35,15,8,5	35,15,8,5
Unscreened pulp yield, %	87.5	86.17	85.64	84.23
Reject, %	1.2	0.9	2.0	1.6
Screened pulp yield, %	86.3	85.27	83.64	82.64
Freeness CSF (ml)	390	404	426	417

Cooking Conditions: - Ambient to 140^0C- 1 hour at 140^0C -2 hours, bath ratio- 1:3.5.

The higher lignin content in mature bamboo stems compared to juvenile bamboo can indeed make the fibers resist to swell and require high mechanical action, that results in a loss of yield and increased fine content [15]. High lignin content also affects physical strength properties it lowers the networking in fiber that affects tensile and bursting index [11]. Table 2 shows that the pulp properties of mature bamboo is less suitable for CTMP pulping while juvenile bamboo gives good results in all aspects.

The physical strength properties i.e. tensile index, tear index and burst factor are found higher for juvenile bamboo CTMP pulp near 23.8%, 22.6% and 50% respectively than mature bamboo that at same dosage of chemical and same freeness (CSF) level. The strength properties are directly related to fiber bonding as well as flexibility and rigidity of fiber. Fiber of mature bamboo is less flexible than juvenile one because it has low lignin content and low cell wall thickness.

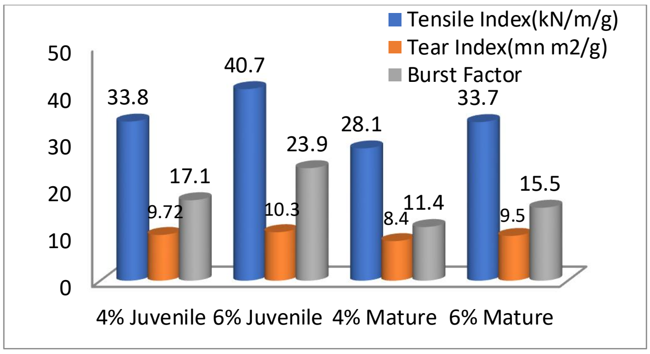

Figure 2:- Physical strength properties of juvenile and mature bamboo at almost same CSF level of 70±1 GSM sheets.

Development of barrier properties for food packaging grade

To develop high-performance cellulose-based packaging materials, it is crucial to focus on sustainable growth within the industry. One intriguing aspect is the development of barrier properties in packaging when exposed to external stress and different kind of loaded material. There is a need to enhance a wide variety of packaging functionalities, such as mechanical strength, grease resistance, and water resistance etc. More efforts must be made to improve the mechanical strength properties of cellulose-based packaging materials. These are achieved through the incorporation of reinforcing agents i.e. AKD, surface coating using poly vinyl alcohol. Poly vinyl alchohol is used for making paper grease proof as well as high air permeance [9]. These additives can enhance the overall strength and durability of the packaging material, allowing it to withstand external stresses and prevent damage during transportation or handling.

Mechanical strength properties

Mechanical strength properties of paper based packaging materials are commonly observed by characterizing burst factor, breaking length or tensile strength. Breaking length of bamboo CTMP pulp was found to be slightly increased after application of internal sizing agent of AKD i.e. 8.4 % while 26 % increase was observed in PVA coated on sized sheets from control. On the other hand breaking length of juvenile bamboo found to be 21 % higher than matured bamboo due to better bonding and increment within mature bamboo of pulp from control to PVA coating is 18 % and this percentile increment is slightly lower than juvenile bamboo, which represents in figure 3(a). Packaging grade products should have high bursting strength as it makes material more reliable for handling and transportation point of view [17]. The burst factor of CTMP pulp sheet at same CSF was 17.1 and 11.4 for juvenile and mature bamboo respectively. After wet end sizing with AKD increment das observed of 4.3 and 4.2 unit of burst factor in juvenile and mature bamboo respectively. The increment in burst factor after PVA coating was found to be 8.4 and 9.4 unit in juvenile and mature bamboo respectively, while final paper property shows burst factor of juvenile bamboo pulp 4.7 unit more than mature bamboo as shown in fig 3 (b). Film forming property i.e. builds up networking on the surface of paper after PVA treatment provides the resistance and shows increment in strength properties. Engin et.al. (2022) also studied addition of sizing agent improves strength properties. TEA reflects the absorbed energy in J/Kg when stress is applied to the paper or paper board that means higher TEA value provide more protection to packaged material [12]. TEA value of AKD sized along with PVA coated pulp sheet increased by 108% and 110 % in juvenile and mature bamboo respectively. The TEA value of PVA coated juvenile bamboo CTMP paper sheet is 19% higher TEA value than mature bamboo shown in 3(c). Elongation obtained an important place in strength properties especially for carry bags type of hanging packaging bags [13]. The stretch or elongation in paper is due to hydrogen bonding within fiber networking of cellulose which is not easy to increase. Stretch increased by 0.31 % and 0.45 % after PVA coating on AKD sized pulp sheets of juvenile and matured bamboo respectively in 3(d). Surface sizing with PVA enhance the bonding of bamboo fibers, leading to better strength properties from control. PVA acts as a binder which improves the inter-fiber bonding and overall cohesion of material. This results in increasing tensile strength and resistance to bursting. The maximum increase in overall strength properties was found in juvenile bamboo pulp using AKD and surface coating with PVA.

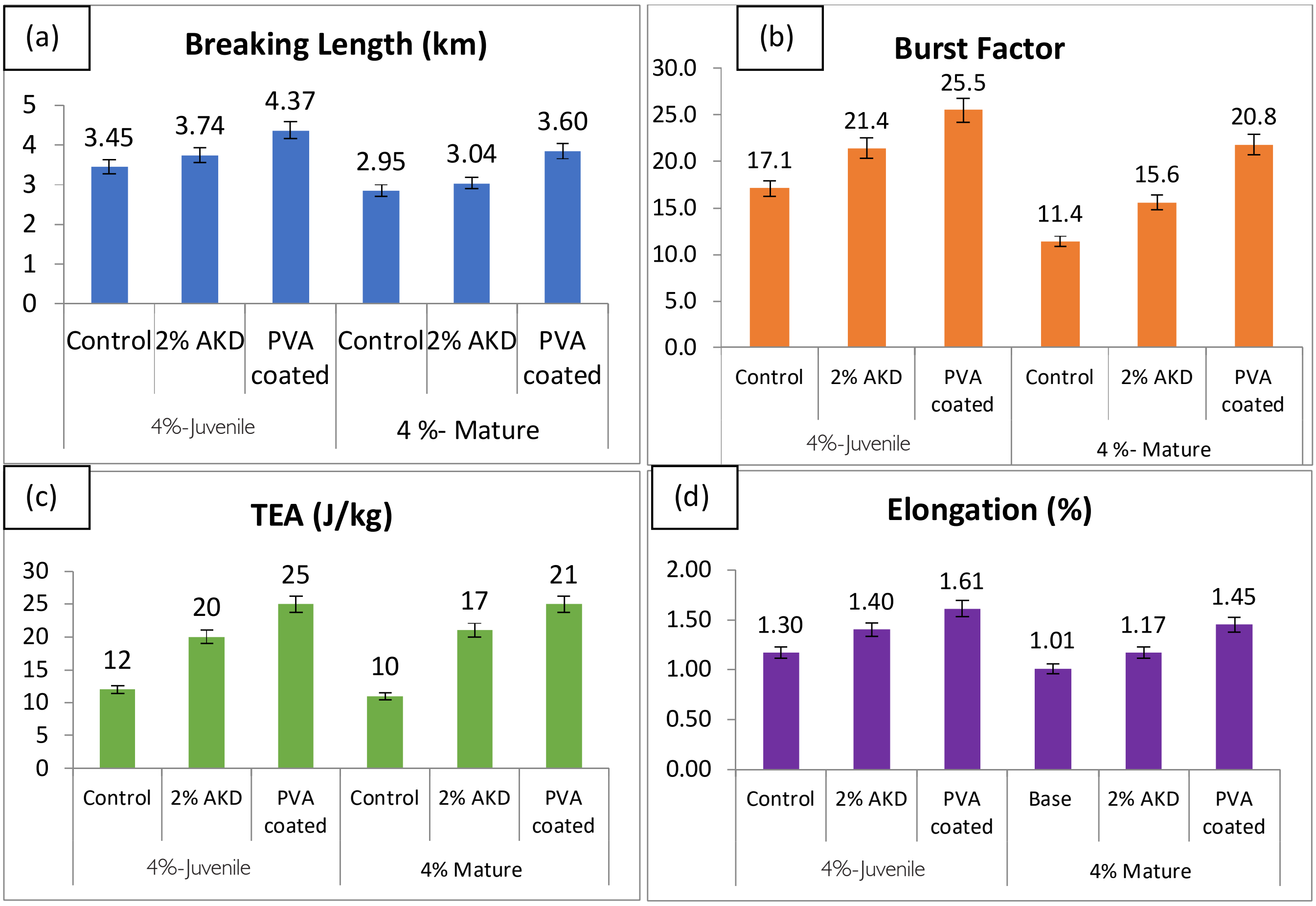

Figure 3: Physical strength properties before and after sizing and coating (a) breaking length (b) burst factor (c) TEA (Tensile energy absorption) and (d) elongation for juvenile and mature bamboo.

Air Permeance

Air permeance of paper provides information of air/gases flow across the paper tested by Gurley instrument. This instrument calculates time in seconds required for passing 100 ml air through the paper sample. For better performance of paper for paper based packaging, the resistance towards the airflow becomes important [15]. The air permeance was observed 4 and 3.5 for mature and juvenile bamboo CTMP pulp sheet respectively. This value slightly increased with the application of AKD as shown in figure 4.

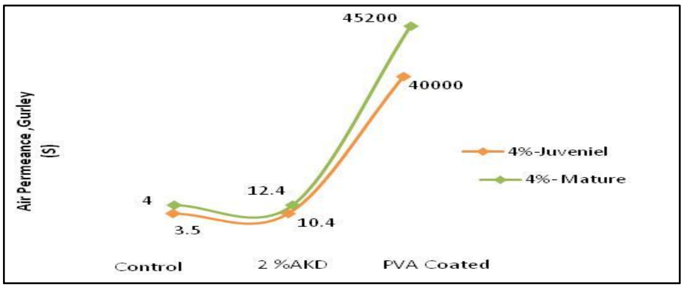

Figure 4 : Air permeance before and after sizing and coating for juvenile and matured bamboo.

Surface coating with PVA shows enormous increased in the air permeance value. Maximum value that the instrument provides Gurley second is 45200. In juvenile bamboo we achieved 40000 Gurley sec while in mature bamboo reached to maximum value of air permeance.

Water absorbancy (Cobb60)

The Cobb value represents ammount of water absorbed on the paper surface during for a specific period of time. This value depends on prosity and sizing of paper. The smaller the Cobb value refletcs better water resistance which imply a key atribute in packaging as strength and cohesion of material can be impaired by too much water [16]. Control CTMP pulp sheet of juvenile and mature bamboo Cobb value obtained 245 and 270 g/m^2 respectively which was given in table 3. By applying 2% AKD (alkyl ketene dimer) during pulp sheet prepration cobb value decreased enoumously i.e. (about 90%), indicating the improved hydrophobicity of pulp fiber. Cobb 60 value of sheet surface coating with PVA (polyvinyl alchohol) was found slightly decrease after AKD sizing i.e. 20 g/m^2 and 24 g/m^2 as compared to AKD sized sheets.

Table 3:- Results of Cobb 60 value in g/m^2 of juvenile and mature bamboo

	Cobb60 g/m^2	
	4 %-Juvenile	4%- Mature
Control	245±2	270±2
2% AKD	21±2	25±2
PVA coated	20±1	24±1

Grease resistance

Grease resistance refers to the ability of a material or surface to resist the penetration or absorption of grease or oily substances from oily food. The grease resistance measured with the help of KIT test . KIT test values are numbered from 0 to 12 as per solution prepared according to standarad methods. With AKD. KIT test value increased from 0 to 4 in juvenile and 5 in matured bamboo pulp sheet. After 3.5 to 4 g/m^2 PVA coating increased to 12 for both prepared pulp sheets. Coating of PVA shows increase in the grease resistence property of paper sheet.

Table 4:- Results KIT test for grease proof of juvenile and mature bamboo

	KIT Value	
	4 %-Juvenile	4%- Mature
Control	0	0
2% AKD	4	5
PVA coated	12	12

Conclusion:- In the present paper, juvenile bamboo is selected as sustainable food packaging raw material. Bamboo is fast growing species and environmental friendly cellulosic raw material which gives better strength properties at juvenile stage compared to matured one. Morphology of fiber also explored the juvenile bamboo has potential for converting into CTMP pulp with desired pulp properties. With a simple procedure of AKD sizing and surface coating with PVA on one side of CTMP pulp sheet of bamboo provides better strength and food packaging properties i.e. water repellent, grease proof as well high burst factor can be achieved. With a wide range of paper grammages (sheet thickness) final product according to end use can be specified for wrapping, moulded table wares for direct and indirect food contact i.e. primary, secondary and tertiary packaging.

References

1. Jelse, K., Eriksson, E. and Einarson, E., 2011. Life Cycle Assessment of consumer packaging for liquid food. IVL, Swedish Environmental Research Institute, www. tetrapak. com, accessed May, 30, p.2011.
2. Johansson, C., Bras, J., Mondragon, I., Nechita, P., Plackett, D., Simon, P., Svetec, D.G., Virtanen, S., Baschetti, M.G., Breen, C. and Clegg, F., 2012. Renewable fibers and bio-based materials for packaging applications—A review of recent developments. BioResources, 7(2), pp.2506-2552.
3. Davis, G., Song, J.H., 2006. Biodegradable packaging based on raw materials from crops and their impact on waste management. Ind. Crops Prod. 23, pp.147–161,2006.
4. Bhardwaj, S., Kaur, P., Bhardwaj, N.K. et al. Surface application of different concentrations of chitosan on recycled paper and its impact on packaging properties. J Coat Technol Res (2023). https://doi.org/10.1007/s11998-022-00743-6
5. Curling, S.F., Laflin, N., Davies, G.M., Ormondroyd, G.A. and Elias, R.M., 2017. Feasibility of using straw in a strong, thin, pulp moulded packaging material. Industrial Crops and Products, 97, pp.395-400.
6. Deshwal, G.K., Panjagari, N.R. and Alam, T., 2019. An overview of paper and paper based food packaging materials: Health safety and environmental concerns. Journal of food science and technology, 56, pp.4391-4403.
7. Anokye, R., Bakar, E.S., Ratnansingam, J. and Awang, K., 2016. Bamboo properties and suitability as a replacement for wood. Pertanika Journal of Scholarly Research Reviews, 2(1).
8. National Bamboo Mission, India, https://nbm.nic.in/national Bambbo Mission India.
9. Saroha, V., Khan, H., Raghuvanshi, S. and Dutt, D., 2022. Preparation and characterization of PVOH/kaolin and PVOH/ talc coating dispersion by one-step process. Journal of Coatings Technology and Research, 19(4), pp.1171-1186.
10. Engin, Merve, Sinan Sönmez, and Öznur Özden. "The effects of coating colours on base papers." Pigment & Resin Technology 51, no. 6 (2022): 553-563.
11. Bamboo Biology - The Morphology, Structure, and Anatomy of Bamboo (completebamboo.com)
12. Sharma, A.K., Dutt, D., Upadhyaya, J.S. and Roy, T.K., 2011. Anatomical, morphological, and chemical characterization of Bambusa tulda, Dendrocalamus hamiltonii, Bambusa balcooa, Malocana baccifera, Bambusa arundinacea and Eucalyptus tereticornis. Bioresources, page 6(4).
13. Suhaimi, N.M., Mohd Hassan, N.H., Ibrahim, R. and Jasmani, L., 2021. Fiber morphology of different bamboo species and age. In Materials Science Forum (Vol. 1025, pp. 312-318). Trans Tech Publications Ltd.
14. Ashaari, Z., Salim, S., Halis, R., Yusof, M.N.M. and Sahri, M.H. 2010. Characteristics of pulp produced from refiner mechanical pulping of tropical bamboo (Gigantochloascortechinii). Pertanika J Trop Agric Sci, 33(2), pp.251-258, 2010.
15. Bhardwaj, S. and Bhardwaj, N.K., 2019. Mixing of oxidized starch and polyvinyl alcohol for surface sizing of paper. Nordic Pulp & Paper Research Journal, 34(3), pp.343-353.
16. Tanpichai, S., Srimarut, Y., Woraprayote, W. and Malila, Y., 2022. Chitosan coating for the preparation of multilayer coated paper for food-contact packaging: Wettability, mechanical properties, and overall migration. International Journal of