Characterization of the Physicochemical Properties of Lignocellulosic Plant Residue

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ABSTRACT
In this research, we investigated a range of plant-based materials, including- Banana Leaf, Pineapple crown, Rice husk, Baggas, Corn husk, as potential for biodegradable cutlery. The materials aimed to optimize raw material by evaluating chemical properties of natural biomass materials. Characterized Including Lignin, Cellulose, Nitrogen, Moisture and Ash content The study demonstrates the viability of agricultural waste-derived composites for durable, fully biodegradable cutlery. Optimized formulations balance functional performance with rapid environmental degradation, supporting circular economy goals. The study demonstrates the viability of agricultural waste-derived composites for durable, fully biodegradable cutlery, balancing functional performance with rapid environmental degradation and supporting circular economy goals.

1. Introduction

The importance of food packaging materials has escalated in today's world, driven by increasing consumer awareness regarding sustainability, food safety, and environmental impact, Conventional packaging methods, habitually rely on the use of petroleum oriented plastics, which continue to be a major threat with their impact on pollution and issue with respect to waste management is growing demand for innovative sustainable alternatives that align with the functional properties and adopt environmentally friendly practices (1). Growing environmental issues about plastic waste necessitate research on sustainable alternatives to single-use items, particularly cutlery. Although convenient, traditional plastic (Polyethylene Terephthalate (PET), High-Density Polyethylene (HDPE), Low-Density Polyethylene (LDPE), Polyvinyl Chloride (PVC) (2). Cutlery creates many ecological challenges since it is not biodegradable and will long remain as a source of pollution. In response to this urgent problem, the production of biodegradable cutlery from plant residues is a promising solution that can be aligned with global sustainability goals. This paper is focused on the characteristics of different plant residues and their potential for the creation of biodegradable cutlery, (3). Plant residues are generally considered agricultural waste and have huge potential as a raw material for development of biodegradable products. These residues are abundant and diverse, ranging from various lignocellulosic materials yielded through crops such as wheat, rice, corn, and several legumes (4). Using these residues saves waste and promotes circularity within an economy where materials are transformed for alternative uses, rather than having to be discarded (5). The extraction of cellulose from plant materials serves as the foundation for creating biopolymers that can mimic the functionality of traditional plastics (6). The use of agricultural waste has minimized the cost of production and simultaneously allowed farmers and firms handling the wastes to receive secondary income (7). The research aimed at finding great insights about diverse types of crop wastes, which may be exploited in making bioplastic cutlery. The paper is looking forward to the introduction of optimum materials found through examination by chemical composition, mechanical properties, and biodegradation rates that can completely replace conventional plastic cutlery (8). We are exploring plant residues as potential resources for biodegradable cutlery. With such research and development areas, we hope to bring about a more sustainable future so that the health of our planet is not compromised by single-use products (9). Advantages of biodegradable cutlery: Environmental Sustainability, Biodegradability, Renewable Resource, Nutrient Recycling, Reduced Carbon Emissions, Health and Safety. Cutlery that is biodegradable and constructed from natural substances frequently lacks the harmful chemicals typically associated with conventional plastics, including BPA (bisphenol A) (10), thus rendering it a more secure option for applications involving food contact. In conclusion, the utilization of plant by-products for the creation of biodegradable cutlery offers a multitude of benefits that not only tackle environmental issues but also foster economic sustainability while catering to consumer demands for environmentally friendly products (11). Production process of biodegradable cutlery from plant residues differ from traditional plastic cutlery The chemical properties such as Lignin, cellulose, moisture, ash and nitrogen are very important to develop biodegradable cutlery. Lignin helps in biodegradation, tends to slow down the overall biodegradation process because it can limit the access of enzymes and water to the cellulose that is more easily degradable, hence potentially extending biodegradation time (12). On the other hand, Lignin contributes to the structure integrity and water resistance of the cutlery. Cellulose is the main constituent of plant-based materials and is highly biodegradable, it maintains the biodegradability of the cutlery while providing structural strength to it (13). The ideal balance between cellulose and lignin depends on the desired properties, higher cellulose content 50-55% may lead to faster biodegradation but potentially weaker structural integrity (14). Higher lignin content may result in slower biodegradation but improved durability and water resistance. The nitrogen content in the biodegradation process is of utmost importance. Compounds having a lower C/N ratio around 12.1 in the composting environment promote fast biodegradation (15). Lower ash content is preferred for biodegradable cutlery as it represents a higher proportion of organic, biodegradable components (16). However, some inorganic content can be helpful in enriching the soil upon biodegradation. Moisture content affects the production process and the product (17). For production, it has been found that about 32% moisture content in the composting material is effective (18). The final product requires smaller moisture content to avoid structural breakdown and degradation. One of the most important parameters for plant residues is their nitrogen content. It is a matter of fact, without which they are not of any use as a fertilizer or in anaerobic digestion processes (19). The biomass' C/N ratio is a kind of the great affecting on its decomposition rate and the resulting product's quality.

This Research paper gives an information about the chemical composition which will be useful for the research scholar, industrialist Entrepreneur to develop biodegradable cutlery which can completely replace the convectional plastic cutlery. So, that the health of our planet is not compromised by single-use products.

2. Material and Methods

Procurement of raw materials

Raw materials were collected from different types of street vendors and farmers from Bidar and Bangalore, Karnataka India. incudes bagasse, pineapple crown, banana leaves, rice husk and corn husk. The study was performed in Department of Food Technology, Ramaiah University of Applied Sciences, Bangalore, India. All the plant residue samples were stored below at room temperature 4°C (20) after collection and prior to experimental use to avoid microbial decay. The plant residue samples were characterized by measuring Cellulose, lignin, Nitrogen, Ash and Moisture Content.

Fig 1. Pineapple crown Ref (21)

Fig 2. Rice Husk Ref (22)

Fig 3. Baggas Ref (23)

Fig 4. Banana Leaf Ref (24)

Fig 5. Corn Husk Ref (25)

3. Methods

Cellulose Content

The cellulose content of the biomass samples is determined in the following manner. Add 3ml of acetic reagent to a known amount of 1g of biomass sample in a test tube and mix it in a vortex mixture. Place the tube in a water bath at 100^{o}c for 30 mins. Cool and then centrifuge the contents for 15-20 mins. Discard the supernatant, Wash the residue with distilled water and add 10 ml of 67% sulphuric acid and allow it to stand for 1 hr. Dilute 1ml solution with 10 ml of anthrone reagent and mix it well. Heat the tubes in boiling water bath for 10 mins, Cool and measure the colour at 630 nm, Set a blank with anthrone reagent and distilled water. Take 100 mg cellulose in a test tube and proceed for standardising (26).

$$Cellulose(\%) = 1 + \frac{(weight\ of\ crucible + weight\ of\ fiber\ left\ in\ the\ crucible) - (weight\ of\ crucible)}{(weight\ of\ sample)} \times 100$$

Lignin Content

The lignin content of the biomass sample is determined in the following manner. In glass test tubes, Take 0.3 g of biomass sample and add 3 ml of 72% H_2SO_4. Keep the sample at room temperature for 2.5 hrs with careful shaking at 30 min intervals to allow complete hydrolysis. After the initial hydrolysis, add 8 4ml of distilled water. The second step of hydrolysis was made to occur in an autoclave for 1 h at 121°C. The slurry was then cooled at room temperature, Hydrolysate was filtered through vacuum using a filtering crucible, The acid insoluble lignin was determined by drying the residues at 105°C for 1 hrs and accounting for ash by incinerating the hydrolysed samples at 575°C in a muffle furnace. The acid soluble lignin fraction was determined by measuring the absorbance of the acid hydrolysed samples at 320 nm. The lignin content was calculated as the summation of acid insoluble lignin and acid soluble lignin (27)

$$Lignine(\%) = \frac{weight\ of\ crucible + Lignin - weight\ of\ crucible + Ash}{weight\ of\ sample\ on\ DM\ bases} \text{ x } 100$$

Nitrogen Content

The nitrogen content of biomass sample was determined in the following manner. Weigh accurately 1g of biomass sample and put it into a beaker of the refluxing apparatus. Add 100 ml acid detergent solution, and heat to boiling temperature for 5 to 10 mins. And then reduce heating as boiling begins in order to avoid foaming. Reflux for 60 min, Filter through a weighed glass crucible and rinse the sample with hot water with minimum temperature of 100^{0}C, Filter the liquid and repeat the washing procedure. Wash twice with acetone in the same manner. Break up all lumps so that the solvent may not come in contact with all particles of fibre. Suck the acid detergent fibre free from hexane and dry at 100^{o}C for overnight and weigh (28).

$$Nitrogen(\%) = \frac{(weight\ of\ the\ crucible = wt. of\ fiber\ left\ in\ the\ crucible) - (weight\ of\ crucible)}{(weight\ of\ sample\ on\ DM\ basis)} x\ 100$$

Moisture content

The weight loss of the plant residue was assessed by the ASTM D4442 method to obtain the moisture content (Bhattarai & Janaswamy, 2024). Accurate weights of the specimen samples were taken (W1). Later, specimen samples were dried at 100 °C for 24hrs in an oven with a constant weight, and the final weight of the sample was recorded (W2). The moisture content in the films was calculated using the following formula (29).

$$\text{Moisture (\%)} = \frac{Initial\ Weight\ (W1) - Final\ Weight}{Final\ Weight (W2)} \times 100$$

Ash Content

The ash content of the biomass sample was determined using the AOAC 942.03 method. The procedure involved weighing an empty crucible, adding 2g of the sample to it, and placing the crucible in a Muffle furnace Model no STXMF142. The furnace was set to a temperature of 700°C for a duration of 4 hours. After the specified time, the crucible was removed from the furnace, and its final weight, including the sample, was recorded. This method allows for the quantification of inorganic residues remaining after the complete oxidation of organic matter in the biomass sample (30).

$$\text{Ash (\%)} = \frac{Weight\ of\ crucible\ with\ ash - weight\ of\ crucible}{weight\ of\ sample} \times 100$$

4. Result and Discussion

When considering the components for making biodegradable cutlery, the optimal combination of lignin, cellulose, nitrogen, ash, and moisture plays a crucial role in determining the product's biodegradability and overall performance (31). Based on the available information, here's an analysis of these components and their contributions to biodegradable cutlery.

Table -1. Chemical Composition of Biomass Sample

Lignin Content

Samples	Mean	SD	CV(%)	SEm +_	Range
Banana Leaf	15.62	1.00	6.40	0.57	14.62-16.23
Pineapple crown	6.26	0.95	15.18	0.12	5.3-7.2
Rice Husk	5.4	1.00	18.52	0.22	4.4 - 6.4
Baggas	32.55	1.00	3.06	0.09	31.56 - 33.55
Corn Husk	5.58	1.01	18.01	0.24	4.56 - 6.59

The analysis of lignin content in various biomass samples provides crucial insights for the development of biodegradable cutlery implications may be associated with the material properties, biodegradability, and general suitability of cutlery especially when compared to control samples (32). The lignin content of different biomass samples is shown in the Table 1. Bagasse had the highest lignin content of 32.55% while also showing the lowest co-efficient of variation at 3.06%. The higher lignin content in cutlery may yield superior mechanical properties i.e, rigidity and tensile strength stated by (33). The same applies to durability in the biodegradable products. Low CV suggests a constant lignin content in samples therefore, bagasse may be utilised as a reliable material for standardized production processes. Banana Leaf has moderate lignin content at 15.62% with a relatively low CV of 6.40%. This may be the combination that can balance strength with flexibility, potentially making cutlery that is both strong and resistant to breaking. Pineapple Crown, Rice Husk, and Cornhusk have lower contents of lignin at 6.26%, 5.4%, and 5.58%, with higher CVs at 15.18%, 18.52%, and 18.01%. Materials in these would likely yield much less rigid cutlery compared to high lignin options. Bagasse and Banana Leaf fall within or exceed the range of 10-25% lignin contents that earlier research (34) often target for optimal performance in biodegradable materials. This would enable them to outperform traditional biodegradable options based on mechanical strength and durability. Conversely, Pineapple Crown, Rice Husk, and Cornhusk would require more reinforcement or modification in order to become comparable with the standards of mechanical performance established. These results hold significant implications for the development of biodegradable cutlery. Bagasse presents as a very viable candidate for making strong, robust cutlery that may potentially compare to the strength of traditional plastics. High lignin content and consistency make it applicable to structural applications where strength is critical (35). Banana Leaf is an intermediate material, thus potentially balancing the strength and biodegradability. Bagasse is suited for making long-lasting products.

Table -2. Chemical Composition of Biomass Sample

Cellulose Content

Samples	Mean	SD	CV (%)	SEm +_	Range
Banana Leaf	17.21	1.04	6.02		16.19-18.26
Pineapple Crown	30.21	1.01	3.33	0.06	29.2-31.21
Rice Husk	25.04	0.99	3.93	0.11	24.04-26.01
Baggas	48.09	0.95	1.93	0.09	47.08-49.09
Cornhusk	34.02	1.00	2.92	0.09	33.02-35.01

The cellulose content analysis of the different samples of biomass can provide critical insight for the production of biodegradable cutlery, especially in comparison to the control samples that were found in previous studies (36). These % have profound effects on the material properties, biodegradability, and the overall application in cutlery. The cellulose content of different biomass samples is shown in the Table 2. With 48.09% of the highest cellulose content, together with a 0.93% CV value, the difference is highlighted on Baggas. High cellulose contents tend to reveal Baggas-based cutlery with a tensile strength level and tensile flexibility compared with other varieties of cutlery (37). Cellulose is the main structural element of the plant cell walls and contributes to this material's strength and durability, Low CV indicate cellulose content is consistent between samples, meaning Baggas is an excellent material for standardized processes of production. Pineapple Crown and Corn Husk have moderate cellulose contents-at 30.21% and 34.02 % with corresponding relatively low CV at 3.33% and 2.92%. These may provide a reasonable balance between strength and biodegradability, thus potentially making cutlery that is structural integrity during service but degrades well after disposal (38). Banana Leaf and Rice husk have lower cellulose contents of 17.21% and 25.04%, respectively, with slightly higher CV at 6.02% and 3.93 %. These materials could produce cutlery that has less tensile strength compared to high-cellulose alternatives. Faster rates of biodegradation may also result from the lesser cellulose content which has environmental benefits. Compared to earlier control samples taken from other related studies (39), that usually aim to have cellulose contents within a range of 30-50% for biodegradable products, Baggas exceeds such a range indicating better mechanical strengths. Pineapple Crown and Corn Husk appear to be under this optimal but still present fair values of cellulose for cutlery applications. Baggas emerges as one of the extremely promising candidates in the production of strong flexible cutlery which may match the performance criteria for the best alternative to conventional plastic. Materials that fall into the moderate cellulose content category, such as Pineapple Crown and Corn Husk, maintain an ideal strength and biodegradability balance while providing great flexibility for versatile cutlery designs. Their cellulose contents indicate they would retain integrity under load but degrade within a reasonable period after disposal. faster degradation rates could be beneficial in composting environments.

Table -3. Chemical Composition of Biomass Sample

Nitrogen Content

Samples	Mean	SD	CV (%)	SEm +_	Range
Banana Leaf	2.52	1.01	39.88	0.58	1.52-2.53
Pineapple Crown	1.08	1.01	93.06	0.23	0.08-2.09
Rice Husk	0.41	0.01	2.44	0.09	0.40-0.42
Baggas	0.4	0.10	25.00	0.08	0.3-0.5
Cornhusk	0.86	0.10	1.16	0.06	19.01-17.01

Nitrogen content analysis of different biomass samples gives an indication of their usability in the production of biodegradable cutlery, especially if compared to controls from previous research (32). The nitrogen content of different biomass samples is shown in the Table 3 Banana Leaf contains the highest amount of nitrogen, amounting to 2.52%, which implies negative aspects. High nitrogen content in materials like protein-based polymers can slow down the biodegradation process. Microorganisms require a balanced carbon-to-nitrogen (C: N) ratio to effectively break down materials higher nitrogen disrupts this balance. Generally, increased nitrogen content translates to more protein content (39). The high CV of 39.88% implies significant variability in the content of nitrogen, which might have an effect on product quality and performance. A moderate content of nitrogen is reported in the Pineapple Crown 1.08%, but with a very high CV of 93.06%, there might be an inconsistency in the composition of the compound. Such high variability may also make it challenging to maintain uniform product quality, and additional processing or blending techniques may be required to achieve consistency in cutlery production (40). Rice Husk and Bagasse have lower nitrogen levels at 0.41% and 0.5% respectively, Faster degradation. Minimal environmental impact during decomposition better compatibility with composting systems in that Baggas shows the lowest nitrogen content in have low nitrogen levels, making them more environmentally friendly. It may also make them biodegrade quicker, which is a great advantage for single-use cutlery.

Table-4. Chemical composition of Biomass Sample

Moisture Content

Samples	Mean	SD	CV (%)	SEm +_	Range
Banana Leaf	34.01	0.81	2.39	0.57	33.02-34.01
Pineapple Crown	20.02	0.96	4.80	0.07	19.1-21.02
Rice Husk	8.07	1.01	12.45	0.19	7.07-9.08
Baggas	7.81	1.00	12.74	0.10	8.81-6.82
Cornhusk	18.02	0.82	4.53	0.13	19.01-17.01

Analysis of various biomass samples towards moisture content critical to the cutlery manufacture from biodegradable material should be viewed considering the previous investigations and their related control samples (41). There are critical importance values that translate to material process, product output, and biodegradable utility in the applicability for producing cutlery. This high moisture content 34.01% for Banana Leaf and 20.02% for pineapple Crown can lead to problems in processing, ultimately impacting the stability of the final product. Such high moisture content can induce greater microbial activity, potentially degrading the structure of the final product and shortening its shelf life. Overly wet material can also alter the mechanical properties of the material, potentially making the produced cutlery more brittle and prone to deformation under use (42). However, these materials have lower co-efficient of variation CV, 2.39% and 4.80%, that may imply more consistent moisture in the samples, hence better quality would be maintained through production. Conversely, Rice Husk and baggas display much lower values of moisture content: 8.08% and 7.81%, respectively These results may imply more stability in the storage and processing of these samples which, in turn may result in superior mechanical properties for the final product. Lesser moisture content makes the product relatively stiffer and stronger, that is beneficially useful for the cutlery application (43). Nonetheless, higher CV of 12.44% and 12.87% for these products indicate greater variation in moisture contents, which necessitates further controls in quality upon production to produce a uniformity of product output Corn husk, in a moisture content level of 18.02% is moderate in between. Compared to other control samples which have been documented in previous literature99, with desired moisture contents often below 10% for an optimal performance within biodegradable materials, Rice Husk and Baggas match the ideal cases. The moisture content analysis revealed that Rice Husk and Cornhusk have lower moisture contents, which may be more favourable for biodegradable cutlery production under optimal conditions determined in earlier research (44).

Table -5. Chemical Composition of Biomass Sample

Ash Content

Samples	Mean	SD	CV (%)	SEm +_	Range
Banana Leaf	10.05	0.82	8.17	0.58	9.04 -11.05
Pineapple Crown	15.55	0.81	5.22	0.08	14.55-15.55
Rice Husk	17.32	0.95	5.47	0.137	17.32-19.3
Baggas	4.02	0.96	23.80	0.23	4.02 -6.02
Cornhusk	17.05	0.82	4.79	0.14	16.04-18.84

Ash content analysis in various biomass samples would be essential in the development of biodegradable cutlery, especially in comparison with the control samples developed in previous studies (45). The Ash contain of different biomass sample are shown on the Table 5. This composition of cornhusk contains the maximum ash content that is 17.05%, and the CV value, that is 4.79%. High ash content means that it is difficult for cornhusk cutlery to show its biodegradable properties or mechanical properties as it will give high brittleness and decrease the flexibility therefore, cutlery is likely to deteriorate (46). Low values could be used for quality regulation and consistent maintenance during production process, Pineapple Crown is known for a more moderate ash amount 15.55 %, with CV 5.22 %. Bagass exhibits such a tremendous difference that biodegradability would not play the significant factor again as the quantity will not affect functionality. Rice husk provides a more modest ash content (5.09%) while at the same time having higher CV 5.47%, and this presents an organic-inorganic mix that promises acceptable biodegradation with sufficiently retained structural features. Banana Leaf and Pineapple Crown contain high percentages of ash, that is, 10.06 and 15.55 % respectively. The % ash value being at high indicates raises concern about consistency in material composition and may need additional processing to ensure uniform product quality. Compared with control samples from previous research (47) that often target ash contents below 5% for optimal performance in biodegradable materials higher percentage of organic matter and that would also Favor the same biodegradable with a very good flexibility along with strength characteristics of the cutlery material. Both Baggas and rice husk fall well within this range This implies that these materials might outperform conventional biodegradable ones in terms of biodegradability and organic content. The findings have important implications for the development of biodegradable cutlery, Materials with a higher ash content, such as Banana leaf and pineapple crown, may have greater utility where a small % of mineral content is desired for a particular composite or blend application (48). Their ash content could give these materials an advantage in stiffness that might find value in cutlery forms that require a specific amount of rigidity but sacrifice a measure of biodegradability. Low-ash materials, for instance, banana leaves, hold promises for products to be biodegradable enough.

5. Conclusion

The research conducted on optimizing the selection of raw materials for biodegradable cutlery reflects the critical urgency for sustainable substitutes for plastic-based utensils in everyday life that cause severe damage to the environment. This work has highlighted numerous findings that will guide development in this arena in the future. These not only reduce fossil fuel dependency but also decrease the amount of greenhouse gases emitted throughout their lifecycle. However, the end-life scenarios of these materials are important as some biodegradable plastics release harmful gases under certain conditions when decomposing. The growing public awareness of the environmental impacts of non-biodegradable plastics is driving demand for sustainable alternatives. As governments implement stricter regulations against plastic use, the market for biodegradable cutlery is expected to expand significantly.

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