Systematic Evaluation of Banana Plantation Waste Fractions for Identification of High-Yield Starch Source from the Different Waste Residues

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ABSTRACT:
Bananas are the second-largest fruit crop in the world, with a high post-harvest waste loss. Since the demand for starch is ever-increasing, banana plantation wastes can serve as a sustainable source of starch. Detailed analysis of wastes was performed through physical, phytochemical, and proximate analysis, as well as microscopic evaluation. The physical evaluation and comparison of relative morphological abundance study proved that banana pseudostem leafsheaths at the harvest stage generate the highest generated wastes and also show high water-soluble extractive and high moisture content. The phytochemical and proximate analysis confirmed that the highest amount of carbohydrates and starch is present in the pseudostem leafsheaths at the harvest stage, more than any other waste remnants. The microscopic evaluation further proved that the starch granules are present in the cellular lumen of the pseudostem leafsheaths at the harvest stage and are prominent as compared to those observed in the meristem. Based on the overall study, it could be concluded that the pseudostem leafsheaths at the harvest stage can be utilized as a high-yield starch source.

Keywords: Banana Plantation Wastes, Starch, Banana Pseudostem leafsheaths, Banana Pseudostem Starch.
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INTRODUCTION:

Starch is one of the widely used polymers in the pharmaceutical and food industries. Starch has been isolated from cereals like maize, wheat, rice, barley, sorghum, oats, rye, sago; tubers like potato, sweet potato, yam, arrowroot; roots like cassava, taro; rhizomes like turmeric, ginger, lotus; fruit seeds like mango, jackfruit, annatto, avocado; fruit pulp like green banana, breadfruit, wolf fruit, peachpalm, and stems like pineapple stem and banana stem. Recent research has also been focused on identifying starches in pseudocereals, legumes, lentils, nuts, millets, and grasses.[1,2]

Not all the starches have commercial or practical applications, but current research is aimed at understanding the composition of starch and the structure of the starch components, the properties of starch that can be utilized for its better applications, the extraction techniques and methodologies that show optimum results qualitatively and quantitatively, and modifications of the starches. The research prospects and focus have been increasing in all these aspects, and complete exploration has been done on only a few sources of starch. Compared to research 2 to 3 decades ago, which only focused on the structural prospects of starch and the identification of a suitable isolation technique, today the focus is also on the sustainable isolation and utilization prospects.[2,3]

The starches that are predominantly commercial and have market viability include maize, wheat, and rice starch. Apart from the majorly explored cereal starches, the root and tuber starches, such as potato and cassava starch, have also undergone research on composition, structure, and physicochemical properties, which makes them a commercially suitable option. Other starches are explored scientifically, but are not utilized commercially to a great extent. Many non-commercial starches are newly being explored and have a long way to go for their complete accountability.[1,4] One of such less-utilized starches is the green banana fruit starch, on which research has been performed to identify the extraction and isolation, the production of commercially viable starch, physicochemical properties, modified starch preparation techniques, and digestibility. Exploration of isolation techniques for the dietary fibers from the raw bananas, in addition to starch, has also been conducted in a few research studies. This approach to the research opened doors for the sustainable production of multiple products from the same raw material source. The research on raw banana starch was explored by the researchers with a view to improving banana economics.[5]

As the utilization of raw bananas improves the banana economy, it will also lead to higher waste production. Also, bananas are the second largest fruit crop in the world, and the post-harvest waste loss is also high enough. Though it is a great idea to explore new starches, giving competition to the existing market demand will only increase the pressure of meeting their supplies in the long run. Since starch demand is ever-increasing due to its varied applications, the need of the hour is the search for a sustainable source. As banana fruit starch is already explored, attention can be paid to a relatively less explored one, such as the banana pseudostem starch. The abundance of waste remnants of banana plantations and the morphological comparison of different waste parts showed that the pseudostem is the highest waste generated, which may serve to consider it for research interest.[6–8]

Banana plantation wastes have been found to have various applications. Value-added products from the banana waste remnants, like peel, pulp, inflorescence, and pseudostem, can be produced by technologies like extraction, milling, drying, enzymatic treatment, and fermentation. These processes produce nutraceutical products and bioactive compounds, banana flour, banana chips, and alcoholic/ non-alcoholic beverages.[9] Different utilization prospects of the waste remnants of banana plantation in the context of bioactive molecules, pharmaceutical aids, nutrients and nutraceuticals, livestock feed, and natural fibers have been researched. The key aspects and challenges of utilizing the products and the sustainability of the approaches have been studied. Banana pseudostem and leaves have been analysed for the chemical contents of lignin, cellulose, and hemicellulose, but the evaluation of the content of starch has not been conducted in particular. Both parts, the leaves and the pseudostem, have been evaluated through proximate, elemental, chemical, heat, and thermo-gravimetric analysis. Though the lower nitrogen and sulphur content of these parts indicates a lower environmental threat upon combustion, a better utilization would always be the identification of a way of utilizing the waste remnants instead of disposal.[10,11]

This study was aimed to perform a detailed evaluation of the banana plantation waste parts for the comparison of the feasibility of valuable byproduct isolation, such as the starch and other products like fibers. Detailed physical, phytochemical, proximate analysis, and microscopic evaluation were performed on all the waste remnants for this comparison.

METHODOLOGY:

1. Physical Evaluation of Banana Plantation Wastes:

The physical evaluation was performed on the dried powdered samples and the fresh samples of the waste remnants according to the tests for physical parameters. Extractive values, total ash value, and loss on drying were performed on the dried powder samples, and the juice content and pH were determined on the fresh samples.

Alcohol-soluble extractive value, water-soluble extractive value, total Ash value, and loss on drying were determined on the powdered samples using the official procedures of the Indian Pharmacopoeia and Bureau of Indian Standards. Juice content was determined by grinding the fresh sample, expressing juice using a muslin cloth, and further filtering using a filter paper. The pH value of the fresh sample was determined using a pH meter.[12–14]

2. Qualitative Phytochemical Evaluation of Banana Plantation Wastes:

The qualitative phytochemical tests were performed on the fresh juice samples or the dried juice powder of the waste remnants according to the test requirements.

The phytochemical tests on primary and secondary metabolites were performed using standard phytochemical methods to determine the presence of carbohydrates, proteins, fats, alkaloids, steroids, terpenoids, flavonoids, tannins, phenolic compounds, resins, and saponins.[15–22]

3. Proximate Analysis of Banana Plantation Wastes:

Proximate analysis was performed on the waste remnants of the banana plantation for the quantification of macronutrients, micronutrients, and trace elements.

The analysis was done for the determination of macronutrients like nitrogen (N) by Kjeldahl method, phosphorus (P_2O_5) by volumetric analysis, potassium (K_2O) by flame photometry; micronutrients like sulphur as S by barium chloride gravimetric analysis; micronutrients like calcium as Ca and magnesium as Mg, and trace elements like iron as Fe, cupper as Cu, zinc as Zn, molybdenum as Mo, manganese as Mn, and boron as B by Atomic Absorption Spectroscopy.[23–26] In addition, the phytochemical composition was quantified for protein by the Kjeldahl method, fat by the Soxhlet method, carbohydrate and starch by Lane Eynon's method, and fibers by the gravimetric method using a muffle furnace, and the pH and electrical conductivity were determined instrumentally for confirmation.[27–29]

4. Microscopic evaluation of Banana Plantation Wastes:

The microscopic evaluation of the tissues of banana plantation wastes was conducted by performing the transverse section of the tissues using phloroglucinol + HCl, Iodine stains, and Sudan Red Stain. The observations were done using a compound microscope, and measurements of microscopic observations were performed by the use of micrometers.

The eyepiece micrometer was calibrated using a stage micrometer and was used for the determination of the dimensions of the microscopic particles.

RESULTS AND DISCUSSION:

1. Physicochemical Evaluation of Banana Plantation Wastes:

The tests for water-soluble extractive value, alcohol-soluble extractive value, loss on drying, and total ash value were performed on the dried powder of banana roots, banana leaf, banana pseudostem, and banana inflorescence. The observations of the same are given in Table 1.

Table 1: Results of Quantitative Physicochemical Evaluation of Dry Banana Waste Powder

Plant Part	Phase (Sample Code)	Total Ash Value (%)	Loss on Drying (%)	Water Soluble Extractive (%)	Alcohol Soluble Extractive (%)
Banana Root	Growth (GBR)	22.86 ± 0.16	1.94 ± 0.18	10.62 ± 0.08	6.44 ± 0.14
	Development (DBR)	23.3 ± 0.06	1.51 ± 0.16	11.85 ± 0.24	6.8 ± 0.11
	Maturity (MBR)	23.74 ± 0.09	1.1 ± 0.13	12.64 ± 0.07	7.98 ± 0.15
	Harvest (HBR)	23.95 ± 0.13	0.89 ± 0.12	13.08 ± 0.2	8.84 ± 0.16
Banana Leaf	Growth (GBL)	11.86 ± 0.12	1.94 ± 0.18	4.35 ± 0.17	8.63 ± 0.23
	Development (DBL)	12.33 ± 0.18	2.51 ± 0.16	5.26 ± 0.14	9.29 ± 0.19
	Maturity (MBL)	13.82 ± 0.3	3.1 ± 0.13	5.78 ± 0.13	10.1 ± 0.12
	Harvest (HBL)	14.18 ± 0.18	2.89 ± 0.12	6.04 ± 0.2	10.77 ± 0.1
Banana Pseudostem	Growth (GBP)	0.73 ± 0.15	1.61 ± 0.16	17.65 ± 0.06	1.73 ± 0.08
	Development (DBP)	3.56 ± 0.31	1.82 ± 0.07	18.06 ± 0.1	2.13 ± 0.19
	Maturity (MBP)	8.62 ± 0.39	2.11 ± 0.12	18.55 ± 0.06	2.31 ± 0.08
	Harvest (HBP)	10.13 ± 0.15	1.99 ± 0.03	18.74 ± 0.13	2.55 ± 0.13
Banana Inflorescence	Maturity (MBI)	10.82 ± 0.3	1.7 ± 0.13	15.54 ± 0.12	7.98 ± 0.15
	Harvest (HBI)	14.18 ± 0.18	1.76 ± 0.13	15.08 ± 0.2	8.87 ± 0.2

*All the values are expressed as Mean ± SD, where n = 3

[GBR-Growth Phase Banana Root, DBR-Development Phase Banana Root, MBR-Maturity Phase Banana Root, HBR-Harvest Phase Banana Root, GBL-Growth Phase Banana Leaf, DBL-Development Phase Banana Leaf, MBL-Maturity Phase Banana Leaf, HBL-Harvest Phase Banana Leaf, GBP-Growth Phase Banana Pseudostem, DBP-Development Phase Banana Pseudostem, MBP-Maturity Phase Banana Pseudostem, HBP-Harvest Phase Banana Pseudostem, MBI-Maturity Phase Banana Inflorescence, HBI-Harvest Phase Banana Inflorescence]

As the drying and powdering of parts is a tedious process for the waste remnants of banana plantations, the evaluation of certain physical parameters was also carried out on the fresh samples of waste remnants of banana plantations at various growth stages. The pH, content of juice expressed, and moisture content were measured on fresh crushed samples. The observations of the same are given in Table 2.

Table 2: Results of Quantitative Physicochemical Evaluation of Fresh Banana Waste Sample

Plant Part	Phase (Sample Code)	pH of Juice Expressed	Content of Juice Expressed (%)	Moisture Content (%)
Banana Root	Growth (GBR)	4.67 ± 0.15	1.72 ± 0.14	9.88 ± 0.36
	Development (DBR)	5.033 ± 0.15	1.35 ± 0.06	9.04 ± 0.09
	Maturity (MBR)	5.13 ± 0.12	0.95 ± 0.08	8.36 ± 0.09
	Harvest (HBR)	5.27 ± 0.06	0.78 ± 0.04	7.68 ± 0.28
Banana Leaf	Growth (GBL)	8.67 ± 0.15	9.38 ± 0.15	89.64 ± 0.32
	Development (DBL)	9.03 ± 0.21	9.04 ± 0.09	82.47 ± 0.43
	Maturity (MBL)	9.3 ± 0.1	8.36 ± 0.09	79.94 ± 0.3
	Harvest (HBL)	9.6 ± 0.1	7.68 ± 0.28	76.62 ± 0.36
Banana Pseudostem	Growth (GBP)	7.6 ± 0.1	19.27 ± 0.32	95.02 ± 1.29
	Development (DBP)	6.93 ± 0.15	15.93 ± 0.34	90.1 ± 0.14
	Maturity (MBP)	6.37 ± 0.15	12.97 ± 0.19	88.76 ± 0.11
	Harvest (HBP)	5.73 ± 0.06	11.69 ± 0.13	87.85 ± 0.14
Banana Inflorescence	Maturity (MBI)	6.13 ± 0.06	5.95 ± 0.18	79.93 ± 0.32
	Harvest (HBI)	5.93 ± 0.15	5.72 ± 0.12	77.68 ± 0.28

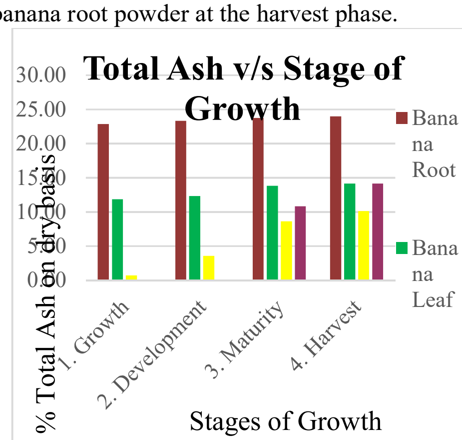
*All the values are expressed as Mean ± SD, where n = 3

[GBR-Growth Phase Banana Root, DBR-Development Phase Banana Root, MBR-Maturity Phase Banana Root, HBR-Harvest Phase Banana Root, GBL-Growth Phase Banana Leaf, DBL-Development Phase Banana Leaf, MBL-Maturity Phase Banana Leaf, HBL-Harvest Phase Banana Leaf, GBP-Growth Phase Banana Pseudostem, DBP-Development Phase Banana Pseudostem, MBP-Maturity Phase Banana Pseudostem, HBP-Harvest Phase Banana Pseudostem, MBI-Maturity Phase Banana Inflorescence, HBI-Harvest Phase Banana Inflorescence]

All the physical parameters were represented graphically for the comparison of parameter variations at the different growth stages of the banana plant parts. Graphs showing the effects of various stages of growth on the parameter change have been given in graphs 1 to 5.

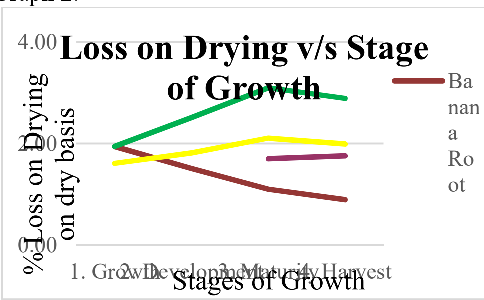
Physicochemical Parameters of Dry Banana Waste Powder:

The total Ash value provides an insight into the inorganic matter content and indicates the presence of inorganic impurities in plant materials. A test for total Ash value was performed on dried powder of parts of the banana plant and indicated the highest values for banana roots, followed by banana leaf, banana inflorescence, and lastly the banana pseudostem, as shown in Graph 1. It was found to increase throughout the various stages of growth and was found to be highest in the harvest phase for each part of banana plant. The highest value of 23.95 ± 0.13 % w/w of dry weight was obtained for banana root powder at the harvest phase.



Graph 1: Graph of the Effect of Stage of Growth on Ash Value of Plant Parts

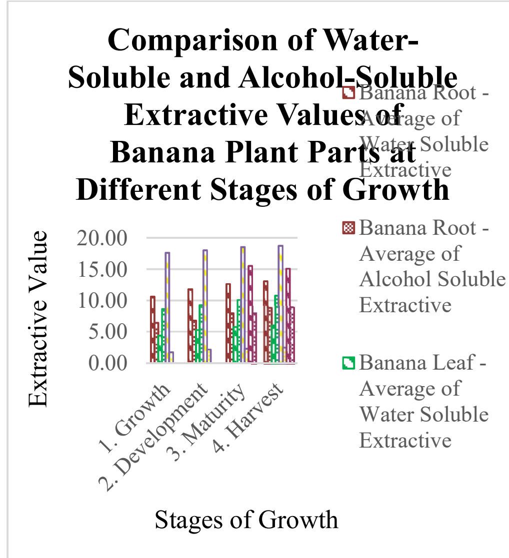
The loss on drying when observed for dried powdered parts of the banana plant was found to be negligible in all the parts of the banana plant and was highest in the banana leaf at the maturity phase, with a value of 3.1 ± 0.13 % w/w of dry weight. The banana root showed a decreasing trend from the growth phase to the harvest phase, whereas the banana leaf, pseudostem, and inflorescence showed an increasing trend. Although the highest readings were obtained at the maturity of the leaf and pseudostem, as shown in Graph 2.



Graph 2: Graph of the Effect of Stage of Growth on Loss on Drying of Plant Parts

The water-soluble extractive value was found to be highest for banana pseudostem, followed by banana inflorescence and roots, and was the least for banana leaves. The water-soluble extractive was found to increase throughout the stages of the life cycle, with the highest values at the harvest phase for each part of the banana plant, except for the inflorescence. The maturity phase showed a higher extractive value compared to the harvest phase. The highest value of 18.74 ± 0.13 % w/w was found in banana pseudostem powder at the harvest phase. The alcohol-soluble extractive, when observed for the dried powder parts of the banana plant, was found to be highest for the banana leaves, followed by banana roots and inflorescence, and was least for the banana pseudostem. It was found to increase throughout the life cycle, with the highest at the harvest phase for each part of the banana plant. The highest value of 10.77 ± 0.1 % w/w, alcohol-soluble extractive value was found in banana leaf powder at the harvest phase.

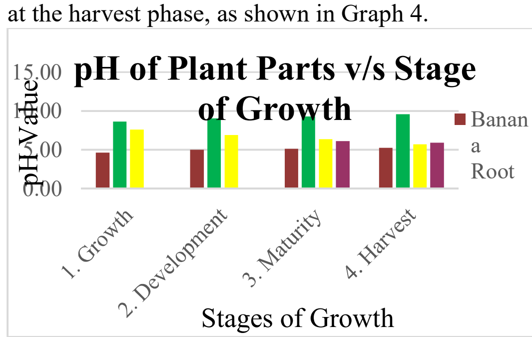
A comparison of the water-soluble extractive and alcohol-soluble extractive values at different stages of the banana plant life cycle indicated that the water-soluble extractives are on the higher side, as shown in Graph 3, except for the banana leaf, which showed a greater value for alcohol-soluble extractive value. The greatest difference in these two values has been obtained for the banana pseudostem.



Graph 3: Graph of Comparison of Water-Soluble and Alcohol-Soluble Extractive Values of Banana Plant Parts at Different Stages of Growth

Physicochemical Parameters of Freshly Crushed Banana Waste Material:

The pH, when observed for the freshly crushed material of banana plant parts, was found to be highest for banana leaves, followed by pseudostem, inflorescence, and roots. The pH values indicated an increasing trend for banana roots and leaves and a decreasing trend for banana pseudostem and inflorescence. The pH of banana root and leaf was found to be increased from 4.67 ± 0.15 to 5.27 ± 0.06 and from 8.67 ± 0.15 to 9.6 ± 0.1, respectively, from the growth phase to the harvest phase. The pH was found to be decreased from 7.6 ± 0.1 for the growth phase of the banana pseudostem to 5.73 ± 0.06 for its harvest phase. For the banana inflorescence, the pH was found to be 6.13 ± 0.06 at the maturity phase and 5.93 ± 0.15 at the harvest phase, as shown in Graph 4.

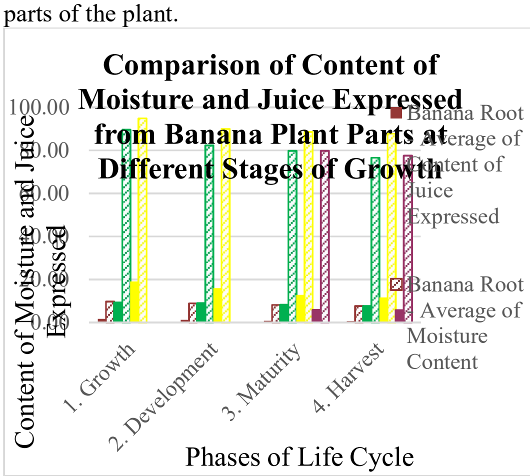


Graph 4: Graph of the Effects of Stage of Growth on pH of Plant Parts

The content of juice expressed from the freshly crushed parts of the banana plant showed a decreasing trend from the growth phase to the harvest phase for all the parts of the banana plant. The highest amount of juice was expressed from the banana pseudostem, followed by banana inflorescence and banana leaf, and was least from the banana root. The highest value of juice expressed from the banana pseudostem at its growth phase was 19.27 ± 0.32 % w/w of fresh weight of plant material, which was observed to be reduced to 11.69 ± 0.13 % at its harvest phase. The moisture content of freshly cut parts of the banana plant showed a similar trend to that shown by the content of juice expressed from the parts of the banana plant. A decreasing trend was observed from the growth phase to the harvest phase for all the parts of the banana plant. This comparison of moisture content and juice expressed is shown in Graph 5.

The highest value of moisture content for the pseudostem was found to be 95.02 ± 1.29 % w/w of fresh weight at its growth phase, which was found to be decreased to 87.85 ± 0.14 % as the plant approached the harvest phase. This was followed by the banana leaf showing a moisture content of 89.64 ± 0.32 % at the growth phase and a decline up to 76.62 ± 0.36 % at the harvest phase. This was followed by the banana inflorescence showing a value of 79.93 ± 0.32 % at the maturity phase and 77.68 ± 0.28 % at the harvest phase. The least amount of moisture content was observed for the banana roots with 9.88 ± 0.36 % at the growth phase and 7.68 ± 0.28 % at the harvest phase.

According to the comparative results, the banana roots showed very little moisture content and almost negligible juice expressed. The banana pseudostem, leaves, and inflorescence showed a high amount of moisture content. Although the content of juice expressed was comparatively very low when compared to the total moisture in the parts of the plant.



Graph 5: Graph of Comparison of Content of Moisture and Juice Expressed from Banana Plant Parts at Different Stages of Growth

As observed in Graph 3, the water-soluble extractive value of each part of the banana plant was found to be higher than the alcohol-soluble extractive value. According to Graph 5, it was evident that the banana pseudostem, leaves, and inflorescence have shown a high value for moisture content, and a considerable amount of juice could be expressed out of these parts. On account of these indications, the water-soluble phytochemicals, such as starch, were considered to be in higher amounts. Also, the evaluation of phytochemical composition was considered to be performed mainly on the water-soluble extract, and a few tests were performed on the dried water-soluble extract.

Correlation of Physical Evaluation to Morphological Abundance:

Banana pseudostem and banana leaf foliage can be considered as the highest amount of waste remnant generated from the banana plantation. As evidenced by the banana plant's lifecycle, the harvest phase produced the most waste compared to the earlier growth stages. The detailed morphological study of the banana pseudostem indicated that it consists of two distinct tissue types, namely the outer leaf-sheaths and the inner meristem. It is further clear that the outer pseudostem leaf-sheaths account for a higher biomass compared to the inner meristem. This evidence further demands a more detailed analysis of the outer leaf-sheaths and the inner meristem separately for better prospects for the research on their utilization. Further evaluation was considered to be performed on the leaf and the pseudostem of the banana plant, as the biomass was highest as per the biomass evaluation.[6]

As the chemical composition of the plant material further helps in finding its utilization prospects, the extractive values were considered important. As the pseudostem and leaf showed a high moisture content, it was evident that these parts contain the highest water content. The results of the extractive values showed that the water-soluble extractives were higher than the alcohol-soluble extractives for the pseudostem of the banana plant. The leaf showed less water-soluble extractives than alcohol-soluble extractives, but the percentage of water-soluble extractives was considerable. Since both pseudostem and leaf have a high moisture content, and as the pseudostem has the largest accountability for waste generation, a consideration was given to the further evaluation of the water-soluble extractive or fresh material of the banana plant parts.

2. Qualitative Phytochemical Evaluation of Banana Plantation Wastes:

As the major waste remnants that need attention were found to be the leaf and pseudostem, qualitative phytochemical evaluation was performed on the expressed juice of fresh samples, and observations are given in Table 3. As the pseudostem shows two distinct parts, namely the outer leaf-sheaths and the inner meristem, separate evaluation of these two parts was considered. As the waste remnants can be obtained from the plantation fields mostly at the harvest phase, and also some plants are removed at the growth phase, the harvest phase and growth phase were considered for the evaluation of these waste remnants for their phytochemical composition. HBM refers to Harvest Phase Banana Meristem.

Table 3: Results of Qualitative Phytochemical Evaluation of Fresh Juice from Banana Plantation Wastes

Plant Part	**Banana Leaf**		**Pseudostem Leafsheaths**		**Meristem**
Phase Test	**Growth (GBL)**	**Harvest (HBL)**	**Growth (GBP)**	**Harvest (HBP)**	**Harvest (HBM)**
Molisch test	+	+	+	+++	+++
Fehling's test	+	+	+	+	+
Benedict's test	+	+	+	+	+
Barfoed's test	-	-	-	-	-
Iodine test	+	+	+	++	++
Biuret test	-	-	-	-	-
Millon's test	-	-	-	-	-
Coagulation test	-	-	-	-	-
Grease Spot test	-	-	-	-	-
Phenolphthalein test	-	-	-	-	-
Dragendroff's test	-	-	-	-	-
Mayer's test	-	-	-	-	-
Wagner's test	-	-	-	-	-
Hager's test	-	-	-	-	-
Liebermann-Burchard's test	-	-	-	-	-
Salkowski test	-	-	-	-	-
Shinoda test	-	+	-	+	-
Lead acetate test	-	+	-	+	-
Vanillin HCl test	-	-	-	-	-
Lead acetate test	-	-	-	-	-
$FeCl_3$ test	-	-	-	-	-
Precipitation test	-	-	-	-	-
Foam test	-	-	+	+	+

*Results are given as: ++ strongly positive, + positive, - negative

[GBL-Growth Phase Banana Leaf, HBL-Harvest Phase Banana Leaf, GBP-Growth Phase Banana Pseudostem Leafsheaths, HBP-Harvest Phase Banana Pseudostem Leafsheaths, HBM-Harvest Phase Banana Meristem]

The Qualitative Phytochemical Evaluation of Fresh Juice indicated that the pseudostem leafsheaths, meristem, as well as the leaf showed the presence of carbohydrates and starch. The pseudostem leafsheaths and the leaves showed the presence of flavonoids at their harvest phase. The pseudostem leafsheaths and meristem also showed the presence of saponins.

As the fresh juice of the plant material showed a prominent presence of carbohydrates, a further proximate analysis for quantitative determination of various physical parameters and phytochemical composition was considered for these two parts of the banana plantation wastes. For a detailed understanding of the composition and the properties of the waste remnants, the evaluation was carried out both on the dry powder and the fresh crush of the plant materials. The evaluation was done on the pseudostem leafsheaths, meristem, and leaves at the harvest phase and on the pseudostem leafsheaths at the growth phase. Since there is only a minor variation in the physicochemical parameters of the leaf from the growth phase to the harvest phase, and due to a very small contribution of the leaf as the waste remnant, the leaves were evaluated only from the harvest phase and not from the growth phase.

3. Quantitative Proximate Analysis of Banana Plantation Wastes:

The proximate analysis was performed on the dry powder and the freshly crushed samples of the banana pseudostem leafsheaths at the growth phase and the harvest phase, and on the banana leaves and meristem at the harvest phase.

Proximate analysis was performed on the waste remnants of the banana plantation for verification of physical parameters like pH, ash value, and moisture content, and in addition, the electrical conductivity was measured, as these parameters are important for the use of products in fertilizer preparation.

Quantitative determination of macronutrients, micronutrients, and trace elements was also performed. The macronutrients like nitrogen, phosphorus, and potassium; micronutrients, namely sulphur, calcium, and magnesium, and the trace elements including iron, copper, zinc, molybdenum, manganese, and boron were analysed. In addition, the phytochemical composition was quantified for protein, fat, carbohydrate, starch, and fiber.

The observations of proximate analysis are given in Table 4.

Table 4: Results of Proximate Analysis of powdered and freshly crushed samples of Banana Waste Remnants

Plant Part	**Pseudostem Leafsheath Powder**	**Meristem Powder**	**Leaves Powder**	**Pseudostem Leafsheath Powder**	**Pseudostem Leafsheath Crush**	**Meristem Crush**	**Leaves Crush**	**Pseudostem Leafsheath Crush**
Phase	**Harvest**	**Harvest**	**Harvest**	**Growth**	**Harvest**	**Harvest**	**Harvest**	**Growth**
Chemical Tests	**(HBPP)**	**(HBMP)**	**(HBLP)**	**(GBPP)**	**(HBPC)**	**(HBMC)**	**(HBLC)**	**(GBPC)**
pH	5.32 ± 0.02	7.2 ± 0.05	7.64 ± 0.04	7.03 ± 0.04	5.8 ± 0.09	8.56 ± 0.07	9.73 ± 0.04	7.51 ± 0.06
EC (mS/cm)	12.72 ± 0.06	16.97 ± 0.11	5.87 ± 0.09	15.39 ± 0.07	2.64 ± 0.06	5.17 ± 0.08	5.23 ± 0.08	2.96 ± 0.04
Nitrogen (N) (%)	1.42 ± 0.03	1.57 ± 0.03	2.52 ± 0.02	1.76 ± 0.03	0.04 ± 0.01	0.12 ± 0.02	0.56 ± 0.03	0.29 ± 0.03
Phosphorus (P_2O_5) (%)	0.83 ± 0.03	1.3 ± 0.04	1.08 ± 0.03	1.17 ± 0.02	0.0029 ± 0	0.003 ± 0	0.051 ± 0.01	0.018 ± 0
Potassium (K_2O) (%)	0.91 ± 0.04	1.47 ± 0.05	1.49 ± 0.04	1.24 ± 0.05	0.0022 ± 0	0.0055 ± 0	0.085 ± 0.01	0.03 ± 0.01
Calcium as Ca (ppm)	0.38 ± 0.05	0.28 ± 0.04	1.1 ± 0.04	0.3 ± 0.06	0.031 ± 0	0.039 ± 0	0.41 ± 0.04	0.034 ± 0
Magnesium as Mg (ppm)	0.2 ± 0.02	0.1 ± 0.01	0.98 ± 0.04	0.19 ± 0.03	0.023 ± 0	0.027 ± 0	0.09 ± 0	0.028 ± 0
Sulphur as S (ppm)	0.49 ± 0.04	0.3 ± 0.02	1.7 ± 0.06	0.34 ± 0.03	0.041 ± 0.01	0.045 ± 0	0.21 ± 0.02	0.049 ± 0.01
Iron as Fe (ppm)	0.037 ± 0.01	0.022 ± 0	0.7 ± 0.03	0.029 ± 0	0.19 ± 0.04	0.2 ± 0.04	0.16 ± 0.02	0.24 ± 0.04
Copper as Cu (ppm)	0.021 ± 0	0.018 ± 0	0.068 ± 0.01	0.021 ± 0	0.017 ± 0	0.019 ± 0	0.015 ± 0	0.02 ± 0
Zinc as Zn (ppm)	0.03 ± 0.01	0.013 ± 0	0.38 ± 0.03	0.029 ± 0.01	0.11 ± 0.03	0.13 ± 0.03	0.17 ± 0.03	0.7 ± 0.04

Plant Part	Pseudostem Leafsheath Powder	Meristem Powder	Leaves Powder	Pseudostem Leafsheath Powder	Pseudostem Leafsheath Crush	Meristem Crush	Leaves Crush	Pseudostem Leafsheath Crush
Phase	Harvest	Harvest	Harvest	Growth	Harvest	Harvest	Harvest	Growth
Chemical Tests	(HBPP)	(HBMP)	(HBLP)	(GBPP)	(HBPC)	(HBMC)	(HBLC)	(GBPC)
Molybdenum as Mo (ppm)	0.02 ± 0	0.022 ± 0.01	0.00	0.037 ± 0.01	0.00	0.00	0.00	0.00
Manganese as Mn (ppm)	0.013 ± 0	0.011 ± 0	0.13 ± 0.04	0.017 ± 0	0.0015 ± 0	0.0029 ± 0	0.003 ± 0	0.002 ± 0
Boron as B (ppm)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total Ash Value (%)	14.97 ± 0.08	25.52 ± 0.09	8.56 ± 0.06	23.33 ± 0.05	1.29 ± 0.02	0.53 ± 0.02	0.049 ± 0	0.029 ± 0
Moisture Content (%)	3.29 ± 0.06	1.23 ± 0.04	3.57 ± 0.02	1.7 ± 0.01	87.53 ± 0.07	95.49 ± 0.04	85.34 ± 0.07	95.59 ± 0.07
Proteins (%)	8.88 ± 0.04	9.79 ± 0.03	15.76 ± 0.05	10.97 ± 0.05	0.25 ± 0.01	0.73 ± 0.03	3.52 ± 0.04	1.8 ± 0.04
Fats (%)	0.22 ± 0.01	0.2 ± 0.01	0.14 ± 0.01	0.28 ± 0.01	0.00	0.00	0.00	0.00
Carbohydrates (%)	10.44 ± 0.04	21.4 ± 0.05	10.09 ± 0.05	9.76 ± 0.04	1.93 ± 0.07	1.22 ± 0.07	1.94 ± 0.05	0.96 ± 0.04
Starch (%)	9.4 ± 0.05	19.26 ± 0.04	9.08 ± 0.05	8.78 ± 0.05	1.74 ± 0.02	1.1 ± 0.04	1.75 ± 0.04	0.86 ± 0.05
Fibers (%)	31.33 ± 0.06	19.13 ± 0.05	31.89 ± 0.04	36.03 ± 0.05	2.61 ± 0.04	0.28 ± 0.03	5.04 ± 0.03	1.09 ± 0.03

*All the values are expressed as Mean ± SD, where n = 3

Based on the proximate analysis, it has been observed that the banana leaf sheath powder, as well as the fresh crush of banana leaf sheaths at the harvest phase, showed the pH values of 5.32 ± 0.02 and 5.8 ± 0.09, respectively. Compared to the inner meristem of the pseudostem and the leaves at the harvest phase and the leafsheaths of the pseudostem at the growth phase, these values were lowest. The powdered samples of the inner meristem of the banana pseudostem and the banana leaves at the harvest phase showed a pH of 7.2 ± 0.05 and 7.64 ± 0.04, respectively. At the growth phase, the pseudostem leaf sheaths showed an acceptable limit for the pH of 7.03 ± 0.04 and 7.51 ± 0.06 for both the powder and fresh samples. The fresh crush of banana meristem and banana leaves at the harvest phase showed the highest pH of 8.56 ± 0.07 and 9.73 ± 0.04, respectively. As the acceptable pH range for crop growth is near neutral, all parts have a near-acceptable pH except the fresh crush of the inner meristem and leaves at the harvest phase.

The electrical conductivity of the freshly crushed samples was found to be lower than that of the powdered samples, except for leaf powder, which showed an EC value of 5.87 ± 0.09 mS/cm. For other powders, it was found to be above 12 mS/cm, and for fresh material, it was observed to be below 5.3 mS/cm. For the fresh crush of pseudostem leafsheath, it was found to be below 3 mS/cm at both the harvest and growth phase. Hence, these are under acceptable limits for use in soil fertility for plant growth. However, the other parts with higher EC values can be controlled by the use of other bulking agents and through the processes used for fertilizer preparation. These observations of EC concluded that the waste parts of the banana pseudostem are not necessarily to be powdered before they are used for fertilizer preparations, as that increases the salinity of the material to a greater extent.

The nitrogen, phosphorus, and potassium content was higher for the powdered samples than for the freshly crushed samples. The nitrogen was found to be the highest compared to the phosphorus and potassium content for each plant material in powdered as well as freshly crushed samples. The phosphorus and potassium content of each material was found to vary based on the part. The leaves were found to have the highest nitrogen and potassium content in the powdered sample and the freshly crushed sample compared to other parts. The phosphorus content was highest for the meristem of the pseudostem. Powdered samples show comparable NPK values, indicating that the preparation of powdered fertilizers can be a way out for the utilization of these waste parts. Freshly crushed materials, when directly used in the fields, do not give comparable NPK values that are necessary for crop growth. Hence, the preparation of fertilizers can be a better choice for the utilization of these parts.

The secondary micronutrients, i.e., calcium, magnesium, and sulphur, were found to be highest in the leaf powder, followed by the freshly crushed leaf samples. The other parts showed a comparatively lower amount of these micronutrients, but the powdered samples of all the parts showed a significant amount of the micronutrients necessary for plant growth compared to the freshly crushed samples. The trace elements that were significantly found in the waste parts of the banana plantation include iron, zinc, copper, and molybdenum in the powdered as well as freshly crushed samples. Fine traces of manganese were observed in the freshly crushed samples. Boron was found to be completely absent in both types of samples. This further concludes that the use of these parts could be made in fertilizer preparation, preferably as a powdered solid fertilizer rather than the direct use of the crushed material in the fields.

The total ash content revealed that the powdered samples showed higher ash values compared to freshly crushed material. The meristem powder at the harvest phase and the leaf sheath powder at the growth phase showed the highest total Ash value of 25.52 ± 0.09 % and 23.33 ± 0.05 %, respectively, followed by the pseudostem leaf sheath powder at the harvest phase, and was found to be the least for the leaf powder. Among the freshly crushed materials, the pseudostem leaf sheath sample at the harvest phase showed the highest value of 1.29 ± 0.02 %, followed by the leaf sample at the harvest phase with a value of 0.53 ± 0.02 %, and the meristem at the harvest phase and the pseudostem leaf sheath sample at the growth phase showed the least values.

The moisture content was found to be highest for the freshly crushed samples of meristem at the harvest phase and pseudostem leafsheaths at the growth stage, with 95.49 ± 0.04 % and 95.59 ± 0.07 %, respectively. The freshly crushed samples of pseudostem leafsheaths and the leaves at the harvest phase showed a moisture of 87.53 ± 0.07 % and 85.34 ± 0.07 %, respectively. The moisture retention in dry powders was observed to be highest for leaf powder with a moisture content value of 3.57 ± 0.02 %, whereas it was found to be lowest for meristem powder at the harvest phase with only 1.23 ± 0.04 % moisture content. At the harvest phase, the pseudostem leaf sheath powder also showed a significant moisture retention of 3.29 ± 0.06 %.

The protein content was found to be highest in leaves and least in the meristem, whereas fat content was found to be negligible in all the parts.

The carbohydrate, starch, and fiber content were found to be highest for the fresh samples of the leaves and pseudostem leafsheaths at the harvest phase. The carbohydrate and starch content were lowest for the fresh sample of pseudostem leafsheaths at the growth phase and moderate for the meristem. The fiber content was lowest for the fresh sample of meristem and moderate for the pseudostem leafsheaths at the growth phase.

Upon drying, the highest values of carbohydrate and starch content were observed in the meristem powder, and moderate values were observed in the pseudostem leafsheath powder and leaf powder at the harvest phase. This was indicative of the losses of carbohydrates and starch content, possibly occurring in the course of the drying of the pseudostem leafsheaths and leaves, leading to a reduction in the carbohydrate and starch content. The pseudostem leafsheaths at the growth phase, when powdered, showed the lowest content of carbohydrate and starch. The fiber content was found to be highest for powdered samples of pseudostem leafsheaths at the growth phase, followed by the leaves and pseudostem leafsheaths at the harvest phase, and least for the meristem powder. This was indicative of no losses in the fiber content during the drying steps.

4. Microscopic Evaluation of Banana Plantation Wastes:

Banana pseudostem being the largest waste remnant obtained from the banana plantation, the pseudostem leafsheaths and meristem were considered for further study, and evaluated microscopically. The phloroglucinol HCl stain was used to understand the microscopic makeup of the parts, and the iodine stain was used to observe and confirm the starch in the microscopic examination of the pseudostem. Sudan red stain was used to evaluate the presence of mucilage.

Phloroglucinol HCl Stain:

Phloroglucinol HCl stain showed the presence of lignified tissue, pseudo-parenchyma, non-lignified fibers, and water tubes in the outer leafsheaths as well as the inner meristem of the pseudostem, as shown in Figure 1.

The microscopic observation of the phloroglucinol HCl slide also showed that, more fiber content was observed in the outer leafsheaths as compared to the inner meristem.

Also, it was evident that a more compact cellular arrangement showing a narrow lumen being observed in the outer leafsheaths of the pseudostem compared to the inner meristem.

Iodine Stain:

The iodine stain showed the presence of a large amount of starch in the outer leafsheaths of the pseudostem and comparatively less starch in the inner meristem, as shown in Figure 2.

The higher intensity of the blue stain of iodine in the TS and LS of the outer leafsheaths of the pseudostem also indicated that the starch is more prominent and granular in the outer leafsheaths as compared to the inner meristem.

Sudan Red Stain:

The Sudan Red stain showed the presence of mucilage in the outer leafsheaths as well as the inner meristem of the banana pseudostem, as shown in Figure 3.

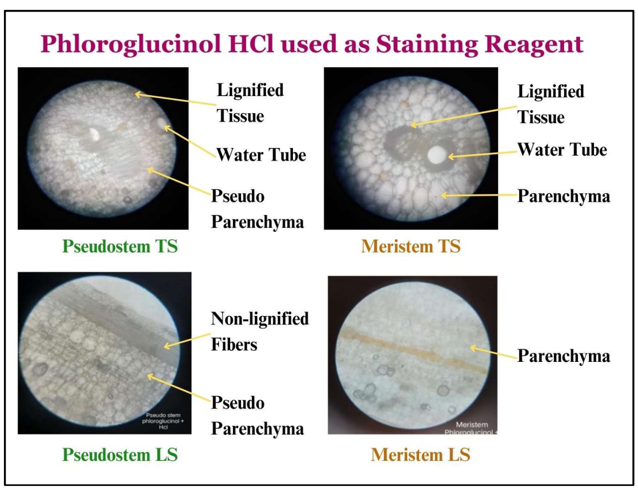


Figure 1: Microscopy of Banana Pseudostem Leafsheaths and Meristem using Phloroglucinol HCl as a Staining Reagent

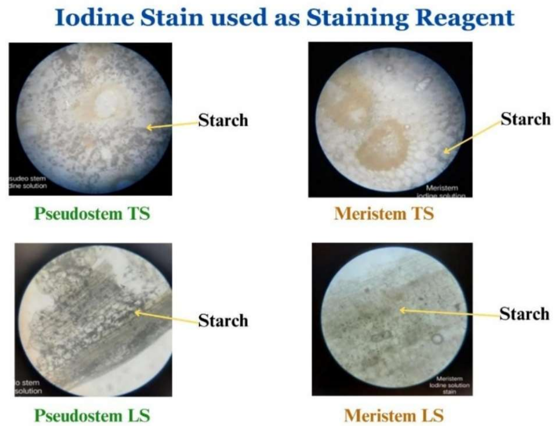


Figure 2: Microscopy of Banana Pseudostem Leafsheaths and Meristem using Iodine Stain as a Staining Reagent

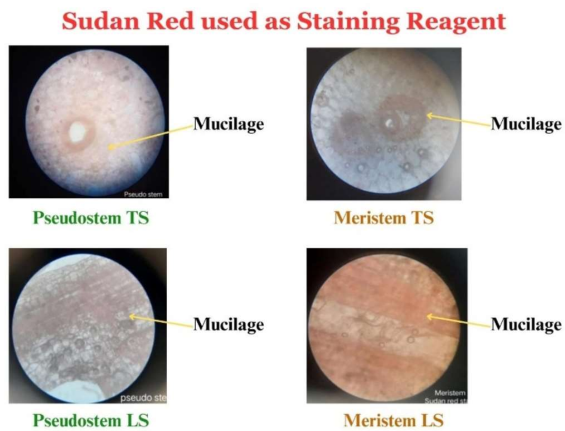


Figure 3: Microscopy of Banana Pseudostem Leafsheaths and Meristem using Sudan Red as a Staining Reagent

CONCLUSION:

According to a study performed on the morphological evaluation of banana plantation wastes, it was evident that two different types of tissues, the outer leafsheath layers and the inner meristem portion, are shown at the harvest phase. The inner meristem is not present at the growth phase and the development phase, but is developed after the fruit bearing at the maturity stage. A major amount of pseudostem waste is developed at the harvest phase and, to some extent, at the growth phase due to the extra daughter plants that are removed from the fields. This indicated that the best utilization of wastes could be by use of harvest phase waste remnants.[6]

The physicochemical evaluation indicated the presence of a huge amount of water content in the outer leafsheaths as well as in the inner meristem portion of the banana pseudostem. The phytochemical evaluation revealed the presence of carbohydrates and starch. The proximate analysis confirmed the presence of starch and fibre content in the pseudostem and the leaves. The fresh samples showed a higher content of carbohydrates and starch in the leafsheaths of the pseudostem as compared to the meristem, in contrast to powders.

According to the results obtained from proximate analysis of pseudostem leafsheaths and meristem, a comparison of the water content or moisture, fiber content, starch content, and the nutrient profile of the powder, as well as the fresh crush, was conducted to understand the valuable prospects of research on these parts. The harvest phase pseudostem leafsheaths showed the highest moisture content for dry powder form, as compared to the meristem and growth phase pseudostem, in contrast to the highest water content of the meristem and growth phase pseudostem compared to the harvest phase pseudostem for the fresh sample.

The observations of microscopy in phloroglucinol HCl stain and iodine stain confirmed the presence of starch and fibers in both the outer leafsheaths and inner meristem of the banana pseudostem, but a prominent content of both starch and fibers could be majorly identified in the outer leafsheaths as compared to that of the inner meristem of the banana pseudostem.

Though the outer leafsheaths of the banana pseudostem showed a narrow lumen compared to the inner meristem, the granular structure of the starch was prominently visible in both TS and LS of the outer leafsheaths. The iodine staining acquired by the TS and LS of the inner meristem was comparatively very faint, indicating that this could be due to less prominent starch grains compared to the outer leafsheaths of the banana pseudostem.

The presence of mucilage in the outer leafsheaths as well as the inner meristem of the banana pseudostem, along with the starch, indicated that the isolation of starch could give variable results as compared to proximate analysis, since there is evidence that mucilage is capable of causing hindrance in the sustenance and extraction of pure starch.

Based on these observations, it could be concluded that the extraction of starch from the banana pseudostem should be conducted when fresh, and no drying step is required before isolation of starch from these parts. Also, it is indicative that the mature pseudostems at the harvest phase could give the best yield for the starch. It could also be concluded that the fibers might be isolated either from the fresh material or upon drying of the pseudostem, as no effect of drying was observed on the content of the fibers, but further evaluation of the effect of drying on the fibers should be conducted if fiber isolation is intended.

As the starch as well as fibers are available in the highest amount in the outer leafsheaths of the pseudostem compared to the inner meristem, the outer leaf sheaths of the banana pseudostem could be used for the isolation of starch along with fibers, and a further evaluation of this is necessary. Meristem can also be used for the isolation of starch, but the content of fibers in meristem is the least. Though the leaves of the banana contain the highest amount of starch as well as fibers, the presence of nutrients and other phytochemicals in the leaves could pose a problem in fiber as well as starch isolation.

Banana pseudostem leafsheaths have been utilized in fresh form for the isolation of fibers. Also, during fibre extraction, the juice of pseudostem leafsheaths is commonly left as a byproduct, which can be further utilised. The leafsheaths showed a higher amount of fibre content compared to the meristem. In fresh form, the outer leafsheaths of the pseudostem at the harvest phase showed the highest amount of starch. This study suggests that the outer leafsheaths could be a high-yielding, sustainable source of starch among the different banana plantation waste fractions. Hence, this study demands further study of isolation techniques and the practical yield of starch from the outer leafsheaths of the banana pseudostem.

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