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REVIEW PAPER

Banana Pseudostem its Nutritional, Health Benefits and its Industrial Applications: A Review

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ABSTRACT

Banana pseudostem, the fibrous aerial stem of the banana plant discarded after fruit harvesting, represents one of the most underutilized agro-residues despite its exceptional nutritional, therapeutic, and industrial potential. Recent scientific investigations have demonstrated that banana pseudostem is a rich reservoir of dietary fibre, cellulose, hemicellulose, lignin, resistant starch, essential minerals, polyphenols, flavonoids, and bioactive phytochemicals that contribute significantly to human health and sustainable industrial development. Pseudostem contains considerable amounts of potassium, calcium, magnesium, iron, and vitamin-rich compounds, along with both soluble and insoluble fibres that aid gastrointestinal function, lipid metabolism, glycemic regulation, and detoxification processes. It's high fibre content improves bowel movement, enhances satiety, reduces cholesterol absorption, and supports gut microbiota modulation, thereby lowering the risk of obesity, diabetes mellitus, cardiovascular disorders, and colon-related diseases. Bioactive constituents such as phenolic acids, tannins, and antioxidants exhibit strong free radical scavenging activity, anti-inflammatory effects, antimicrobial properties, and nephroprotective potential, particularly in the prevention of kidney stone formation and urinary tract disorders. Recent years, banana pseudostem has emerged as a promising functional food ingredient and nutraceutical resource. The tender central core is increasingly utilized for the development of health-oriented value-added products including juice, syrup, squash, candy, pickles, jam, flour, cookies, bread, noodles, and dietary fibre supplements. Scientific studies have reported that incorporation of banana pseudostem powder or fibre into food formulations improves nutritional quality, water-holding capacity, texture stability, and antioxidant activity while reducing caloric density. Furthermore, pseudostem extracts have shown potential therapeutic applications in traditional and modern medicine due to their diuretic, hypoglycemic, hepatoprotective, and antiurolithiatic properties.

Keywords: Banana pseudostem, Dietary fiber, Nutritional Value, Biodegradable, Ecofriendly, Value-added products, Nutraceutical, Non-edible Products

Banana (*Musa acuminata)* is a herbaceous plant of the family *Musaceae*. In terms of overall production, it is the second place after citrus, according for about 16% of the total fruit production (Ma, 2015). It is one of the important fruit crops grown almost in every state of India and ranks fourth in the world as a staple food after rice, wheat and corn. Total world production of banana is 139.90 million tons. India is the largest producer of banana (29.80 million tons) (Department of Agriculture and Farmer Welfare). Followed by china (10.60 million tons) Uganda (9.80 million tons), Philippines (9.20 million tons), Ecuador (7.6 million tons), Brazil (6.9 million tons) and

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Indonesia (6.2 million tons) (Food and Agriculture Organization, 2013). Utilization of banana waste-pseudostems has gained more attention in recent years, contributing about 23% of world production, India is the largest producer of banana and the major producing states are Maharashtra, Kerala, Tamil Nadu, Gujarat, Bihar, West Bengal, Assam, Andhra Pradesh and Karnataka. Banana is commonly known as Kela in Indian sub-constituent and regionally as Vazhappazham in Kerala, Vezhakkai in Tamil Nadu, Aratipandu in Andhra Pradesh, Kola in Bengali and Kol in Assam Sreekumar and Padhan (2022).

The banana pseudostem is a thick stalk grows up from the ground and form the backbone of the herbaceous plant. The edible part of the banana stem is the inner portion of the fibrous stalk called as banana centre core. Banana stem is rich in fibre, potassium and vitamin B6 which aid in the treatment of ulcers and in the development of a sport drink, which together benefits the muscles and production of hemoglobin and insulin (Munishamanna *et al.* 2020). The pseudostem fiber is used for making several value-added products namely rope, cordage, fishing net, mat, packaging material, paper sheets, textile fabrics, bag, table cloth, handicrafts, absorbent, polymer/ fiber composites etc (Subagyo and Chafidz, 2018).

The banana psedostem could potentially be used more in food rather in other industries. The exploitation of waste banana psedostems into products could significantly benefit the environment and increase its economic value (Ma, 2015). There are a number of long-stored food products developed containing potent bioactive properties like pickles, squash, drink, and so on giving a high therapeutic value to the functional food. There are several ways in which the banana pseudostem can be used as a substrate for mushroom and microalgae growth. It is also used as a biofuel in the production of biodiesel and also as a biofertilizer. It is good for the removal of dyes (Pillai *et al.* 2024). The banana pseudostem is particularly rich in cellulose, hemicellulose, protein, fat and dietary fibres along with other nutritive elements. The presence of polyphenols and flavonoids, viz. ferulic acid, cinnamic acid, catechin, gingerol, with promising antioxidative activities has been reported (Rochana *et al.* 2017). There are reports on development of different value-added products viz., fibre, yarn, fabrics, vermi compost, liquid fertilizer, quality papers, RTS beverage juice, candy and pickles from banana pseudostem core (Munishamanna *et al.* 2020).

Vigneswaran *et al.* (2015) reviewed on banana fibre, scope and value-added product development and authors reported that banana fibre is a natural best fibre which has wide range of uses in hand craft product developments such as mat, rope, twines but only 10 per cent of the pseudostem is being used for making products and remaining is waste or used as fertilizer. Fig. 1 shows the components of banana pseudostem.

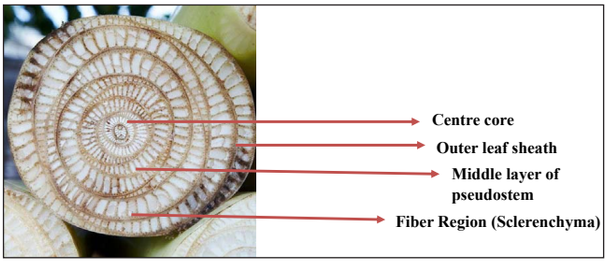

Fig. 1: Components of banana pseudostem

The colour of banana pseudostem is reported to have a red, reddish green colour and yellowish colour. At the centre of pseudostem, there is tube-like tender core (Figure 1. With a diameter 5-6 cm) the fibre extracted from banana pseudostem can be used as a food additive (Ali *et al.* 2020). The centre core is the innermost portion of the pseudostem and is primarily composed of soft, spongy parenchymatous tissue. It has a very high moisture content, typically ranging from 90% to 95%, which makes it highly perishable but also nutritionally valuable. Due to its high water-holding capacity and swelling properties, the centre core is widely studied for use in functional foods and nutraceutical products. It is commonly processed into juice, fibre powder, and other health-promoting products Reddy and Yang (2005).

The soft fibre is obtained from the middle layers of the pseudostem. These fibres are finer, more flexible, and

less coarse compared to the outer fibres. The chemical composition of soft fibre typically includes about 50–60% cellulose, moderate hemicellulose, and around 10–15% lignin) Brunda (2023). These characteristics make them suitable for textile applications, especially in blended fabrics and eco-friendly materials. Additionally, soft fibres are used in handicrafts and biodegradable composite materials (Mohapatra *et al.* 2010).

The hard fibre is extracted from the outermost layers of the pseudostem. These fibres are coarse, strong, and highly lignified, providing excellent mechanical strength. The cellulose content in hard fibre is relatively high (around 60–65%), while lignin content ranges from 15–20%. Due to their high tensile strength and stiffness, hard fibres are widely used in industrial applications such as rope making, mat production, paper manufacturing, and reinforcement in composite materials. However, these fibres are less flexible compared to soft fibres Brunda (2023). The centre core is mainly used for nutritional and food-related purposes, whereas the fibres are utilized for material and industrial applications. Soft fibres serve as a balance between flexibility and strength, while hard fibres provide maximum durability and strength Reddy and Yang (2005).

Nutritional Value of Banana Pseudostem

Banana pseudostem has very high content of dietary fibre and has caught the attention of food scientists in recent years. It could be used more in food rather than in the feed industry Aziz *et al.* (2011) and Bhaskar *et al.* (2012) have reported the proximate composition of banana pseudostem and are presented in Table 1 also BPS is a rich source of fibre total carbohydrate and cellulose Saravanan *et al.* (2011). Cellulose was the main insoluble dietary fibre and pectin was the dominant soluble dietary fibre in the pseudostem. Banana pseudostem is characterized by its high moisture content, typically exceeding 90%, which makes it a low-calorie food suitable for dietary applications. Despite its high-water content, it contains appreciable amounts of carbohydrates, fiber, and essential micronutrients (Ramu *et al.* 2022). Banana psedostem has functional and technological properties. Due to its fiber-rich nature, banana pseudostem can be incorporated into bakery and food products to improve texture, water-holding capacity, and nutritional quality (Bhaskar *et al.* 2012).

Banana pseudostem is a highly nutritious, fiber-rich, and sustainable food resource. Its composition of dietary fiber, essential minerals, and bioactive compounds makes it beneficial for digestive health, weight management, and chronic disease prevention Gayathry and John (2024). The nutritional value of the banana pseudostem is given in Table 1.

Table 1: Nutritional Value of Banana Pseudostem

Sl. No.	Nutrients	Content (%)
1	Protein	2.5
2	Fat	1.7
3	Free Sugar	3.4
4	Soluble dietary fibre	1.4
5	Insoluble dietary fibre	27.4
6	Starch	27.3
7	Ash	0.3
8	Moisture	15.1

Bhaskar et al. (2012).

Health benefits of Banana Pseudostem

Banana pseudostem is a food with great nutritional value and potential health benefits. It is exceptionally nutrient-dense and can offer a range of positive health effects. Its richness in fiber, the banana pseudostem can be an excellent addition to the diet of health-conscious individuals. Emphasizing the fiber content highlights its potential to support digestive health, promoting regular bowel movements and aiding in digestion (Padam *et al.* 2014). Fig. 2 shows the Principal Function and Health Benefits of Banana Pseudostem.

Encouraging the consumption of the psedostem could promote a more sustainable use of the entire banana plant, reducing waste and increasing its overall value. It has less glycemic index and high dietary-fibre and antioxidant content which is good for diabetes

(Bhaskar *et al.* 2012). Stem is a rich source of fibre and helps in weight loss and also rich in potassium and vitamin B6 (Chandrasekaran, 2012). Banana pseudostem powder well known remedy for urinary disorders, stomach troubles like diarrhoea, dysentery and flatulence. In southern India, it is consumed as fresh juice to prevent kidney stones (Devu *et al.* 2025) Banana stem juice has been reported to have excellent therapeutic efficacy such as dissolving the pre-formed stones and preventing stones in urinary bladder (Kailash and Varalakshmi, 1992).

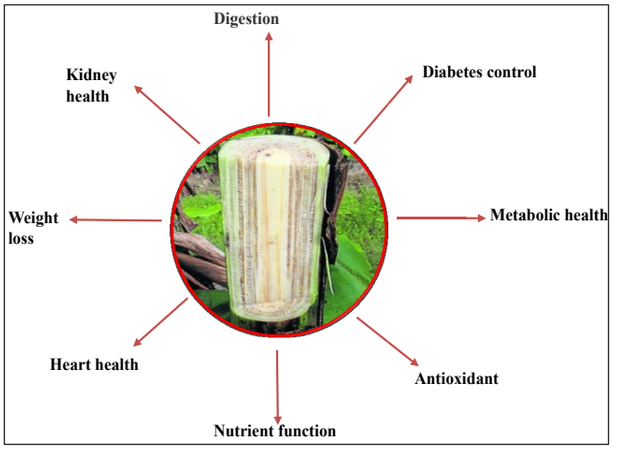

Fig. 2: Principal Function and Health Benefits of Banana Pseudostem

Advances in the research on Banana Psedostem

(Usadadia *et al.* 2016) conducted extensive research on the utilization of banana pseudostem for the preparation of various value-added products. Their studies focused on converting agricultural waste into economically useful products such as banana fibre, handmade paper, non-woven fabrics, organic liquid fertilizers, vermicompost, boards, and edible products like candy. Their research highlighted the importance of banana pseudostem as a sustainable raw material for agro-industrial applications.

(Badanayaka *et al.* 2023) worked extensively on banana pseudostem fibre extraction and fibre-based products. Their research led to the development of eco-friendly dishware, biodegradable products, wall panels, and textile-grade fibres. They demonstrated that banana fibre possesses excellent mechanical strength and biodegradability, making it suitable for sustainable packaging and textile industries.

(Chakraborty *et al.* 2021) investigated the incorporation of banana pseudostem powder into bakery products. Their research on wheat flour biscuits enriched with banana pseudostem showed significant improvement in dietary fibre content, antioxidant activity, and nutritional quality while maintaining acceptable sensory properties. The study confirmed the potential use of banana pseudostem as a functional food ingredient.

Gayathry and John (2024) conducted research on bioactive compounds extracted from banana pseudostem and inflorescence. Their work focused on the development of microencapsulated powders rich in antioxidants and functional compounds. The study revealed that banana pseudostem extracts possess promising applications in nutraceutical and functional food industries.

Kumar and Birundha (2026) studied advanced green extraction technologies for obtaining dietary fibre from banana pseudostem. Their research used microwave-assisted and ultrasound-assisted extraction techniques to improve the techno-functional and bioactive properties of dietary fibre. The researchers reported that these technologies enhance fibre quality and increase its application potential in functional foods.

Stenzel and Arcot (2017) explored the extraction of cellulose from banana pseudostem for the preparation of biodegradable packaging films. Their research demonstrated the suitability of banana pseudostem cellulose as an eco-friendly alternative to petroleum-based plastic packaging materials. The study emphasized sustainability and waste valorization through agricultural biomass utilization.

(Uma *et al.* 2022) developed and promoted the technologies Banana fibre extraction from pseudostem sheath, Fibre-based products such as ropes, mats, bags, baskets, carpets, and handicrafts and Processing of pseudostem waste into commercially useful products.

Various Parts of Banana Pseudostem Used for Value-Added Products

1. Pseudostem central core

Banana pseudostem core is an inner most tender portion of pseudostem which is edible and used in preparation of candy, drinks and pickles (Mohiuddin, 2014). About 10 to 12 t/ha central core could be generated / ha and it is consumed as vegetable in some countries like Malaysia, India and Srilanka (Kennedy, 2009 and Subbaraya, 2006). It has several medicinal properties including antimicrobial property and pathogenesis protein (Mohiuddin, 2014)

2. Pseudostem Tender core

The **banana pseudostem tender core** is the soft, edible inner central portion of the banana pseudostem. It is obtained after removing the outer fibrous sheaths of the banana plant. In many parts of India, especially Kerala, Tamil Nadu and Maharashtra, the tender core is traditionally consumed as a vegetable, juice, pickle, salad, curry and functional food ingredient Dayod and Abat (2018).

3. Banana pseudostem sap

Banana pseudostem sap is the liquid extracted from the banana pseudostem during harvesting or fibre extraction. It is considered an important agro-industrial by-product because it contains several bioactive compounds, minerals, natural antioxidants and plant nutrients. Traditionally, banana sap has been used in folk medicine and agriculture, while recent scientific studies have explored its applications in food, pharmaceuticals, textiles and environmental management (Ramu *et al.* 2022).

4. Residual biomass:

Banana pseudostem biomass is mainly composed of cellulose, hemicellulose, lignin, pectin, ash, moisture, and various bioactive compounds. Scientifically, it is categorized as lignocellulosic biomass because of its high cellulose content. Cellulose is the major structural component and generally ranges from 50–74%, while hemicellulose constitutes about 12–18% and lignin about 5–15%. In addition, the pseudostem contains significant amounts of dietary fiber, potassium, calcium, magnesium, iron, polyphenols, flavonoids, and antioxidants (Badanayaka *et al.* 2023). One of the most important properties of banana pseudostem biomass is its biodegradability and renewability. The biomass also possesses low density, good tensile strength, high moisture absorption capacity, flexibility, and thermal stability (Pillai *et al.* 2024).

5. Outer leaf sheath

The outer leaf sheath is the outermost layer of the banana pseudostem and is one of the most important components utilized for industrial and commercial purposes. The outer sheath is comparatively thick, coarse, fibrous, and highly rich in lignocellulosic materials such as cellulose, hemicellulose, and lignin. Due to its strong fibrous nature and mechanical strength, the outer leaf sheath is extensively explored for the production of various value-added products in textile, paper, packaging, and composite industries Subagyo and Chafidz (2018).

The outer sheath mainly contains high cellulose content ranging from 50–65%, hemicellulose around 15–20%, and lignin about 5–12%. Cellulose is the major structural polysaccharide responsible for the strength and durability of banana fibers. The presence of lignin provides rigidity and stiffness, while hemicellulose contributes to flexibility and water absorption capacity (Padam *et al.* 2014).

Value-Added Products from Banana Pseudostem

1. Squash

The squash is prepared in the normal method, but the banana pseudostem extract is used instead of water here. It can be successfully preserved with 350 ppm of KMS and citric acid for 6 months in Polyethylene Terephthalate (PET) bottle 200 ml at 20°C − 35°C considered room temperature. The TSS, acidity, and organoleptic evaluation is done in 0, 2, 4, and 6 months. It is found that the best- blended squash with consistent nutritional value can be made

with 75% banana pseudostem sap, 10% mango pulp, 10% papaya pulp, and 5% aloe vera. The pseudostem squash is shown in Fig. 3.

Fig. 3: Banana pseudostem squash

The use of banana pseudostem sap/juice lowers production costs and improves the nutritional value of the finished product. Fruit juice and pulp blending produced squash with good sensory and nutritive qualities (Singh *et al.* 2016).

2. Ready-to-drink juice

The banana pseudostem of species like Vayal vazhai and Ottu vazhai is collected. It is cleaned and weighed into pieces of 1 kg, sliced and the fiber is removed diced, and soaked in 2% citric acid solution for 10 minutes to prevent the unwanted browning reaction. it is steam blanched for 3 minutes at 65°C then mechanically crushed and filtered using muslin cloth. The obtained juice is mixed with water in a ratio of 3:1. In this study natural flavours like mint and lemon are used. The pseudostem Ready-to-drink juice is shown in Fig. 4. Before the addition of BPS juice to the flavours and sugar syrup it is pasteurized at 72– 80°C then cooled and other ingredients like KMS 70 ppm, CMS 1%, and the rest is added and bottled in a sterile state crocked heated up to 72–80°C for 20 minutes.

Fig. 4: Pseudostem Ready-to-drink juice

It is found that the lemon-flavored banana pseudostem juice is best in both nutritive and organoleptic ways have a shelf life of 45 days (Buvaneshwari *et al.* 2020).

3. Pickel

Fig. 5: Banana pseudostem pickel

Banana pseudostem is also utilized for pickle preparation. The tender core is chopped into small pieces, blanched, and mixed with spices such as chili powder, turmeric, mustard, fenugreek, salt, and edible oil. The prepared mixture is stored

in sterilized containers for maturation. Banana pseudostem pickle has good sensory quality and is rich in dietary fiber and antioxidants. The pickel from banana pseudostem is shown in Fig. 5. It provides an excellent method for preserving pseudostem and increasing its utilization in household food products Sreekumar and Padhan (2022).

4. Banana Pseudostem Powder

Fig. 6: Banana pseudostem powder

Banana pseudostem powder is another highly valuable product. For powder preparation, the pseudostem core is sliced into thin pieces, blanched, and dried using solar drying, tray drying, or freeze-drying methods. The dried material is ground into fine powder and packed in moisture-proof containers. Banana pseudostem powder is rich in dietary fiber and can be incorporated into bakery products, soups, nutritional supplements, and health formulations. The banana pseudostem powder is shown in Fig. 6. The powder enhances nutritional quality and provides functional benefits in food products (Mohpatra *et al.* 2010).

5. Candy

Another important value-added product is banana pseudostem candy. In this process, the tender pseudostem core is cut into cubes and blanched in hot water. The pieces are soaked in sugar syrup of gradually increasing concentration for proper sugar absorption. After soaking, the cubes are dried using tray dryers or solar dryers to obtain chewy fiber-rich candy. The banana pseudostem candy is shown in Fig. 7.

Fig. 7: Banana pseudostem Candy

The product has a pleasant taste, improved shelf life, and nutritional value compared to conventional synthetic candies. Banana pseudostem candy is becoming popular as a healthy snack product (Mohpatra *et al.* 2010).

6. Cookies

Fig. 8: Banana pseudostem Cookies

The banana pseudostem central core flour is incorporated into normal refined and wheat flour

of cookies at different percentages like 5, 10 and 15. Then it is baked and proximate, physical, and sensory analysis is done. The Cookies from banana pseudostem is shown in Fig. 8. It is found that the acceptance of 10 and 15% of banana pseudostem central core flour is high Ambrose and Lekshman (2016).

7. Bread

Fig. 9: Banana pseudostem Bread

The peeled banana pseudostem is rinsed with normal water then with distilled water and diced and boiled in water for 30 minutes. It is then dried in a ventilated dryer at 60°C for 24 hr blended into powder and sieved of size 355 µm. This banana pseudostem flour replaces the normal wheat flour in bread making in 10 g/100 g proportion and xanthan gum, Carboxymethylcellulose, salt, sugar, milk powder, and *Saccharomyces cerevisiae* (instant yeast) are added and then baked at 180°C for 20 minutes. Its analysis is done like moisture, protein, crude fat, crude fiber, antioxidant, total phenolic content, weight, color, volume, specific volume, and sensory. The banana pseudostem bread is shown in Fig.9. The result showed that a 10% substitution of banana pseudostem flour with wheat flour can improve the nutritive as well as organoleptic properties of bread Ho *et al.* (2013).

8. Jam

The preparation of banana pseudostem jam begins with the selection of fresh, tender, and disease-free pseudostems. The outer fibrous sheaths are removed carefully, and the inner edible core portion is collected for processing. This core is soft, light in color, and comparatively less fibrous than the outer layers. The selected material is washed thoroughly with clean water to remove dirt, latex, and other impurities. After cleaning, the pseudostem core is cut into small pieces. Since banana pseudostem undergoes rapid enzymatic browning after cutting, the pieces are immersed in water containing citric acid or lemon juice. This treatment helps in maintaining color and improving the appearance of the final product. The banana pseudostem jam is shown in Fig. 10.

Fig. 10: Banana pseudostem Jam

The pieces are then subjected to blanching in hot water for about three to five minutes. Blanching softens the tissue, reduces microbial load, and inactivates enzymes responsible for browning and quality deterioration. The blanched pseudostem pieces are then converted into pulp using a grinder, mixer, or pulper. The prepared pulp is filtered if necessary to obtain a smooth consistency. For jam preparation, sugar is added to the pulp in appropriate proportion along with citric acid and pectin. Pectin is important for gel formation and proper texture development. In some cases, natural flavors such as pineapple or banana flavor may be incorporated to improve taste and consumer acceptability (Padam *et al.* 2014).

Table 2 shows the Banana Pseudostem Raw Material Used in Various Application.

Table 2: Banana Pseudostem Raw Material Used in Various Application

Sl. No.	Raw Material Used	Product	Product Image	Application	Reference
1	Outer Sheath	Fiber		Textile and Handicrafts	Ramchandran *et al.* 2004
2	Fibre pulp	Paper		Eco-friendly paper	Cordeiro *et al.* 2012
3	Inner core	Candy		Functional food	Kowsalya *et al.* 2016
4	Tender core	Pickel		Various food product	Kowsalya *et al.* 2016
5	Central core	Juice/Squash/RTS		Health beverages	Cordeiro *et al.* 2012
6	Fiber	Biodegradable plates		Packaging material	Stenzel and Arcot, 2017

Non-Edible Products from Banana Pseudostem

1. Natural fiber

Fig. 11: Natural fiber from banana pseudostem

Banana pseudostem fibre is one of the important natural fibres obtained from agricultural waste generated after banana harvesting. The banana pseudostem, which appears like a trunk, is actually made up of tightly packed leaf sheaths. Traditionally, this pseudostem was discarded after harvesting the banana bunch, but recent scientific research has shown that it is a valuable source of strong, biodegradable, and eco-friendly fibre. The natural fiber from banana pseudostem is shown in Fig. 11. Due to its excellent mechanical properties, banana fibre is widely used in textiles, handicrafts, paper production, ropes, mats, packaging materials, and reinforced composite products (Cordeiro *et al.* 2004).

2. Yarn

Fig. 12: Banana pseudostem yarn

Banana pseudostem fibre has emerged as an important natural fibre for the textile industry because of its biodegradability, strength, lightweight nature, and eco-friendly properties. After harvesting banana fruits, the pseudostem is generally discarded as agricultural waste; however, it contains high-quality cellulose fibres that can be processed into yarn for textile applications. Banana fibre yarn is increasingly used in sustainable textiles, handicrafts, blended fabrics, ropes, mats, and decorative products. The banana pseudostem yarm is shown in Fig. 12. The manufacturing of yarn from banana pseudostem involves several processing steps including fibre extraction, retting, softening, spinning, and finishing (Ortega *et al.* 2016).

3. Ecofriendly handicrafts

Fig. 13: Ecofriendly handicrafts

Banana pseudostem handicrafts are biodegradable, renewable, lightweight, and environmentally safe. These products help reduce plastic usage and provide

an additional source of income to farmers and rural women entrepreneurs. Due to increasing awareness regarding sustainable products, banana fibre handicrafts are gaining importance in domestic and international markets. The ecofriendly handicrafts is shown in Fig.13. Researchers have also reported that banana fibre possesses good tensile strength, durability, and flexibility, making it suitable for textile and handicraft applications Subagyo and Chafidz (2020).

4. Paper

Fig. 14: Handmade paper

Handmade paper prepared from banana pseudostem possesses good tensile strength, biodegradability, and eco-friendly properties. The production process requires low energy and contributes to waste utilization and rural employment generation. Banana fibre paper is increasingly used for eco-friendly packaging, handicrafts, stationery products, and decorative applications due to growing environmental awareness and demand for sustainable materials (Badanayak *et al.* 2023). The handmade paper from banana pseudostem fiber is shown in Fig. 14. Banana fiber is an excellent substitute for the pulp and paper industry, which is regarded as one of the most polluting due to its high cellulose and low lignin content (Balda *et al.* 2021).

5. Handmade bag

The preparation of handmade bags from banana pseudostem is considered a sustainable approach for agricultural waste utilization and rural entrepreneurship development. Banana fibre bags are lightweight, biodegradable, reusable, and environmentally safe alternatives to plastic bags. Handmade bags prepared from banana pseudostem are eco-friendly, biodegradable, reusable, and sustainable. These bags help reduce plastic pollution and provide additional income opportunities to farmers, women self-help groups, and rural artisans. The ecofriendly bag is shown in Fig. 15.

Fig. 15: Ecofriendly Bag

Due to increasing consumer awareness regarding sustainable products, banana fibre bags are gaining popularity in domestic and international handicraft markets Subagyo and Chafidz (2020).

6. Textile

Fig. 16: Textile application

The fiber of banana pseudostem is isolated and used for the processing of curtains, cloth fiber, and

cushion cover (Vigneswaran *et al.* 2015). The textile application from banana pseudostem is shown in Fig. 16.

7. Biodegradable Sheets and Wrapping Material

Fig. 17: Biodegradable Sheets and Wrapping Material

Banana pseudostem packaging materials are lightweight, biodegradable, renewable, and environmentally safe. These materials decompose naturally without causing pollution and help reduce the usage of plastic packaging. In addition, the utilization of banana agricultural waste provides additional income opportunities for farmers and rural industries. The biodegradable sheets and Wrapping material from banana pseudostem is shown in Fig. 17. Due to their eco-friendly nature, banana fibre packaging materials are increasingly used for food packaging, gift wrapping, fruit trays, disposable containers, and protective packaging applications (Vinay *et al.* 2024).

The Utilization of Banana Pseudostem Powder in Dairy Products such as Shrikhand, Paneer and Cheese given in the Table 3.

Table 3: Utilization of Banana Pseudostem Powder in Dairy Products such as Shrikhand, Paneer and Cheese

Sl. No.	Dairy Products	Application	Reference
1	Shrikhand	• The dietary fiber present in pseudostem powder increases the viscosity and water retention ability of shrikhand, resulting in improved body and texture. Fiber also acts as a stabilizing agent that minimizes whey separation during storage.	Aneja *et al.* 2002
		• Ramchandran *et al.* (2004) reported that incorporation of approximately 2–5% banana pseudostem powder into shrikhand improves nutritional composition without significantly affecting sensory quality. The product becomes rich in dietary fiber and minerals while maintaining acceptable flavor, color, texture, and overall acceptability.	Ramchandran *et al.* 2004
2	Paneer	• Paneer is a heat and acid coagulated dairy product widely consumed in India. It is rich in milk proteins and fat; however, it lacks dietary fiber because milk naturally does not contain fiber. Incorporation of banana pseudostem powder into paneer can significantly enhance its nutritional and therapeutic value.	Mohapatra *et al.* 2010
		• The addition of 1–3% banana pseudostem powder produces paneer with improved nutritional profile and acceptable sensory properties. The developed functional paneer exhibits increased fiber and mineral content, particularly potassium and calcium. Such fortified paneer products can be beneficial for individuals suffering from constipation, obesity, diabetes, and cardiovascular disorders due to the therapeutic properties associated with dietary fiber.	Padam *et al.* 2014
3	Cheese	• Addition of pseudostem powder enhances dietary fiber content and improves the nutraceutical properties of cheese. The bioactive compounds present in banana pseudostem, including polyphenols and flavonoids, contribute antioxidant activity which may help reduce oxidative damage in the product. Furthermore, fiber enrichment may improve digestive health and support beneficial intestinal microflora.	Singh *et al.* 2016
		• Functional properties of banana pseudostem powder, particularly water absorption and moisture retention, influence cheese texture and rheological characteristics. Small quantities of powder improve product consistency and spreadability, whereas excessive addition may lead to harder texture and slight color changes. Therefore, optimization of incorporation level is essential to maintain sensory quality.	Aneja *et al.* 2002

Table 4: Nutraceutical Composition of Banana Pseudostem

Sl. No.	Bioactive/Nutraceutical Component	Major Compound	Functional Role	Reference
1	Dietary Fiber	Cellulose, hemicellulose, lignin	Improves gastrointestinal function	Emaga *et al.* 2008
2.	Soluble Fiber	Pectin and gums	Water absorption and gel formation	Mohapatra *et al.* 2010
3	Insoluble fiber	Cellulose and lignin	Adds bulk to stool	Mohapatra *et al.* 2010
4	Phenolic compound	Gallic acid, tannins	Antioxidant activity	Someya *et al.* 2002
5	Flavonoids	Catechin, Quercetin	Free radical scavenging	Pereira and Maraschin, 2015
6	Vitamin B6	Pyridoxin	Enzyme metabolism	Kumar *et al.* 2026
7	Antioxidant Enzymes	Polyphenol oxidase	Neutralizes reactive oxygen species	Someya *et al.* 2002
8	Low Fat Content	Lipids	Low calorie food	Pereira and Maraschin, 2015
9	Minerals Content	Mineral nutrient	Electrolyte balance, Bone metabolism	Mohapatra *et al.* 2010
10	Bioactive phytochemicals	Polyphenols and Sterols	Functional food activity	Vijayakumar *et al.* 2021
11	Natural Sugars	Glucose, fructose	Energy source	Kowsalya *et al.* 2016

Table 4 shows the nutraceutical composition of banana psedostem.

Soluble and Insoluble Fiber in Banana Pseudostem

Banana pseudostem is an important agricultural by-product rich in dietary fiber and bioactive compounds. The dietary fiber present in banana pseudostem is mainly classified into two forms has soluble dietary fiber (SDF) and insoluble dietary fiber (IDF). Both types of fiber play significant roles in human nutrition and functional food development (Bhaskar *et al.* 2012).

Soluble dietary fiber is present in smaller quantities compared to insoluble fiber but possesses significant physiological benefits. Soluble fiber dissolves partially in water and forms a viscous gel-like substance in the digestive tract. This property helps in lowering blood cholesterol, regulating blood glucose levels, and improving gut health through fermentation by intestinal microbiota (Shivashankar *et al.* 2006).

Banana pseudostem soluble fiber contains pectic substances, gums, and other non-cellulosic polysaccharides that contribute to water-holding and antioxidant properties. Research on banana pseudostem and related banana plant parts demonstrated that soluble fiber exhibits good hydration, adsorption, and antioxidant capacities, making it suitable for functional food formulations (Badanayak *et al.* 2023).

Insoluble dietary fiber is the major fraction found in banana pseudostem. It mainly consists of cellulose, hemicellulose, and lignin. These components are structural polysaccharides that provide rigidity to the plant tissue. Insoluble fiber does not dissolve in water and helps in increasing fecal bulk, improving bowel movement, and preventing constipation. Due to its high cellulose and lignin content, banana pseudostem has gained attention as a natural source of functional fiber for food and nutraceutical applications. Studies reported that lignocellulosic materials constitute nearly 60–85% of the dry weight of banana pseudostem, with cellulose being the dominant component (Khoozani *et al.* 2011).

The balance between soluble and insoluble fiber makes banana pseudostem a valuable ingredient for health-promoting food products. Insoluble fiber mainly supports digestive regularity, whereas soluble fiber contributes to metabolic health and prebiotic effects. Because of these nutritional properties,

banana pseudostem is increasingly utilized in the preparation of dietary fiber powders, bakery products, beverages, and nutraceutical supplements. Additionally, its high fiber content supports the development of low-calorie and high-fiber functional foods (Cordeiro *et al.* 2012).

Therapeutic value

The banana pseudo-stem sap has the potential to be a good source of bioactive chemicals with a variety of pharmacologically significant qualities beyond antioxidant, antibacterial, and anticancer activities, according to the results of the current study. The presence of epimedin A, dihydrorescinnamine, and rescinnamine derivatives may be responsible for these bioactive qualities. With the potential for their use in herbal cosmeceutical and nutraceutical formulations, our study serves as a model for opening up metabolomic studies of banana sap in its non-oxidized state and valorizing what is now considered a waste product (Gupta *et al.* 2022).

The pseudostem exhibits notable pharmacological properties, including antioxidant, anti-inflammatory, antimicrobial, and anti-urolithiatic effects. These properties make it potentially beneficial for managing chronic illnesses such as cancer, diabetes, cardiovascular diseases, and kidney stones. The high fiber content of the pseudostem further enhances its potential as a natural remedy for metabolic and digestive health conditions (Govindan *et al.* 2025). The Banana pseudostem have been shown to contain a range of phytochemicals, including saponins, terpenoids, steroids, anthocyanins, fatty acids, tannins, phenols, and alkaloids (Kendole *et al.* 2022). The phytochemical constituents were: Alkaloid (8.16%), Flavonoids (4.02%), Saponin (3.5%), Phenols (5.57 mg/kg, tannin (9.13%), Oxalate (0.162%), Haemagglutinin (1.8814 mg/kg), Phytate (1.2967 mg/kg), and Cardiac Glycoside (1.6%). Gallic acid molecules and glucose combine to form tannic acid. It is astringent, antibacterial, and anti-enzymatic (Onyema *et al.* 2016).

Banana pseudostem also shows promising anti-urolithiatic activity, particularly in the prevention and management of kidney stones. Traditional medicine systems have long recommended pseudostem juice for urinary disorders. Scientific reviews suggest that the high potassium and fiber content help improve urinary flow, reduce calcium crystal deposition, and assist in detoxification of the urinary tract. These effects contribute to kidney health and may reduce the recurrence of renal calculi Saravanan and Aradhya, (2011).

Another important therapeutic property is its cardiovascular protective effect. Banana pseudostem is rich in potassium and low in sodium, which helps regulate blood pressure and maintain electrolyte balance. Recent studies indicated that regular consumption of pseudostem-based products may aid in reducing hypertension and improving cardiovascular function. The high fiber content additionally contributes to lowering serum cholesterol levels and reducing the risk of heart diseases Jamuna and Nandini (2014). Furthermore, banana pseudostem contributes to digestive health because of its exceptionally high dietary fiber content. The fiber improves bowel movement, prevents constipation, enhances gut microbiota, and promotes satiety, which may assist in weight management. The detoxifying and digestive benefits make pseudostem juice and fiber-enriched products increasingly popular as health foods (Devi *et al.* 2025).

Method Used for Preparation of Vermicompost from Banana Pseudostem

Make small pieces (5-10 cm) of banana pseudostem and dry it under sunlight. Put the dried pieces of banana pseudostem in plastic bed (size 3.0 m x 1.0 m x 0.6 m LWH). Sprinkle water on banana pseudostem (waste) to get it wetted. After one week, mix the Anubhav Biodegradable Bacterial Consortium (ABBC) 100 ml/ 10 L water & spread on materials kept in the bed. Similarly, spread the slurry prepared by mixing 5 kg cow dung in 10 L of water. After that, release 500 g earthworms (*Eudrilus eugeniae*) in 100 kg pieces of banana pseudostem in plastic bed. Cover the bed with old gunny bags till the compost is ready by sprinkling the water. Sprinkling of water is

discontinued when compost is ready. Vermicompost is collected after 8-10 days; thereafter sieve the material for use. The vermicompost will be ready within 70 to 75 days (Parmar *et al.* 2019).

CONCLUSION

The utilization of banana pseudostem can substantially improve farmers' income and promote rural entrepreneurship. Since banana cultivation generates large quantities of pseudostem residue annually, its systematic utilization can create opportunities for small-scale industries, self-help groups, fibre extraction units, food processing enterprises, and biodegradable product manufacturing sectors. Thus, banana pseudostem serves as an important component in achieving sustainable agriculture and circular bioeconomy models.

The tender central core of banana pseudostem and extracted juice are increasingly utilized for the preparation of functional beverages, squash, syrup, ready-to-drink juice, candy, pickle, jam, bakery products, cookies, bread, flour, and nutraceutical powders. These products not only improve the economic utilization of banana waste but also enhance nutritional diversification in food industries. Banana fibre extracted from pseudostem is biodegradable, renewable, lightweight, and eco-friendly, making it a sustainable alternative to synthetic fibres. Scientific advancements have enabled its application in textile manufacturing, handicrafts, ropes, mats, geotextiles, paper production, fibreboards, polymer composites, biodegradable packaging materials, and biofilm development. Therefore, banana pseudostem utilization represents an innovative and sustainable strategy for improving human health, environmental sustainability, and industrial development simultaneously.

GENERATIVE AI DECLARATION

The author(s) confirm that there was no use of artificial intelligence (AI)-assisted technology for assisting in the writing or editing of the manuscript, and no images were manipulated using AI. The authors developed and verified all scientific content, data analysis, interpretation of results, and conclusions. The authors take full responsibility for the accuracy, integrity, and originality of the work presented, and no AI tool was listed as an author.

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