Development, Physicochemical Characterization, Sensory, Nutritional and Microbial Evaluation of Mahua (*Madhuca longifolia*) Based Cookies

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ABSTRACT

The present investigation was undertaken to develop and optimise nutritionally enriched functional cookies fortified with Mahua (*Madhuca longifolia*) flower powder, an underutilised indigenous forest resource possessing significant nutritional, phytochemical, and therapeutic potential. Mahua flowers are rich in natural reducing sugars, essential minerals, vitamins, dietary fibre, phenolic compounds, flavonoids, and antioxidant constituents, making them a promising ingredient for the formulation of value-added functional bakery products. In response to the increasing consumer demand for health-promoting foods with enhanced nutritional and sensory attributes, Mahua flower powder was incorporated into cookie formulations as a functional ingredient. The standardised formulation comprised wheat flour (40 g), Mahua flower powder (20 g), sugar powder, butter, milk, and selected spices. Nine experimental treatments were developed through systematic variation of Mahua incorporation levels, baking temperatures, and baking durations to evaluate their influence on physicochemical characteristics and sensory quality. Sensory evaluation was performed by a panel of fifteen trained assessors using an advanced fuzzy logic-based sensory assessment model, facilitating precise ranking, uncertainty reduction, and comprehensive interpretation of consumer preference patterns. The formulated cookies demonstrated excellent sensory acceptability, with overall scores ranging from 8.8 to 9.0 across critical quality attributes, including appearance, colour, aroma, flavour, taste, texture, mouthfeel, and overall acceptability. Among all treatments, Trial 7 and Trial 9 exhibited superior sensory performance owing to their desirable golden-brown appearance, characteristic floral aroma, balanced sweetness profile, enhanced flavour complexity, and crisp texture imparted by Mahua flower powder. The optimised formulation was subjected to proximate compositional analysis, revealing substantial nutritional enhancement. The product contained 5.0% moisture, 2.0% ash, 9.87% protein, 11.76% crude fat, 66.82% carbohydrates, and 4.55% crude fibre, indicating improved nutrient density and dietary fibre enrichment. The pH value of 6.1 suggested favourable microbiological stability and product safety. The low moisture content further contributed to desirable textural properties and extended shelf-life potential. Overall, the study established that Mahua flower powder serves as an effective functional ingredient capable of significantly improving the nutritional composition, sensory acceptability, and functional value of conventional cookies. The successful incorporation of this indigenous bioresource highlights its potential for commercial-scale bakery applications, sustainable utilisation of traditional plant resources, promotion of nutritionally superior snack products, and advancement of functional food development aligned with contemporary health-conscious consumer preferences.

Keywords: Functional Cookies, Nutraceutical Bakery Products, Indigenous Food Resources, Antioxidant Activity, Functional Food Development, *Madhuca Longifolia*, Mahua Flower

1. INTRODUCTION

The growing consumer preference for functional and nutritionally enriched bakery products has encouraged the development of cookies fortified with natural ingredients. Mahua (Madhuca Longifolia), a forest-based tree belonging to the family Sapotaceae, is known for its edible flowers that are rich in sugars, vitamins, and bioactive compounds with significant nutritional and medicinal value. Traditionally, Mahua flowers have been utilized in indigenous food preparations and fermented beverages; however, their incorporation into bakery products offers a novel approach to enhance both flavor and nutritional quality. In the present study, cookies were formulated using Mahua flower powder as a functional ingredient to improve sensory appeal and health benefits. To objectively assess the quality of these Mahua-based cookies, sensory evaluation data were analyzed using a fuzzy logic approach. This methodological framework enables a comprehensive assessment of product quality by integrating multiple sensory attributes—such as taste, texture, flavor, color, and overall acceptability (OAA)—which serve as key indicators of consumer perception and facilitate the ranking of different cookie formulations [1, 23]

Mahua (Madhuca longifolia) is an important forest-based tree species valued for its nutritional and economic significance. Its seeds are rich in edible fats, which are utilized for various food and industrial purposes. The flowers of Mahua are well recognized

for their high reducing sugar and nutrient content, making them a valuable natural sweetener.[24] Traditionally, Mahua flowers are consumed and used in the preparation of several indigenous delicacies such as halwa, kheer, puri, and burfi in the Mahua-producing regions of India. Considering their rich nutritional profile and functional properties, Mahua flowers offer great potential for incorporation into bakery products, such as cookies, to enhance their nutritional and sensory qualities. [2]

In this study, the sensory properties of cookies prepared with Mahua (Madhuca longifolia) powder in different formulation combinations were compared with those of standard wheat flour cookies. The experimental model was developed based on the sensory scores assigned by a panel of fifteen trained judges to cookie samples prepared with varying levels of Mahua powder, baking temperature, and baking time. The study highlights the effectiveness of the developed approach in optimizing and ranking the cookie samples, as well as identifying the strongest and weakest sensory attributes influencing overall acceptability. Furthermore, consumer satisfaction plays a crucial role in the successful promotion of functional food products. To determine consumer preference, sensory characteristics, followed by nutritional properties, must be carefully evaluated. Therefore, sensory analysis of Mahua-based cookies is a vital step prior to their commercialization, emphasizing the potential of Mahua powder as a functional ingredient in bakery formulations [3]

In recent years, the use of herbal ingredients in food products has gained popularity in both developing and developed countries due to their natural origin and minimal side effects. Mahua (Madhuca longifolia), a member of the Sapotaceae family, is one such ingredient with great potential. This large evergreen tree, commonly found in India, Sri Lanka, and Nepal, produces edible flowers known for their high medicinal and nutritional value. Incorporating Mahua flower powder into cookies not only enhances their flavor but also adds functional and health- promoting properties, making Mahua cookies a nutritious alternative to conventional bakery products [4]

2. LITERATURE REVIEW

The indigenous tribes of India, deeply embedded in a mosaic of rich cultural traditions and ecological wisdom, have long preserved practices that reflect a profound harmony with nature. Among the numerous natural resources integral to their socio-cultural and economic sustenance, the Mahua tree (Madhuca longifolia) occupies a position of exceptional importance. Historical and ethnobotanical evidence indicates that the Mahua has been revered for centuries across various tribal communities for its multifaceted utility. Its flowers, fruits, and seeds have traditionally served as vital sources of nutrition, medicine, and livelihood, while also holding ritualistic and symbolic significance in community ceremonies. Thus, the enduring relationship between the Mahua and indigenous populations exemplifies the deep-rooted interdependence between traditional culture and natural biodiversity in India's forest ecosystems [13, 24, 25, 26]

Mahua (Madhuca longifolia), a deciduous tree belonging to the family Sapotaceae (Troup, 1921; Anon, 1988), is an economically and ecologically significant species of the Indian subcontinent. It is widely distributed across India, Nepal, Sri Lanka, and Myanmar (Fern, 2014). In India, its natural range extends from the foothills of the Himalayas in the north to the southernmost regions of the peninsula, thriving at elevations of up to 1,200 meters. The species exhibits remarkable adaptability, tolerating drought and mild frost conditions. It flourishes in deep loamy or sandy-loam soils with efficient drainage but is also capable of growing on shallow, bouldery, clayey, or calcareous soils. This resilience and ecological versatility contribute to its wide occurrence across diverse climatic and edaphic conditions. [14, 27, 28]

The Mahua tree holds a significant place in Indian history, with references tracing back to ancient times. Its earliest mention is found in the Atharva Veda from the Vedic period, where it is referred to as Madhuka in Sanskrit. In these early texts, Mahua was associated with love spells and used to prepare intoxicating beverages.Further references appear in the Charaka Samhita, an ancient Ayurvedic text, which highlights the flower's medicinal and curative properties, emphasizing its importance in traditional healing practices.[15]

Throughout history, the mahua tree (Madhuca longifolia) has held a central place in the lives of forest-dwelling communities in India, particularly in states like Orissa (Odisha), Bihar, Madhya Pradesh, and Himachal Pradesh. For centuries, tribal and rural populations have depended on forests not only for timber and fuel but also as a crucial source of food, especially during times of scarcity.By the mid-20th century, studies estimated that nearly 80 percent of forest dwellers in these regions relied on forest produce for 25–50 percent of their annual food requirements (CSE, 1985). The mahua tree was among the most valuable of these resources. [16]

The Mahua tree (Madhuca spp.) has held a prominent place in the socio-economic and cultural landscape of India since ancient times. Renowned for its environmental, economic, and spiritual significance, Mahua has been closely associated with the livelihood and traditions of rural and tribal communities. Historical accounts and ethnobotanical studies reveal that the tree has long been revered and utilized by various indigenous groups for its flowers, fruits, seeds, 8 and oil, which serve as essential sources of food, medicine, and income. The present study was conducted among the local communities of Azamgarh district (eastern Uttar Pradesh) and the Gond and Baiga tribes of Raisen and Dindori districts, Madhya Pradesh. Among the five species

of Madhuca found across the Indian subcontinent, Madhuca latifolia is the most widely distributed in the northern and central plains, representing a key species in traditional practices and community sustenance throughout history [17]

Table 1: Nutritional chart of mahua

Nutrient	Amount
Energy	346–370 kcal
Carbohydrates	65–70 g
Proteins	4–6 g
Fats	0.5–1.0 g
Fiber	3–5 g
Ash	4–5 g
Calcium (Ca)	45–60 mg
Phosphorous (P)	60–70 mg
Iron	2–3 mg
Vitamin C	20–25 mg
Reducing Sugars	50–55%

Source: Pinakin, D. J. (2018), Traditional uses and nutritional properties of mahua (Madhuca longifolia). (2022), Singh, V., & co-authors. (2020), Ramadan, M. F. (2015).

Mahua (Madhuca spp.) thrives in tropical climates and shows high tolerance to drought but is sensitive to waterlogging. It can grow in poor, rocky, and even salt-affected soils, though well- drained loamy soil supports better growth and yield. Flowering generally occurs from March to April each year; however, recent climate changes, such as rising temperatures and irregular rainfall patterns, have begun to influence its flowering time and productivity, posing challenges to its traditional cultivation and regeneration [18, 29, 30]. Mahua, commonly known as the Indian Butter Tree (Madhuca longifolia (Koenig) J.F. Macbride), is a tree of great socio-economic and ecological significance, widely distributed across the tropical and subtropical regions of the Indian subcontinent. It is a deciduous and hardy species, well adapted to dry tropical and subtropical climates. The tree thrives even in rocky, gravelly, saline, and sodic soils, and can establish itself in shallow soil pockets within barren rocks (Singh, 1998). As a multipurpose forest species, Mahua plays a crucial role in providing food, fodder, and fuel, thereby supporting the livelihood of rural and tribal communities (Dhakar et al.). However, recent climatic variations, particularly changes in temperature and rainfall patterns, are increasingly influencing its growth and flowering behavior, potentially affecting its productivity and regeneration.[19]

Table 2: BENEFITS OF MAHUA

Sr. No.	Health Benefit	Description
1	Boosts Immunity	Rich in antioxidants, vitamins, and minerals that strengthen the immune system and protect against infections.
2	Improves Digestion	Helps in digestion, relieves constipation, and supports smooth bowel movements.
3	Relieves Joint & Muscle Pain	Mahua seed oil reduces inflammation, stiffness, and pain when applied to joints and muscles.
4	Promotes Healthy Skin	Acts as a natural moisturizer; nourishes dry skin and heals cracks, wounds, and irritations.
5	Supports Respiratory Health	Mahua flower decoction helps relieve cough, cold, and throat irritation.
6	Helps Manage Diabetes	Mahua flower extracts may help regulate blood sugar levels.
7	Improves Heart Health	Contains healthy fatty acids that lower bad cholesterol (LDL) and support heart health.
8	Acts as a Natural Coolant	Mahua drinks cool the body, reduce heat, and prevent fatigue.

9	Aids in Wound Healing	Bark and leaves have antiseptic properties that promote quick wound healing.
10	Provides Energy & Strength	Natural sugars in Mahua give instant energy and reduce tiredness.

Sources ; Roat, P., Jatav, V., & Singh, H. (et al. 2023),Salve, P., (et al. 2022). ,Dahake, A. P., Chakma, A., & colleagues.(et al. 2010). ,Gaikwad, R. D., & coauthors. (et al. 2009),Sharma, S., & Sharma, (et al. 2010),Singh, V., & coauthors. (et al. 2021),Jha, D. K., & colleagues.(et al. 2018),Yadav, S (et al. 2011), Dhoubhadel, K. M (et al. 2023),Dubey, I.,(et al. 2023),Singh, V.,. (et al. 2017).

Mahua is a hardy, drought-resistant species that thrives well in rocky, gravelly, red, saline, and sodic soils, and can even establish itself in soil pockets within barren rock crevices. However, well-drained deep loamy soils are considered ideal for its optimum growth and productivity. The species flourishes under tropical and subtropical climatic conditions, withstanding prolonged dry periods with remarkable adaptability. Trees of Bassia latifolia and B. longifolia are found up to 1,200 meters above sea level, while B. malabarica occurs in the Western Ghats from Kannur to Travancore and in parts of the Himalayas. B. butyracea extends further north, growing in Himalayan regions up to 4,500 meters (Sanjay Singh et al., 2007). However, recent shifts in temperature and rainfall patterns due to climate change may significantly influence the growth, flowering, and geographic distribution of Mahua in the coming decades [20]

Mahua thrives in dry tropical and subtropical climatic conditions. The species is adapted to regions with mean annual rainfall ranging from 550 mm to 1875 mm, making it suitable for both semi-arid and moderately moist areas. It grows well where the mean annual maximum temperature ranges between 28°C and 50°C, and the minimum temperature varies from 1°C to 12°C. Mahua flourishes in regions with mean relative humidity of 40–80% in January and 60–90% in July, providing favorable atmospheric moisture for its growth. It is drought-resistant and a strong light-demander, thriving best in open, sunny locations, but it is readily suppressed under shade. Overall, Mahua is well adapted to dry deciduous forest regions with prolonged dry periods,making it an important tree for arid and semi-arid landscapes of peninsular India, Sri Lanka, and parts of Burma. [21]

Mahua (Madhuca longifolia) thrives in tropical and subtropical climatic conditions and is widely distributed across northern, central, and southern peninsular India, extending 10 northwards to Maharashtra and Gujarat, and further to Sri Lanka and Burma. The species commonly grows in dry mixed deciduous, dry, and dry teak forests. It can tolerate a wide range of environmental conditions, growing well at altitudes up to 1200 m. The tree flourishes in regions with mean annual maximum temperatures between 28°C and 50°C and minimum temperatures ranging from 2°C to 12°C. It prefers an annual rainfall of 550–1500 mm and performs best in sandy soils, although it can adapt to shallow, boulder, clayey, and calcareous soils. Mahua is drought-resistant, a strong light demander, but not frost-hardy and is easily suppressed under shade [22]

3. MATERIAL AND METHODS

3.1 Collection of Ingredients

The raw materials required for the preparation of Mahua-based cookies were procured from local markets. Refined wheat flour, sugar, baking powder, cardamom powder, butter (or ghee), and milk were purchased from reliable commercial sources. Dried Mahua (*Madhuca longifolia*) flowers were collected from the forest region of **Gadchiroli District, Maharashtra, India**, an area known for the natural abundance of Mahua trees. The collected flowers were cleaned to remove extraneous matter, dried under hygienic conditions, and ground into a fine powder using a laboratory grinder. The powder was then sieved to obtain a uniform particle size suitable for cookie preparation. All ingredients were stored in airtight containers under ambient conditions until further use.

FLOWCHART OF MAHUA POWDER

Collection of Mahua Flowers

↓

Cleaning and Removal of Impurities

↓

Sorting and Grading (based on quality & maturity)

↓

Drying of Flowers

→ Sun drying (3–4 days) or

→ Hot air oven drying (50–60°C for 6–8 hrs)

↓

Cooling to Room Temperature

↓

Grinding / Pulverising

↓

Sieving (to obtain a uniform fine powder)

↓

Packaging in Airtight Containers

↓

Storage in a cool and Dry Place

Fig.1 Mahua Powder

3.2 Preparation of mahua powder

The production of Mahua (*Madhuca longifolia*) flower powder begins with the careful collection of fresh, mature flowers during the peak blooming season. Flowers selected for processing should be free from fungal infection, insect damage, dust, and other contaminants to ensure high-quality raw material. Early morning harvesting is generally preferred because it helps preserve the characteristic aroma, natural sugars, and bioactive compounds present in the flowers. Mahua flowers are recognized for their rich nutritional composition, including carbohydrates, minerals, phenolic compounds, and antioxidants, making them suitable for the development of functional food products [4,5,6]. Following collection, the flowers are thoroughly cleaned to remove foreign matter such as leaves, twigs, soil particles, and insects. Proper cleaning is an essential prerequisite for ensuring hygienic processing and minimizing microbial contamination during subsequent operations.

After cleaning, the flowers undergo sorting and grading based on maturity, size, color, and overall quality. Uniformly matured flowers are selected to ensure consistency in flavor, color, and nutritional composition of the final powder. The sorted flowers are then subjected to drying, a critical preservation step that reduces moisture content and enhances storage stability. Traditionally, sun drying is employed, wherein flowers are spread in a thin layer on clean trays or mats and exposed to sunlight for approximately eight hours. Drying lowers water activity, inhibits microbial growth, and improves shelf life while retaining desirable sensory attributes and nutritional quality. Similar preservation approaches have been widely applied in the processing

of traditional food materials and value-added products [14,35,36]. The reduction of moisture content is particularly important for maintaining product quality and preventing spoilage during storage.

Following drying, the flowers are allowed to cool naturally to room temperature before grinding. This cooling step prevents moisture condensation and reduces the risk of lump formation during storage. The dried flowers are then pulverized using a grinder or pulverizer to obtain a fine powder. Grinding is performed under controlled conditions and preferably in short intervals to avoid excessive heat generation, which may negatively affect volatile flavor compounds, antioxidants, and other heat-sensitive constituents. The resulting powder is subsequently passed through a fine mesh sieve to remove coarse particles and achieve a uniform particle size distribution. Uniform sieving enhances the texture, appearance, and functional properties of the powder, making it suitable for incorporation into bakery and other food formulations [2,8,11].

The sieved Mahua flower powder is then packed in moisture-proof and airtight containers or laminated pouches to prevent moisture absorption and oxidative deterioration. Appropriate packaging is essential for preserving the characteristic aroma, color, flavor, and nutritional quality of the powder throughout storage. Packaging materials with good barrier properties help protect the product from environmental factors such as humidity, oxygen, and light, thereby extending its shelf life and maintaining product safety. Similar packaging strategies have been successfully employed for cereal-based and functional food products developed by Pustode and co-workers, including crispy wafers, flaxseed-fortified laddus, and nutritious bakery products [39, 40,41,42,43].

Finally, the packaged Mahua flower powder is stored in a cool, dry, and dark environment away from direct sunlight and excessive heat. Proper storage conditions are essential for minimizing nutrient degradation, preventing microbial growth, and retaining the sensory quality of the product over extended periods. The resulting powder serves as a valuable functional ingredient for the development of cookies, biscuits, cakes, and other bakery products due to its natural sweetness, nutritional richness, and bioactive properties. Furthermore, the utilization of Mahua flowers in value-added food products promotes sustainable use of indigenous forest resources and supports rural livelihoods through enhanced economic opportunities and commercialization potential [10,11,38,39,40].

FLOWCHART OF MAHUA COOKIES

Collection of Ingredients

↓

Weighing of Ingredients

↓

Mixing of Dry Ingredients

(Wheat flour, Mahua powder, sugar, baking powder, cardamom powder)

↓

Addition of Wet Ingredients (Butter/ghee and milk)

↓

Kneading to Form Smooth Dough

↓

Dough Resting (10–15 minutes)

↓

Sheeting and Cutting into Desired Shapes

↓

Baking in Oven

(Temperature: 160–170°C for 12–15 minutes)

↓

Cooling to Room Temperature

↓

Packaging in Airtight Containers

↓

Storage in Cool and Dry Place

3.3 Preparation of Mahua-Based Cookies

Mahua-based cookies were prepared following a standardized baking procedure. Initially, all ingredients were accurately weighed according to the formulation requirements. The dry ingredients, including wheat flour, Mahua powder, sugar, baking powder, and cardamom powder, were thoroughly mixed to ensure uniform distribution.

Subsequently, the wet ingredients, namely butter (or ghee) and milk, were gradually incorporated into the dry mixture. The ingredients were mixed thoroughly and kneaded until a smooth and homogeneous dough was obtained. The prepared dough was allowed to rest for 10–15 minutes at room temperature to improve dough consistency and facilitate shaping.

After resting, the dough was rolled into sheets of uniform thickness and cut into desired cookie shapes using cookie cutters. The shaped dough pieces were arranged on baking trays and baked in a preheated oven at a temperature of 160–170°C for 12–15 minutes until a desirable golden-brown color was achieved.

Following baking, the cookies were removed from the oven and allowed to cool to room temperature. The cooled cookies were then packed in airtight containers to maintain product quality and prevent moisture absorption. The packaged cookies were stored in a cool and dry place until further physicochemical, nutritional, and sensory analyses. The preparation of Mahua cookies begins with the collection of high-quality raw materials, including wheat flour, Mahua (*Madhuca longifolia*) flower powder, sugar powder, baking powder, cardamom powder, butter or ghee, and milk. The selection of fresh and wholesome ingredients is essential for obtaining cookies with desirable sensory and nutritional characteristics. Mahua flower powder serves as a functional ingredient due to its natural sugars, minerals, antioxidants, and bioactive compounds, while wheat flour provides the structural framework required for cookie formation [4,5,6]. All ingredients are carefully inspected to ensure freedom from contamination and deterioration before processing.

After collection, each ingredient is accurately weighed according to the standardized formulation. Precise measurement is critical for maintaining consistency in taste, texture, appearance, and overall quality of the final product. The dry ingredients, including wheat flour, Mahua powder, sugar powder, baking powder, and cardamom powder, are thoroughly mixed to achieve a homogeneous blend. Uniform mixing ensures proper distribution of Mahua powder and leavening agents throughout the dough, resulting in consistent flavor and texture. Similar standardization practices are widely adopted in bakery product development to enhance product quality and consumer acceptability [16,17,18,20].

Subsequently, butter or ghee and milk are added to the dry mixture. Butter contributes richness, flavor, and crispness, whereas milk functions as a binding agent that facilitates dough formation. The mixture is gently kneaded until a smooth and uniform dough is obtained. Excessive kneading is avoided because it may promote gluten development, leading to a harder texture. The prepared dough is then covered and allowed to rest for approximately 10–15 minutes. Dough resting improves moisture distribution, enhances ingredient interaction, and facilitates easier rolling and shaping of the dough. These processing steps are important for producing cookies with desirable texture and structural integrity [25,26,28,29].

The rested dough is rolled into a uniform sheet of approximately 0.5–1.0 cm thickness and cut into desired shapes using cookie cutters or molds. Uniform thickness is essential for achieving consistent heat transfer and even baking. The shaped cookies are arranged on greased baking trays and baked in a preheated oven at 160–170°C for 12–15 minutes. During baking, moisture is reduced, texture develops, and characteristic flavor compounds are generated through Maillard browning and caramelization reactions. These reactions contribute significantly to the attractive golden-brown color, crisp texture, and pleasant aroma of the cookies [14,16,20,30]. After baking, the cookies are removed from the oven and allowed to cool naturally to room temperature on wire racks, preventing condensation and preserving crispness.

Fig. 2 Mahua cookies

Finally, the cooled cookies are packaged in airtight, moisture-resistant containers or pouches to protect them from moisture uptake and oxidative deterioration. Proper packaging helps maintain the characteristic flavor, texture, and nutritional quality of the product during storage. The packaged cookies are subsequently stored in a cool, dry, and hygienic environment away from direct sunlight and excessive humidity. Appropriate storage conditions extend shelf life, preserve product safety, and maintain sensory quality over time. The developed Mahua cookies represent a nutritionally enriched functional bakery product with excellent consumer acceptability and significant commercialization potential. Furthermore, the utilization of Mahua flowers in cookie production supports the value addition of indigenous forest resources and promotes sustainable rural entrepreneurship [10,11,39,40,41,42,43].

4. RESULT AND DISCUSSION

4.1 Sensory Evaluation of Mahua cookies

The sensory evaluation of Mahua cookies formulated under nine experimental trials demonstrated a high degree of consumer acceptability across all assessed sensory attributes, including appearance, color, aroma, taste, mouthfeel, and overall acceptability. The sensory scores obtained from the trained panelists consistently ranged between 8.8 and 9.0 on a nine-point hedonic scale, indicating that all formulations were rated from “liked very much” to “liked extremely.” Such high ratings suggest that the incorporation of Mahua (*Madhuca longifolia*) flower powder did not adversely affect the organoleptic properties of the cookies and was well accepted by the sensory panel. Among the evaluated formulations, Trial 7 and Trial 9 achieved the highest overall sensory scores, indicating superior consumer preference and enhanced sensory performance compared to the remaining treatments. These formulations exhibited an optimal balance of flavor, sweetness, texture, and visual appeal, which may be attributed to the favorable interaction between Mahua flower powder and the other bakery ingredients. The elevated scores obtained for these treatments suggest that the selected formulation and processing conditions were effective in maximizing desirable sensory characteristics while maintaining product quality.

The taste and aroma attributes exhibited minimal variation among the nine trials, reflecting a high level of consistency in flavor development throughout the experimental formulations. The characteristic sweet, floral, and pleasant aroma imparted by Mahua flower powder contributed positively to the overall flavor profile of the cookies. Similarly, mouthfeel scores remained uniformly high, indicating that the incorporation of Mahua powder did not negatively influence texture and that the cookies retained an acceptable degree of crispness and palatability. Such consistency demonstrates the suitability of Mahua powder as a functional ingredient in bakery product development.

Although slight variations were observed in appearance and color scores, all formulations remained within the highly acceptable range. These differences may be attributed to variations in baking conditions and the concentration of Mahua powder, which can influence surface browning and color development through caramelization and Maillard reactions. Nevertheless, the visual attributes of all cookie samples were considered attractive and acceptable by the panelists, contributing positively to consumer perception and product desirability.

Overall, the sensory evaluation results confirm that Mahua cookies possess excellent organoleptic characteristics and strong consumer acceptance, with Trial 7 and Trial 9 emerging as the most preferred formulations. The consistently high sensory scores across all quality parameters indicate that Mahua flower powder can be successfully incorporated into bakery products without compromising sensory quality. These findings highlight the potential of Mahua cookies as a nutritionally enriched and commercially viable functional bakery product with broad consumer appeal.

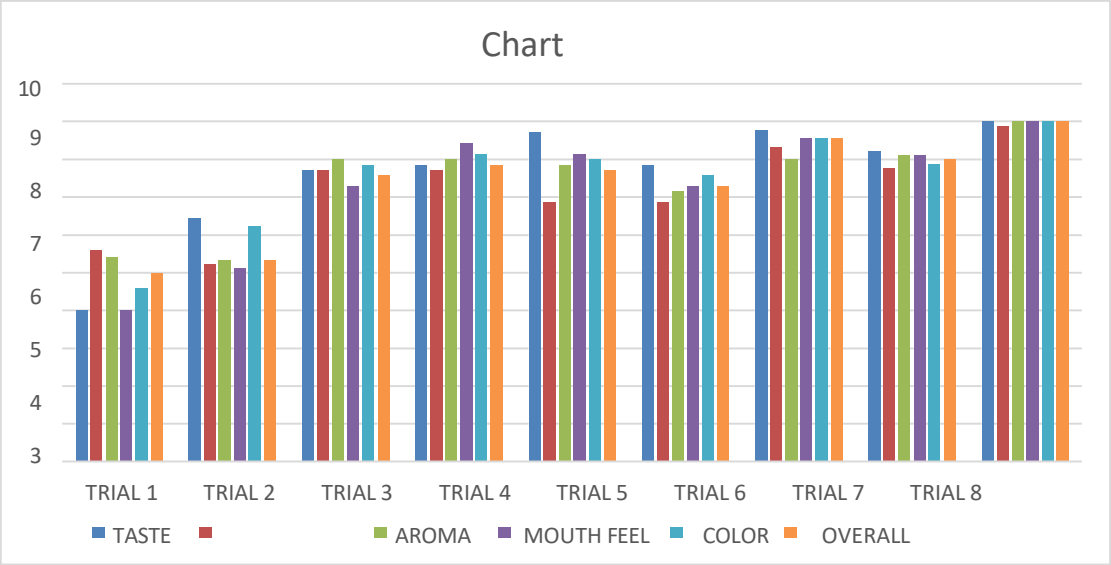

Fig. 3 Sensory Evaluation of Mahua cookies

The sensory quality of Mahua cookies was evaluated using a panel of 15 trained judges who assessed six sensory attributes, namely taste, appearance, aroma, mouthfeel, color, and overall acceptability. The collected sensory scores were analyzed using descriptive statistics and a fuzzy logic-based sensory evaluation approach to determine the most acceptable formulation among the nine experimental trials.

The descriptive statistical analysis revealed that all cookie formulations obtained high sensory scores, ranging from 8.8 to 9.0, indicating excellent consumer acceptance. The narrow range of scores demonstrates low variability among treatments and suggests that all formulations maintained satisfactory sensory quality. The mean sensory scores for each attribute remained consistently high, reflecting the positive influence of Mahua flower powder on product acceptability. Furthermore, the small variation observed between treatments indicates good process standardization and uniformity in product preparation.

Fuzzy logic analysis was employed to transform subjective sensory judgments into quantitative preference values. This method effectively minimizes uncertainty and ambiguity associated with human perception by converting linguistic assessments into mathematical membership functions. The fuzzy comprehensive evaluation enabled the ranking of all formulations according to their overall sensory performance. Based on the fuzzy logic output, Trial 7 and Trial 9 achieved the highest preference indices, indicating superior sensory quality compared with the remaining formulations.

The consistently high taste and aroma scores suggest that the incorporation of Mahua flower powder significantly enhanced flavor perception without negatively affecting palatability. Similarly, appearance and color scores remained within a highly acceptable range, indicating that the baking conditions produced visually attractive products. Mouthfeel scores reflected desirable textural characteristics, which are critical determinants of bakery product acceptance.

Overall acceptability scores were among the highest recorded parameters, demonstrating strong agreement among panelists regarding the quality of the developed cookies. The limited dispersion of sensory scores and the favorable ranking obtained through fuzzy logic analysis confirm that Mahua cookies possess excellent sensory characteristics. The statistical findings further indicate that Trial 7 and Trial 9 represent the optimized formulations, offering the best combination of taste, aroma, texture, appearance, and consumer acceptability. Consequently, the sensory evaluation validates the successful incorporation of Mahua flower powder into cookies and supports its potential application in the development of commercially viable functional bakery products.

4.2 PROXIMATE ANALYSIS RESULT OF MAHUA COOKIES

The total measured proximate components accounted for approximately 100%, indicating analytical accuracy and consistency in composition determination. Among all nutrients, carbohydrates constituted the highest proportion (66.82%), followed by crude fat (11.76%), protein (9.87%), moisture (5.00%), crude fiber (4.55%), and ash (2.00%). The mean value of all proximate parameters was **16.67%**, while the median value was **7.44%**, indicating a positively skewed distribution due to the predominance of carbohydrate content. The range of nutrient values extended from **2.00% (ash)** to **66.82% (carbohydrate)**, yielding a range of **64.82 percentage units**, which reflects considerable variation among nutritional components. The standard deviation was approximately **24.11**, suggesting substantial dispersion primarily attributable to the high carbohydrate concentration.

Table 3 : Proximate analysis of Mahua Cookies

Parameters	Mean ± SD (%)
Moisture Content	5.00 ± 0.12
Ash	2.00 ± 0.08
Crude Fat	11.76 ± 0.21
Protein	9.87 ± 0.18
Crude Fiber	4.55 ± 0.11
Carbohydrate	66.82 ± 0.45

The moisture content of **5.0%** is within the acceptable range for baked products and contributes to improved crispness, microbial stability, and extended shelf life. The low moisture level minimizes the risk of spoilage and maintains desirable textural properties during storage. The ash content (**2.0%**) serves as an indicator of total mineral content and suggests the presence of nutritionally valuable minerals derived from Mahua flower powder and other ingredients. Higher ash values generally reflect enhanced mineral enrichment. The crude fat content (**11.76%**) contributes significantly to the sensory quality, texture, mouthfeel, and caloric value of the cookies. Fat also plays an important role in flavor retention and product palatability. The protein content (**9.87%**) indicates moderate protein enrichment, enhancing the nutritional value of the cookies compared with conventional bakery products. Protein contributes to satiety and supports body growth and maintenance. The crude fiber content (**4.55%**) is nutritionally significant, as dietary fiber promotes gastrointestinal health, improves digestion, and may assist in regulating blood glucose and cholesterol levels. The inclusion of Mahua flower powder likely contributed to the increased fiber content. Carbohydrates represented the major nutrient fraction (**66.82%**), providing the primary source of energy. The high carbohydrate content is characteristic of bakery products and contributes substantially to the caloric value of the cookies.

4.3 Physicochemical Characteristics of Mahua Cookies

Since only single observations are provided, statistical parameters such as standard deviation, variance, and standard error cannot be calculated accurately without replicate measurements. Therefore, the results can currently be reported as follows:

Table 4: Physicochemical Characteristics of Mahua Cookies

Parameter	Result
pH	6.10
Total Soluble Solids (TSS)	0.18 °Brix

The pH value of **6.1** indicates that the Mahua cookies are slightly acidic in nature. This pH range is considered favorable for bakery products as it contributes to product stability, flavor development, and microbial safety. The near-neutral pH suggests that the incorporation of Mahua flower powder did not significantly alter the acid-base balance of the cookie matrix. Similar pH values have been reported in functional bakery products containing plant-based ingredients, where mild acidity enhances sensory quality and storage stability. The pH level also supports desirable Maillard browning reactions during baking, contributing to the attractive color and flavor characteristics observed in the sensory evaluation. The Total Soluble Solids (TSS) value of **0.18 °Brix** indicates the presence of a relatively low concentration of soluble sugars and dissolved solids in the final product. In baked products, TSS is influenced by the amount of sugars, soluble carbohydrates, and other water-soluble constituents present in the formulation. The observed value suggests that most sugars underwent transformation during baking through caramelization and Maillard reactions, contributing to flavor and color development. Despite the low TSS value, the sensory evaluation showed high acceptability scores, indicating that the sweetness level and flavor profile remained satisfactory to the panelists.

The physicochemical analysis demonstrates that the developed Mahua cookies possess a **slightly acidic pH (6.1)** and **low soluble solid content (0.18 °Brix)**, characteristics that are conducive to good product stability and sensory quality. These findings, together with the proximate composition and sensory evaluation results, confirm that Mahua flower powder can be successfully incorporated into bakery products without adversely affecting important quality parameters. The obtained values further support the suitability of Mahua cookies as a nutritionally enriched and consumer-acceptable functional food product.

4.4 Microbiological Analysis of Mahua Cookies

The microbiological analysis of the developed Mahua cookies indicated excellent microbial quality and safety. The Total Plate Count (TPC) was found to be **4.6 × 10¹ CFU/g**, which is considerably low for a bakery product and reflects good hygienic practices during preparation, handling, and storage. A low microbial load is generally associated with reduced moisture content, proper baking conditions, and effective packaging, all of which contribute to enhanced shelf stability. The absence of **Escherichia coli** indicates that the product was free from fecal contamination and that sanitary conditions were adequately maintained throughout processing. *E. coli* is commonly used as an indicator organism to assess the hygienic quality of food products; therefore, its absence confirms good manufacturing and handling practices. Similarly, **Salmonella spp.** were not detected in the cookie samples. The absence of *Salmonella* is particularly significant because it is one of the major foodborne pathogenic microorganisms responsible for gastrointestinal infections. The non-detection of this pathogen demonstrates that the thermal processing conditions employed during baking were sufficient to ensure microbiological safety.

Table 5: Microbiological Quality Assessment of Mahua Cookies

Parameter	Result
Total Plate Count (TPC)	4.6 × 10¹ CFU/g*
Escherichia coli	Absent
***Salmonella* spp.**	Absent

The microbiological results demonstrate that the Mahua cookies possess satisfactory microbial quality and are safe for human consumption. The low Total Plate Count can be attributed to the low moisture content (5.0%) of the cookies, which limits microbial growth and proliferation. Additionally, the baking process exposes the product to elevated temperatures, effectively reducing microbial populations and eliminating potential pathogens. The complete absence of *Escherichia coli* and *Salmonella* further confirms the microbiological integrity of the product. These findings suggest that the incorporation of Mahua flower powder did not adversely affect microbial safety. Furthermore, certain phytochemical constituents present in Mahua flowers, including phenolic compounds and antioxidants, may contribute indirectly to microbial inhibition and product preservation. Overall, the microbiological assessment indicates that the developed Mahua cookies meet acceptable food safety standards and possess good microbiological stability, supporting their potential for commercial production and consumer acceptance.

Future Aspects

The commercialization potential of Mahua (*Madhuca longifolia*)-based cookies is highly promising due to the increasing consumer preference for traditional, natural, and nutritionally enriched food products. Growing awareness regarding indigenous food resources and their health benefits has created a favorable market environment for value-added Mahua products. Rich in natural sugars, vitamins, minerals, dietary fiber, and bioactive compounds, Mahua flowers can serve as a functional ingredient in bakery formulations, enabling the development of healthier snack alternatives. The rising demand for clean-label, minimally processed, and nutrient-dense foods further strengthens the market prospects of Mahua cookies. Moreover, opportunities exist for product diversification through the incorporation of cereals and millets such as ragi, oats, and pearl millet, as well as the development of specialized variants including high-fiber, vegan, and gluten-free products. These innovations can enhance product appeal among health-conscious consumers and support entry into premium domestic and international markets. The increasing global interest in ethnic, organic, and sustainable foods also presents significant export opportunities for Mahua-based bakery products.

Beyond market growth, Mahua cookies offer substantial socioeconomic and environmental benefits. Mahua is an important non-timber forest product that contributes significantly to the livelihoods of tribal and rural communities, particularly in central and eastern India. Large-scale utilization of Mahua flowers can promote rural entrepreneurship, generate additional income, and encourage sustainable forest resource management. The eco-friendly nature of Mahua sourcing aligns with biodiversity conservation goals and appeals to environmentally conscious consumers. However, several challenges must be addressed to realize the full commercial potential of Mahua cookies. These include the seasonal availability of Mahua flowers, limited consumer awareness beyond traditional consumption regions, and the need for advanced processing techniques to minimize bitterness and optimize sensory quality. Furthermore, comprehensive nutritional profiling, product standardization, shelf-life studies, quality certification, and regulatory clarity regarding Mahua utilization in food products are essential for enhancing consumer confidence and facilitating large-scale commercialization. Continued research and development efforts will be crucial in establishing Mahua cookies as a sustainable, functional, and commercially successful bakery product.

5. CONCLUSION

Mahua (*Madhuca longifolia*) cookies were successfully developed as a nutritionally enriched functional bakery product by incorporating Mahua flower powder along with wheat flour, sugar powder, cardamom powder, baking powder, essence, dry fruits, and buttermilk. The inclusion of Mahua flower powder imparted a unique natural sweetness, characteristic floral aroma, and desirable flavor profile, distinguishing the product from conventional cookies. Sensory evaluation demonstrated excellent consumer acceptability, with high scores obtained for taste, aroma, appearance, texture, and overall acceptability, indicating that the developed product was highly preferred by the sensory panel.

The proximate composition analysis confirmed the nutritional superiority of the cookies. The product contained low moisture content (5.0%), which contributes to improved crispness, microbial stability, and extended shelf life. The ash content (2.0%) reflected the presence of valuable mineral constituents, while the nutritional profile consisting of 11.76% crude fat, 9.87% protein, 4.55% crude fiber, and 66.82% carbohydrates demonstrated a balanced composition capable of providing energy and essential nutrients. The pH value of 6.1 indicated a mildly acidic and microbiologically safe product. Furthermore, microbiological analysis revealed a low total plate count and the absence of *Escherichia coli* and *Salmonella*, confirming the hygienic quality and safety of the cookies.

The attractive light-brown color, crisp texture, and pleasant Mahua aroma further enhanced the market appeal of the product. In addition to its nutritional and sensory advantages, Mahua cookies can be produced economically on both small and large scales, making them suitable for household production, micro-enterprises, and commercial bakery industries. The utilization of Mahua flowers also supports the value addition of indigenous forest resources and promotes livelihood opportunities for rural and tribal communities. Therefore, Mahua cookies represent a promising functional food product with significant potential for commercialization, consumer acceptance, and sustainable utilization of traditional plant-based resources.

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