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Enhancing Sustainable Livelihood and Development through Agroforestry: Leveraging the Health Benefits of Black Mulberry and Corn Silk for Rural Women's Well-being

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ABSTRACT

This research paper highlights the potential role of an underutilized agro-forestry crop, black mulberry, which has many therapeutic uses and can help rural women generate sustainable employment and income, even by extending its cultivation of agricultural wasteland. The paper presents how black mulberry, combined with another agricultural crop, black soybean and an agricultural by-product/waste in corn silk, can be used to develop a functional beverage. These three agricultural plant resources are rich in flavonoids, phenolic compounds, and essential vitamins and minerals and exhibit strong antioxidant, antibacterial, and anti-inflammatory properties. Moreover, they offer potential health benefits for diabetes, hypertension, and kidney. Mulberry-based agroforestry systems are also effective in reducing soil erosion on degraded lands. This study was designed to develop functional beverages from raw ingredients and examine antioxidant properties using diverse assays. Antioxidant activities were evaluated through DPPH IC50 and FRAP content assays. Minerals were evaluated through atomic absorption spectroscopy, and vitamins by HPLC-DAD. The comprehensive analysis of black mulberry, corn silk and black soybean and their formulated beverages revealed distinct antioxidant profiles and nutritional characteristics that underscore their potential for sustainable development and the creation of functional foods, nutraceuticals, and pharmaceutical products. Corn silk emerged as a rich source of natural antioxidants, exhibiting the highest total phenolic content (67.6 ± 0.83 mg GAE/ml). Black soybean demonstrated the strongest overall antioxidant profile, with the highest total flavonoid content (15.8 ± 0.42 mg QCE/ml) and the most potent antioxidant activity in DPPH and FRAP assays. Its high zinc (11.9 ± 0.24 mg/100g) and vitamin E (2.1 ± 0.72 mg/100g) content further enhance its potential in developing functional foods targeting immunity enhancement and antioxidant supplementation. Black mulberry showed a balanced antioxidant profile and stood out for its high calcium (444.1 ± 0.88 mg/100g), magnesium (109.4 ± 0.69 mg/100g), and vitamin C (36.1 ± 0.66 mg/100g) content, suggesting a promising ingredient for products aimed at bone health and overall nutritional supplementation. The diverse nutritional profiles of these agricultural resources offer opportunities for innovation in the food, nutraceutical, and pharmaceutical industries. Their incorporation into value chains aligns with sustainable development goals by utilising agricultural by-products like corn silk. It will promote economic growth and women's empowerment in rural areas by creating new market opportunities for these crops. The significant amount of iron in formulated beverages can also pave the way for the Anemia Mukt Bharat programme.

Keywords: Agroforestry, functional beverages, sustainable development, women empowerment

JEL codes: I00, I31, L66, Q16, Q56

I

INTRODUCTION

Women's empowerment and sustainable development are intrinsically linked, representing critical pillars for global progress and equitable growth. The intersection of these concepts has gained increasing prominence in international development agendas, particularly since the adoption of the 2030 Agenda for Sustainable Development and its 17 Sustainable Development Goals (SDGs) in 2015. Women's empowerment is fundamental to sustainable development, encompassing multiple dimensions, including economic participation, social equality, and political

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representation. SDG 5 explicitly targets gender equality and the empowerment of all women and girls, recognizing that gender disparities persist across various sectors and hinder overall development. Sustainable development, as defined by the Brundtland Commission, aims to meet the needs of the present without compromising the ability of future generations to meet their own needs. This concept integrates economic growth, environmental protection, and social well-being, with women playing a crucial role in each aspect. Women's empowerment in sustainable development is multifaceted: it can increase productivity and economic diversification, contribute to poverty alleviation efforts, enhance food security, promote environmental stewardship, and improve social development outcomes. Despite progress, significant challenges remain, as women continue to face discrimination, limited access to resources, and underrepresentation in decision-making processes. Addressing these issues requires a holistic approach that considers the interconnected nature of the SDGs and recognizes women as both beneficiaries and active agents of change in sustainable development efforts. As the global community works towards achieving the SDGs by 2030, integrating women's empowerment into all aspects of sustainable development strategies is a matter of rights and a crucial factor in creating more equitable, prosperous, and sustainable societies for all. This research directly helps to achieve the 3rd SDG, 'good health and well-being'. Also, it supports SDG 13 on 'climate action' by expanding the cultivation of black mulberry on wasteland and addressing SDG 1 and SDG 2 on No Poverty and Zero Hunger, respectively.

Natural resources are pivotal in sustaining rural livelihoods, serving as the foundation for economic activities, food security, and social well-being in many communities worldwide. These resources, including land, water, forests, and biodiversity, provide essential ecosystem services and raw materials that underpin various economic sectors such as agriculture, forestry, fishing, and small-scale manufacturing. In rural areas, where access to formal employment opportunities may be limited, natural resources often serve as a critical safety net, offering both subsistence and income-generating possibilities. The importance of these resources is further magnified by their multifaceted contributions to rural households, ranging from direct consumption and sale of products to indirect benefits such as soil fertility maintenance and climate regulation. Moreover, natural resources are deeply intertwined with cultural identities and traditional knowledge systems, contributing to the social fabric of rural communities. However, the sustainable management of these resources faces numerous challenges, including overexploitation, climate change, and competing land-use demands. As global attention shifts towards achieving sustainable development goals, the significance of natural resources in rural livelihoods has gained increased recognition. This has led to a growing emphasis on integrated approaches that balance conservation efforts with the socio-economic needs of rural populations. Understanding and harnessing the potential of natural resources, particularly underutilized or neglected species, presents an opportunity to enhance rural livelihoods while promoting environmental sustainability. By focusing on innovative and sustainable utilization of resources such as corn silk, black soybean, and black mulberry, there is potential to create new economic opportunities, especially for women, who often play a crucial role in natural resource management but face disproportionate barriers to financial empowerment. This approach not only contributes to poverty alleviation and gender equality but also aligns with broader sustainable development objectives, fostering resilience and long-term prosperity in rural communities. Agroforestry is a multifunctional agricultural approach that deliberately integrates woody perennials, including trees, into productive farming systems. This practice offers numerous ecosystem services, such as soil stabilization through extensive root systems, ground protection via canopy cover and leaf litter, carbon sequestration, oxygen production, and biodiversity enhancement. Enabling trees involves a single soil disturbance event, eliminating the need for annual tillage and promoting long-term soil health and organic matter accumulation. Agroforestry has demonstrated its potential to rehabilitate degraded landscapes, economies, and communities globally, particularly relevant to the Appalachian region. The natural propensity of Appalachian terrain to support tree growth suggests that a transition to tree-based agriculture could be both ecologically appropriate and economically beneficial. The Appalachian region boasts diverse native fruit and nut trees that could serve as the foundation for a robust food system and a thriving renewable resource-based economy. Examples include hickory nuts, which are considered more flavorful than pecans, and improved black walnut cultivars with enhanced nut characteristics. The region already hosts the world's largest pawpaw processor, Integration Acres, in Albany, Ohio. There is potential to expand the production of native species such as persimmons and acorns, as well as adaptable non-native species like Chinese chestnut and hybrid hazelnut. While these species all offer promising opportunities for sustainable agroforestry systems, J. Russel Smith, in his work "Tree Crops: A Permanent Agriculture," highlights a particular species as the "King [of crops] without a throne," suggesting its exceptional potential for agroforestry applications in the region.

Black mulberry (*Morus nigra*), a species of the Moraceae family, is gaining attention due to its attractive colour and higher content of phenolic compounds, especially anthocyanins, compared to other mulberry species. Black mulberry fruits are rich in bioactive substances, including anthocyanins, polysaccharides, polyphenols, and flavonoids, contributing to their antioxidant, anti-inflammatory, and anti-tumour activities. Corn silk (*Stigma maydis*), the silky fibres from corn ears, is rich in flavonoids and traditionally used to treat various ailments, including oedema, depression, and hyperglycaemia. It contains bioactive compounds such as maysin, flavonoids, and terpenoids, contributing to its antioxidant and anti-inflammatory properties. Black soybeans (*Glycine max*), a variety of soybeans with a distinctive jet-black seed coat, are known for their high nutritional value and potential health benefits. They are rich in protein, dietary fibre, and various micronutrients, including iron, calcium, and B vitamins.

These three natural resources offer potential health benefits and opportunities for sustainable livelihoods and economic empowerment, particularly for women in rural areas. The research by Kaushal *et al.* (2024) highlights several benefits of mulberry-based agroforestry systems in combating soil erosion and enhancing carbon sequestration in degraded lands of the Himalayan foothills. Mulberry-based agroforestry systems are effective in reducing soil erosion on degraded lands. The extensive root system of mulberry trees helps stabilize soil particles, preventing them from being washed away by water or blown away by wind. This is particularly important in the fragile ecosystems of the Himalayan foothills, where soil erosion is a significant concern. The canopy management practices associated with mulberry cultivation contribute to enhanced carbon sequestration. Mulberry trees act as carbon sinks, absorbing atmospheric CO2 and storing it in their biomass and the soil. This process helps mitigate climate change and improves soil organic matter content, enhancing soil fertility and structure. Mulberry-based agroforestry systems are particularly well-suited for rehabilitating degraded lands in the Himalayan region. These systems can thrive in poor soil conditions and help restore ecosystem functions in areas adversely affected by human activities or natural processes. Integrating mulberry trees with other crops in agroforestry creates a more diverse and resilient ecosystem. This diversity enhances the overall carbon sequestration potential of the land while also providing additional ecosystem services such as improved water retention and increased biodiversity. Farmers can optimize the balance between soil conservation and productivity by implementing appropriate canopy management practices. These practices allow for the cultivation of understory crops while maintaining the soil protection and carbon sequestration benefits of the mulberry trees. The research suggests that mulberry-based agroforestry systems offer a sustainable approach to land management in the Himalayan foothills. They provide a win-win solution by addressing soil erosion issues, enhancing carbon sequestration, and delivering economic benefits to local communities by producing mulberry leaves and associated products. Corn silk, black soybean, and black mulberry are natural resources with significant potential for sustainable development and women's empowerment.

II

NUTRITIONAL AND MEDICINAL PROPERTIES

Black Mulberry: Mature mulberry fruit is highly esteemed for its exquisite flavour, aroma, and nutritional richness. Mulberries are renowned for their substantial nutritional advantages, containing vital nutrients that contribute to human health and well-being (Yuan & Zhao, 2017). Black mulberry fruit is a significant source of carbohydrates, lipids, proteins, vitamin C, and minerals, including calcium, phosphorus, potassium, magnesium, sodium, and fibre (Veberic *et al.*, 2015). The primary sugars in mulberries are fructose and glucose, which increase as the fruit ripens. *Morus alba* has the highest fat content among various mulberry varieties, with primary fatty acids being oleic acid, palmitic acid, and linolenic acid (Yu *et al.*, 2018). Mulberries contain various organic acids, including citric acid, tartaric acid, malic acid, succinic acid, and fumaric acid, with the most abundant malic acid (Zhang *et al.*, 2016). Black Mulberry and its bioactive constituents offer diverse potential advantages, making it a promising natural resource in healthcare (Liao *et al.*, 2017). These benefits encompass a spectrum of pharmacological effects, including anti-inflammatory, anti-microbial, anti-hyperglycemic, anti-lipidemic, and anti-cancer (Lee *et al.*, 2020). Research highlights its potential to mitigate inflammation, offering a promising avenue for treating chronic diseases like cardiovascular conditions, autoimmune disorders, age-related ailments, and cancer (Mascarello *et al.,* 2018). Extracts from various plant parts, including leaves, bark, root bark, and fruits, have demonstrated significant anti-inflammatory properties by reducing oedema and inhibiting pro-inflammatory cytokines (Wen *et al.,* 2019). Moreover, recent studies have shown that *Morus nigra* extracts can improve survival rates and reduce lung inflammation in septic mice (Onnom *et al.*, 2020). In addition to its anti-inflammatory properties, it also possesses impressive antimicrobial activity (Kim *et al.*, 2017). It has been found effective against many bacteria, including those responsible for dental caries, inflammatory pain, acne, and tuberculosis (Jung *et al.*, 2019). *Morus alba* has also been investigated for its anti-diabetic and anti-obesity properties (de Padua *et al.*, 2018). Numerous research studies have investigated the advantages of integrating mulberry fruit components into various food products (Zhang *et al.*, 2019). The use of pectinase for extracting *Morus nigra* fruit has been found to enhance the levels of anthocyanins, including delphinidin, Cyanidin-3-Glucoside, and quercetin. Additionally, researchers have explored the in vitro accessibility of black mulberry fruit jam, revealing its richness in anthocyanins, which contribute positively to the quality of food products (Tomas *et al.*, 2017). Furthermore, incorporating concentrated mulberry juice into dried minced pork slices has enhanced their antioxidant properties and phenolic stability, reducing lipid and protein oxidation during preparation and storage (Aybastier, 2021). Fortifying dark chocolate with black mulberry fruit has increased in vitro antioxidant activity and elevated polyphenolic content. Moreover, including black mulberry juice concentrate in probiotic yoghurt has significantly increased the quantity and viability of probiotics (Godocikova *et al.*, 2017). Formulations of various *Morus nigra* fruit pastilles using different hydrocolloids have shown variations in texture and colour, with specific formulations being preferred over others (Kanokpanont *et al.*, 2018). The physical, chemical, and antioxidant properties of black mulberry spray-dried juice powder were significantly influenced by adding proteins and maltodextrin, as discussed in a study by Cheng *et al.* (2018). It was noted that animal proteins led to higher powder recoveries compared to plant proteins. Additionally, research by Kavas and Kavas (2018) explored the impact of *Morus nigra* fruit juice polyphenols on the oxidation resistance, biosafety, and physicochemical characteristics of Cantonese sausages. The results demonstrated improved biosafety and the prevention of lipid and protein oxidation without any adverse effects on the physicochemical properties of the sausages. These findings highlight the potential of incorporating mulberry fruit components in various food products, such as meat, dairy, and food packaging, to enhance their quality and health benefits. This research underscores the versatility of mulberry fruit in culinary applications, showcasing improved stability, heightened antioxidant activity, and increased nutritional value (Zhang *et al.*, 2019).

Cornsilk: The nutritional profile of corn silk is quite diverse, encompassing moisture, protein, fat, dietary fibre, and carbohydrates (Singh *et al.*, 2022). Additionally, corn silk is a rich source of essential vitamins and minerals such as sodium, potassium, calcium, magnesium, iron, zinc, manganese, copper, vitamin C, vitamin E, and vitamin K (Swapna *et al.*, 2020). These nutritional characteristics are influenced by factors such as geographical origin and the maturity stage of the corn. Mexican corn silk varieties, including Gordo brown, Conico pink-red, and Cristalino green-yellow, show variations in protein, fat, carbohydrate, and fibre content (Limmatvapirat *et al.*, 2020). Several studies have highlighted the potential health benefits of corn silk and its bioactive components, establishing it as a valuable natural resource in healthcare (Amjad *et al.,* 2022). Research has shown that corn silk extract exhibits strong antioxidant properties, effectively combating free radicals, preserving cell integrity, and inhibiting oxidative processes (Gorniak *et al.*, 2021). This is attributed to the extract's high concentration of natural bioactive chemicals, such as flavonoids and chlorogenic acids, further enhancing its antioxidant capabilities (Aukkanit *et al.*, 2015). Moreover, studies have demonstrated that corn silk extract possesses antibacterial properties, inhibiting the growth of various disease-causing and spoilage bacteria, making it a beneficial natural antibacterial agent (Okon *et al.,* 2018). In addition, it has been found to have anti-hyperlipidemic properties, capable of lowering cholesterol and triglyceride levels, thereby contributing to the prevention of cardiovascular diseases (Guo *et al.*, 2019). Its diuretic and kaliuretic effects are noted to be beneficial in managing kidney stones and urinary tract issues (Jiao *et al.*, 2022). Indonesian and Thai corn silk varieties exhibit distinct phytochemical compositions, with certain varieties, such as Bisma and purple waxy corn, demonstrating higher antioxidant content and activity (Senphan *et al.*, 2019). Furthermore, corn silk extract demonstrates potential anti-diabetic effects by improving glycemic control and insulin secretion. It has also been shown to have anti-hypertensive properties, lowering blood pressure and suppressing angiotensin-converting enzyme activity (Marunaka *et al.*, 2017). The extract of corn silk is known for its anti-inflammatory and nephrotoxicity-reduction properties, making it a promising natural treatment for various health conditions (Patel *et al.*, 2018). Research has shown that corn silk extract exhibits anti-cancer effects by reducing cell viability and inducing apoptosis in human breast cancer cells (Oyagbemi *et al.*, 2020). Moreover, corn silk possesses anti-inflammatory properties that can help alleviate inflammation and pain, particularly in cases of gout and arthritis (Chaudhary *et al.*, 2022). Studies have also indicated its potential to reduce nephrotoxicity by counteracting the harmful effects of nephrotoxic chemicals on the kidneys, as demonstrated by Xu *et al.* (2019) and Mozos *et al.* (2021). The potential of corn silk in various food products such as bread, crackers, tea, vinegar, wine, meatballs, beef patties, cooking oil, and traditional dishes like paratha, chapati, raita, and dhal has been extensively studied, demonstrating its versatility in culinary applications (Zhou *et al.*, 2023). The extraction of corn silk has been explored for its diverse uses in different food sectors. Additionally, the development of corn silk tea has shown promise as a natural therapy for hypertension. A combination of corn silk and lemon fruit has been formulated to create corn silk lemon-infused tea, enhancing its antioxidant benefits while preserving a flavour similar to commercial tea and demonstrating significant antihypertensive effects. Corn silk has been utilized to create healthy wine and vinegar due to the presence of volatile chemicals with antibacterial qualities, making dried baby corn silk vinegar a potential functional food (Wans *et al.*, 2021). Moreover, corn silk extract has been employed in Sikhe, a traditional Korean dessert drink, to enhance the total phenolic content and improve antioxidant properties, underscoring its functional significance in food and beverages (Krusong *et al.*, 2020).

Black Soybean: Black Soybean (*Glycine max*) is a valuable legume plant known for its high protein, carbohydrate, lipid, water, and essential minerals like calcium, phosphorous, magnesium, potassium, sodium, selenium, and a variety of vitamins, including Vitamin E and the B complex. Its lipid profile comprises unsaturated fatty acids, including linoleic acid, linolenic acid, and oleic acid, which benefit human health (Varnosfaderani *et al.*, 2019). It is rich in essential amino acids like histidine, leucine, isoleucine, phenylalanine, tryptophan, and threonine (Mateos-Aparicio *et al.*, 2018). Its main byproduct, soybean meal, is also beneficial as animal feed. Due to anthocyanins, chlorophyll, and various pigments, including black, yellow, green, and brown, soybeans exhibit a range of seed coat colours, including black, yellow, green, and brown (Naresh *et al.*, 2019). Soybeans with a high anthocyanin content have shown promising health potential. They can be used as adjunctive treatments and ingredients in various formulations due to their antioxidant, anti-inflammatory, kidney-protective, antidiabetic, anticancer, anti-infertility, anti-obesity, anti-arthritic, neuroprotective, antihyperlipidemic, anti-cataract, and wound-healing properties. They are particularly advantageous for enhancing bone stability and reducing blood pressure. These antioxidants help neutralize harmful free radicals in the body, contributing to overall health (Bray *et al.*, 2018). Black soybeans have potential as anti-diabetic agents by inhibiting enzymes involved in glucose absorption and contributing to better blood sugar regulation. They also aid in controlling obesity by influencing cholesterol and fatty acid metabolism, making them valuable in managing metabolic disorders and obesity (Dey & Lakshmanan, 2023). Furthermore, research suggests that black soybeans have anti-cancer properties, inducing apoptosis in cancer cells and inhibiting their growth. These soybeans have anti-inflammatory effects, reducing inflammation markers, and they can contribute to heart health by lowering blood pressure and enhancing cardiovascular function. Soybeans are increasingly valued as functional health foods due to their diverse nutrients and antioxidants, which can help combat lifestyle-related diseases (Hirata *et al.*, 2016). *Rhizopus oligosporus*-fermented black soybean milk has been found to exhibit antioxidant and cytotoxic properties, suggesting potential applications in functional foods and pharmaceuticals. While the food and pharmaceutical industries traditionally focus on fruits and vegetables rich in anthocyanins and other bioactive compounds for therapeutic supplements, black soybean grains contain various nutritional compounds and antioxidants, making them a promising choice for human health and nutrition. Encouraging their use as nutraceuticals or functional foods is crucial to realizing their commercial potential and generating income (Fetriyuna, 2015).

III

SUSTAINABLE LIVELIHOOD STRATEGIES

Integrating agricultural waste products, agroforestry fruits, and underutilized crops into value chains represents a multifaceted approach to sustainable development and women's empowerment, particularly in rural areas where economic opportunities are often limited. This strategy aligns with the broader goals of the 2030 Agenda for Sustainable Development, addressing multiple Sustainable Development Goals (SDGs) simultaneously. Developing value chains for these agricultural resources involves multiple stages, each offering opportunities for innovation and economic engagement: Implementing sustainable farming practices to improve yield and quality; Developing efficient methods for collection, cleaning, and storage to maintain product integrity; Creating value-added products through extraction, fermentation, or other processing techniques; Formulating new products such as teas, supplements, cosmetics, and functional foods and establishing channels for local and international markets; leveraging the growing demand for natural and health-oriented products. These stages present diverse opportunities for women's participation, from small-scale farming to entrepreneurship in product development and marketing. For instance, in Thailand, efforts to create new supply chain models for fresh mulberry fruit incorporate active packaging technology, demonstrating how innovation can extend to various aspects of the value chain (Atapattu *et al.,* 2024).

The focus on these agricultural resources aligns closely with women's empowerment and sustainable development principles by providing income-generating opportunities. These initiatives contribute to women's financial independence and economic security. Engagement in various value chain stages promotes acquiring new skills in agriculture, processing, and business management. Utilizing agricultural by-products and promoting sustainable farming practices contributes to environmental conservation and resource efficiency, and empowering women can lead to improved family welfare, better education for children, and enhanced community development. While the potential is significant, several challenges need to be addressed: Ensuring women have equal access to land, credit, and technology necessary for participation in these value chains; Developing robust market linkages and overcoming barriers to entry in competitive industries; Providing education on sustainable farming practices; processing techniques, and business management and implementing policies that support women's participation in agricultural value chains and promote sustainable development. As research continues to uncover new applications and benefits of these agricultural resources, the potential for economic growth and sustainable development expands. The integration of women into these emerging value chains not only contributes to gender equality but also enhances the overall effectiveness and sustainability of agricultural systems. By focusing on these underutilized resources and empowering women through their development, communities can work towards achieving multiple SDGs, including gender equality, decent work and economic growth, responsible consumption and production, and climate action. This holistic approach to sustainable development recognizes women as both beneficiaries and active agents of change, crucial for creating more equitable, prosperous, and sustainable societies for all (Ahmed, 2016).

IV

METHODOLOGY

4.1 Raw Materials

Mulberries used in this research were sourced from TRIKAYA, a company located in Bangalore, and were transported to the CFTRI, Mysore campus under freeze-packed conditions. Black soybean and corn silk were obtained from a local store in Mysore, while lemon and ginger Extracts were prepared in the laboratory. The mulberries were consistent in size, fully ripe, and showed no signs of bruising. Sample preparation was conducted in the Fruits and Vegetable Technology Department, and subsequent analysis took place in various departments of the Institute, depending on instrument availability. Sterilized plastic bottles were used to pack and store ready-to-serve (RTS) beverages in the institute's laboratory. These beverages were maintained at refrigerated temperatures for further testing.

4.2 Formulation of Ready-to-Serve Beverage

The corn silk was separated from the selected corn to prepare the extract. Black soybeans were handpicked, washed off dirt and kept for drying. As previously stated, completely ripened, bruise-free, consistent mulberries were chosen for beverage preparation. The corn silk, black mulberry and soybean were rinsed under running tap water to remove the adherent dirt. The corn silk was weighed and then subjected to boiling treatment (temperature 100-150 °C) for 30-45 minutes and cooled in normal water. Afterwards, the extract was filtered through double muslin cloth to eliminate contaminants and big particles, and the same was done for black soybeans. The mulberries were put in a blender/pulper, and pulpy juice was extracted. In the variants FB1, FB2, and FB3, the corn silk extract was combined with mulberry juice and black-soybean extracts in the following ratios: FB1 (40:56:4), FB2 (40:52:8) and FB3 (40:48:12) initially. The extracts of ginger and lemon were mixed with the juice treatments for palatability and enhancement of nutritional properties, thus modifying the ratios of the treatments to FB1 (40:50:4:4:2), FB2 (40:46:8:4:2) and FB3 (40:42:12:4:2). The similar method was used in all treatments. The final juices were homogenized with a juicer for overall uniform proportion. The Produced juices were pasteurized for 10 minutes at 80°C temperature. The pasteurized juice was poured into 200 ml clean, pre-sterilized, dried plastic bottles with a 2.0 cm headspace and sealed airtight with a crown corking machine. All four formulated beverages were then refrigerated for further estimation and sensory analysis.

4.3 Antioxidant Content and Activity

An aluminium chloride colourimetric assay was employed to assess the total flavonoid content (mgQE/g) in the beverages, following the procedure outlined by Nirmala *et al.* 2020. The total phenolic content (mgGAE/g) was determined using the Folin-Ciocalteu test, following the methodology described by Ramirez *et al.* in 2021. Each measurement was conducted in triplicate. The assessment of DPPH Radical Scavenging Activity (IC50 g/ml) followed the protocol established by Baliyan *et al.* in 2022. The IC50 value was determined by plotting the percentage of inhibition against the sample concentration. Ascorbic acid (Vitamin C) was used as the positive control, and the results are presented in terms of IC50 values. Ascorbic Acid served as the standard for the Ferric Reducing Antioxidant Assay (mgAscE/g), while pure water was used as the blank control. A standard curve was constructed using Ascorbic Acid concentrations ranging from 5 to 100 mg/g, following the procedure outlined by Xiao *et al.* in 2020.

4.4 Determination of Monomeric, Polymeric, Color Density, Browning Index and Total Anthocyanin Content

The determination of both Total Anthocyanin Content (TAC) and Monomeric Anthocyanin Content (MAC) was conducted using the pH differential method (Le *et al.*, 2019). The dilution factor was determined to be 20, which was calculated by dividing the final sample volume by the initial volume. Subsequently, two dilutions of the aqueous extract, each approximately 1 ml in volume, were prepared. One dilution was created using a 0.025 M Potassium Chloride buffer of pH 1, while the other was prepared using a 0.4 M sodium acetate buffer of pH 4.5. Both dilutions were adjusted using the previously determined dilution factor. Absorbance measurements were performed using a UV/VIS Spectrophotometer at their respective maximum wavelengths, 520 nm and 700 nm, following a 20-minute equilibrium period. The calculation of both total anthocyanin content and MAC was conducted using the equation. (1).

$$\text{Total Anthocyanin} = \frac{A \times MW \times DF \times 1000}{E \times L} \quad (1)$$

In the provided equation, where A represents the calculation involving absorbance values at pH 1.0 and pH 4.5 with specific wavelengths

(A520 - A700), it is important to consider the following parameters:
- MW (molecular weight) equals 449.2 g/mol for cyanidin-3-glucoside.
- DF stands for the dilution factor.
- 1 represents the path length in centimetres.
- ε represents the molar extinction coefficient of 26,900 L/(mol · cm) for cyanidin-3-glucoside.
- Factor 1000 is applied to convert from grams to milligrams.

The determination of Polymeric Color (PC), Percent Polymeric Color (PPC), and Color Density (CD) followed the method outlined described by Aamer *et al.* (2021). To achieve this, the beverages were first diluted with distilled water until their absorbance readings fell within the range of 0.5 to 1.0 at an unspecified wavelength. Next, 0.2 mL of a potassium metabisulfite solution (0.90M) was introduced into 2.8 mL of the diluted sample, creating a bisulfite-bleached sample. Simultaneously, 0.2 mL of distilled water was combined with 2.8 mL of the diluted sample to form a non-bleached control sample. These samples were allowed to equilibrate for 30 minutes. Subsequently, the samples were assessed at wavelengths of λ = 700 nm, 510 nm, and 420 nm. The CD was calculated using the non-bleached control sample and the following Equation (1). Equation 4 was used to compute the browning index (BI), which represents the ratio of total anthocyanin pigment loss to the development of brown colour. Absorbance was measured after diluting the beverages with distilled water (1:1).

CD = [(A420nm-A700nm) + (A510nm-A700nm)] x dilution factor (1)
PC = [(A420nm-A700nm) + (A510nm-A700nm)] x dilution factor (2)
PPC= (PC/CD) x 100 (3)
BI = (A 420 nm)/(A 520 nm) (4)

4.5 Determination of Co-pigmentation Effects

The hyperchromic shift, which measures the increase in absorbance when a co-pigment is present compared to when it is absent, was calculated using the following Equation (1). The bathochromic shift, which quantifies the difference between the initial maximum wavelength (λ0) and the increased maximum wavelength (λ) after the addition of the co-pigment, was determined using the following Equation (2) (Klisurova *et al.*, 2019).

Hyperchromic effect = ((A - A0) / A0) × 100 (1)
Where A represents the absorbance in the presence of the co-pigment,
A0 represents the absorbance in the absence of the co-pigment
Bathochromic effect = ((λ - λ0) / λ0) × 100 (2)
Where λ represents the maximum wavelength after the addition of the co-pigment
λ0 represents the initial maximum wavelength in the absence of the co-pigment

4.6 *Mineral and Vitamin Estimation*

The mineral analysis used the Atomic Absorption Spectroscopy method for zinc, iron, calcium, magnesium, sodium, potassium and manganese as per standard procedures. Vitamins were determined by the HPLC-DAD method (Levêques *et al.*, 2019)

4.7 Statistical analysis

Data was submitted to one-way analysis of variance (ANOVA)and Tukey's Test considering 5% probability ($p \leq 0.05$), along with Mean ±SEM. Statistical analysis was performed using Statistical software, version 10 (Sta Soft Inc., Tulsa, USA.)

V

RESULTS AND DISCUSSION

5.1 Antioxidant Content and Activity

Corn silk exhibited the highest TPC (67.6 ± 0.83 mg GAE/ml), followed by black mulberry (37.8 ± 0.47 mg GAE/ml) and black soybean (33.6 ± 0.88 mg GAE/ml). The differences between all samples were statistically significant ($p < 0.05$). Black soybean showed the highest TFC (15.8 ± 0.42 mg QCE/ml), followed by black mulberry (11.3 ± 0.77 mg QCE/ml) and corn silk (4.2 ± 0.57 mg QCE/ml). Again, all differences were statistically significant ($p < 0.05$). Black soybean demonstrated the lowest IC50 value (17.0 ± 0.26 μg/ml), indicating the highest antioxidant activity, followed by black mulberry (25.0 ± 0.57 μg/ml) and corn silk (31.0 ± 0.43 μg/ml). Lower IC50 values indicate higher antioxidant activity. Black soybean exhibited the highest FRAP value (154 ± 0.51 mg AscE/ml), followed by black mulberry (68.1 ± 0.49 mg AscE/ml) and corn silk (5.5 ± 0.95 mg AscE/ml). Higher FRAP values indicate greater antioxidant capacity. The results reveal distinct antioxidant profiles for each studied sample, suggesting their potential for various applications in the food, nutraceutical, and pharmaceutical industries. Corn silk had the highest total phenolic content, significantly surpassing black mulberry and soybean. This finding indicates that corn silk is a rich source of phenolic compounds known for their antioxidant properties. The high TPC in corn silk suggests its potential use as a natural antioxidant in various applications, mainly when flavonoid content is not the primary concern. Black soybeans exhibited the highest total flavonoid content and the strongest antioxidant activity measured by DPPH and FRAP assays. This combination of high flavonoid content and potent antioxidant activity makes black soybeans a promising candidate for developing functional foods and nutraceuticals to combat oxidative stress-related conditions. Black mulberry showed moderate levels across all measured parameters, positioning it as a balanced source of antioxidants. Its diverse antioxidant profile suggests potential for use in various applications where a combination of different antioxidant compounds is desired. The inverse relationship between DPPH IC50 values and FRAP results across the samples confirms the consistency of the antioxidant activity measurements. Black soybean's low IC50 value and high FRAP value corroborate its strong antioxidant potential. It's important to note that while corn silk had the highest phenolic content, it showed the lowest flavonoid content and relatively weaker performance in DPPH and FRAP assays. This suggests that the phenolic compounds in corn silk may have different antioxidant mechanisms or potencies than those in black soybean and black mulberry.

Individuals should incorporate appropriate dietary habits involving bioactive antioxidant compounds, as free radicals can harm health (Forni *et al.*, 2021; Khan *et al.*, 2021). Natural antioxidants with non-enzymatic properties can be found in fruits and vegetables, and they primarily fall into four major categories: vitamins, carotenoids, polyphenols, and minerals. Among polyphenols, two significant subgroups are to consider: flavonoids and phenolic acids (Arias *et al.*, 2022). Table 1 illustrates the application of the Folin-Ciocalteu test, which quantifies total phenols in natural products through an oxidation/reduction reaction with a challenging endpoint after 120 minutes. Phenolic compounds, known for their antioxidant and redox characteristics, include gallic acid, the second most prevalent chemical in this context. Gallic acid can inhibit the overproduction of reactive oxygen species, possibly reducing the risk of neurological diseases such as Parkinson's and Alzheimer's (Bhuia *et al.*, 2023). The study identified significant differences in Total Phenolic Content among three formulated beverages, with FB1 having the highest phenolic content. Flavonoids, a subgroup of naturally occurring polyphenols found in vegetables, fruits, grains, and tea, play pivotal roles in various biological processes and plant responses to environmental stimuli. They are particularly well-known for their ability to modulate the activity of key cellular enzymes and possess properties such as antioxidative, anti-inflammatory, anti-mutagenic, and anti-carcinogenic effects (Panche *et al.*, 2016). The study also detected notable differences in the Total Flavonoid Content among the three formulated beverages, with FB3 having the highest content (10.6±0.31 mg QCE/g) while FB1 had the lowest. All these values showed significant differences at a significance level of $p \leq 0.05$. The antioxidant activity of fruits plays a crucial role in combating degenerative diseases like mutagenesis, carcinogenesis, cardiovascular issues, and ageing. These diseases are often triggered by free radicals produced within biological systems or encountered from external sources. Therefore, understanding the concentration and activity of antioxidants in foods is essential for preventing oxidative damage and maintaining economic and nutritional value (Singh and Kedare, 2011). The assay measures the ability of biological samples to reduce DPPH, a deep purple free radical, to 1,1-diphenyl-2-picryl hydrazine. The colour change observed depends on the ability of antioxidants to donate hydrogen atoms, with higher antioxidant activity indicating greater radical scavenging capacity (Baliyan *et al.*, 2022). In the study, DPPH levels (Table 1) were analyzed in three formulated beverages, with beverage 1 having an IC50 (μg/ml) of (21.6±0.06) and formulated beverage 3 having an IC50 (μg/ml) of (16.8±0.16). The FRAP test involves electron transport to reduce Fe^{3+} to Fe^{2+} and operates primarily at an acidic pH of 3.6. The reaction, in the presence of 2,4,6-trypyridyl-s-triazine, produces a colourful complex with Fe2+, and the degree of hydroxylation and conjugation influences the FRAP value (Cerretani and Bendini, 2010). The study identified significant differences in FRAP content among the three formulated beverages, with beverage 3 having the highest content at 48.4±0.25 mg AscE/g, suggesting potential health benefits.

TABLE 1. ANTIOXIDANT PROPERTIES OF CORN SILK-MULBERRY FORMULATED BEVERAGES INCORPORATED WITH BLACK-SOYBEAN EXTRACT AT DIFFERENT CONCENTRATIONS

Antioxidant properties	Aqueous Extracts			FB 1	FB 2	FB 3
	Black Mulberry	Black Soybean	Corn Silk			
Total Phenolic Content (mg GAE/ml)	37.8 ± 0.47 ^{a}	33.6 ± 0.88 ^{b}	67.6 ± 0.83 ^{c}	46.3^{b}± 0.20	45.3^{c}± 0.20	44.4^{d}± 0.26
TotalFlavonoids Content (mg QCE/ml)	11.3 ± 0.77 ^{a}	15.8 ± 0.42 ^{b}	4.2 ± 0.57 ^{c}	8.6^{b}± 0.23	9.5^{c}± 0.11	10.6^{d} ± 0.31
DPPH IC50 (µg/ml)	25.0 ± 0.57 ^{a}	17.0 ± 0.26 ^{b}	31.0 ± 0.43 ^{c}	21.6^{b}± 0.06	19.5^{c}± 0.05	16.8^{d}± 0.16
FRAP (mg AscE/ml)	68.1 ± 0.49 ^{a}	154 ± 0.51 ^{b}	5.5 ± 0.95 ^{c}	43.3^{b}± 0.6	45.3^{c}± 0.20	48.4^{d}± 0.25

Values are Mean ± SEM of triplicate determinations. Values sharing different superscript letters between rows are significantly different at $p \leq 0.05$

5.2 Monomeric, Polymeric, Color Density, Browning Index and Total Anthocyanin Content

Anthocyanins are natural pigments in various parts of plants, such as fruits, flowers, seeds, and vegetative tissues, imparting colours ranging from orange, red, and purple to blue. These compounds can absorb UV light and possess antioxidant properties, improving health by reducing the risk of chronic diseases (Mattioli *et al.*, 2020). Table 2 illustrates the Mean±SEM values of Total Anthocyanin Content (mgCy-3-G/L) for three formulated beverages (FB): FB 1, 2, and 3. Among these beverages, FB 3 displayed the highest total anthocyanin content (mgCy-3-G/L) at 9070, while FB1 had the lowest total anthocyanin content (mgCy-3-G/L) at 7048.3. Importantly, all beverages exhibited significant differences at the significance level of $p \leq 0.05$.

In a liposomal system, certain anthocyanins, such as pelargonidin-3-glucoside, cyanidin-3-glucoside, and delphinidin-3-glucoside, exhibit strong antioxidant properties and can inhibit the production of malondialdehyde (Khoo *et al.*, 2019). The study further analysed the chemical composition of the four formulated beverages, focusing on Cyanidin-3-Rutinoside (Cy-3-R) and Pelargonidin-3-Glucoside (Pg-3-G). It was observed that the highest concentrations of Cy-3-R (2458±0.57 mg/L) and Pg-3-G (1086.6±0.66 mg/L) were found in FB3, whereas the lowest concentrations were observed in FB1, with Cy-3-R at 2307±0.88 mg/L and Pg-3-G at 933±0.27 mg/L. Once again, all three beverages exhibited significant differences at the $p \leq 0.05$ level. Polymeric colour, colour density and % polymeric colour content amplified significantly with an increase in the concentration of black soybean extract. The highest concentration of PC (1.363 ± 0.11), CD (11.9 ± 0.02), %PC (11.4±0.01) was found in formulated beverage 3, while the lowest was in FB 1 PC (0.383 ± 0.01), CD (6.6± 0.22), %PC (5.7±0.40). All three beverages showed significant differences at the $p \leq 0.05$ level. The Browning Index for formulated beverage 3 (1.58 ± 0.09) was significantly higher than FB 1(1.25 ± 0.02). The increasing BI implies a buildup of brown pigments at the expense of diminished red anthocyanin pigments, as supported by the significant ($p \leq 0.05$) correlation.

TABLE 2. MONOMERIC, POLYMERIC COLOR, PERCENT POLYMERIC COLOR, COLOR DENSITY, BROWNING INDEX AND TOTAL ANTHOCYANIN CONTENT OF CORN SILK-MULBERRY FORMULATED BEVERAGES INCORPORATED WITH BLACK-SOYBEAN EXTRACT AT DIFFERENT CONCENTRATIONS

Formulated Beverages	Anthocyanins						
	Monomeric		Polymeric				Total
	Cy-3-R (mg/L)	Pg-3-G (mg/L)	Polymeric Color	Colour Density	%Polymeric Colour	Browning Index	TAC (mg Cy 3-G/L)
FB 1	$2307^{b}\pm0.88$	$933^{b}\pm0.27$	$0.383^{b}\pm0.01$	$6.6^{b}\pm0.22$	$5.7^{b}\pm0.40$	$1.25^{b}\pm0.02$	$7048.3^{b}\pm0.58$
FB 2	$2431^{c}\pm0.88$	$1059^{c}\pm0.87$	$0.793^{c}\pm0.20$	$8.9^{c}\pm0.02$	$8.8^{c}\pm0.01$	$1.34^{c}\pm0.02$	$8375.6^{c}\pm0.88$
FB 3	$2458^{d}\pm0.57$	$1087^{d}\pm0.66$	$1.363^{d}\pm0.11$	$11.9^{d}\pm0.02$	$11.4^{d}\pm0.01$	$1.58^{d}\pm0.02$	$9070^{d}\pm0.57$

Values are Mean ± SEM of triplicate determinations. Values sharing different superscript letters between columns are significantly different at $p \leq 0.05$.

5.3 Determination of Copigmentation Effect

The findings regarding the copigmentation effect in all four formulated beverages assessed reactions at 20°C have been consolidated in Table 3. It was observed that an increase in the molar ratio also led to a greater hyperchromic shift ($p<0.05$), signifying that the copigmentation process is influenced by the concentration of the copigment under investigation. A molar ratio of 48:12 (2.44) in the complexation reaction yielded the most significant hyperchromic effect compared to the other two formulated beverages. The most substantial enhancement of colour intensity, denoted by the hyperchromic shift, during the copigmentation of C3G at 20°C was observed in FB 3. Among these copigments, the most pronounced hyperchromic shift indicated a notably stronger intermolecular interaction with C3G ($p<0.05$). Furthermore, in addition to the hyperchromic shift, the bathochromic shift in all reactions also increased with a higher copigment concentration at 20°C, at 564 nm, the formulated beverage 3 had the greatest λ max, as detailed in Table 3. Copigmentation was visible in all of the formulated beverages copigmented by BSE. Both hyperchromic and bathochromic shifts were evident in the observations. The hyperchromic shift was characterized by elevated absorption values at λ max, which escalated from 0.96 to 2.44. Notably, concentrations exceeding 4% led to a further rise in absorbance at λ max. Table 3 provides a comprehensive overview of the impact of incrementally increasing the copigment percentage while keeping the volume of the prepared beverages constant. The bathochromic shift was evident in the displacement of λ max towards longer wavelengths. This shift caused the wavelength to move from 520 nm to 564 nm.

TABLE 3. HYPERCHROMIC AND BATHOCHROMIC SHIFT OF CORN SILK-MULBERRY FORMULATED BEVERAGES INCORPORATED WITH BLACK-SOYBEAN EXTRACT AT DIFFERENT CONCENTRATIONS

Formulated Beverages	Hyperchromic Shift (Abs)	Bathochromic shift (λ max)
FB 1	$0.96^{b}\pm0.02$	$520^{b}\pm0.03$
FB 2	$1.79^{c}\pm0.03$	$543^{c}\pm0.13$
FB 3	$2.44^{d}\pm0.02$	$564^{d}\pm0.30$

Values are Mean ± SEM of triplicate determinations. Values sharing different superscript letters between columns are significantly different at $p \leq 0.05$

5.4 Mineral and Vitamin Content

The provided data in Table 4 presents a comparative analysis of the nutritional composition of Black Mulberry, Black Soybean, and Corn Silk, focusing on their mineral and vitamin content per 100g of sample and FB (FB 1, FB 2, FB 3). This analysis reveals significant variations in nutrient profiles among these three agricultural products, offering insights into their potential nutritional and functional properties.

Potassium stands out as the most abundant macro-mineral across all three samples, with Corn Silk containing the highest concentration (3560.4 ± 0.55 mg/100g), followed by Black Soybean (2055.3 ± 0.52 mg/100g) and Black Mulberry (1134.5 ± 0.58 mg/100g). This high potassium content suggests that all three products could contribute significantly to dietary potassium intake, essential for maintaining proper fluid balance, nerve signals, and muscle contractions. Calcium content varies considerably, with Black Mulberry showing the highest concentration (444.1 ± 0.88 mg/100g), substantially higher than Corn Silk (70.8 ± 0.59 mg/100g) and Black Soybean (42.1 ± 0.56 mg/100g). This indicates that Black Mulberry could be a valuable source of calcium, vital for bone health and cellular signalling. Magnesium levels are also highest in Black Mulberry (109.4 ± 0.69 mg/100g), followed by Corn Silk (36.5 ± 0.66 mg/100g) and Black Soybean (15.4 ± 0.49 mg/100g). Magnesium plays a crucial role in numerous biochemical reactions and may contribute to the potential health benefits of these products. Iron content is notably high in Black Mulberry (19.2 ± 0.49 mg/100g) and Black Soybean (15.6 ± 0.26 mg/100g) while significantly lower in Corn Silk (0.4 ± 0.27 mg/100g). This suggests that Black Mulberry and Black soybeans could be valuable sources of dietary iron, which is vital for oxygen transport and energy metabolism. Zinc levels are highest in Black Soybean (11.9 ± 0.24 mg/100g), followed by Black Mulberry (8.3 ± 0.88 mg/100g) and Corn Silk (4.3 ± 0.55 mg/100g). Zinc is essential for immune function and protein synthesis, indicating potential immunological benefits from these products. Manganese content is highest in Black Mulberry (10.4 ± 0.15 mg/100g), with lower levels in Corn Silk (4.0 ± 0.29 mg/100g) and Black Soybean (3.7 ± 0.87 mg/100g). Manganese is vital for bone formation and metabolism of carbohydrates, proteins, and fats. Vitamin C is most abundant in Black Mulberry (36.1 ± 0.66 mg/100g), followed by Corn Silk (15.9 ± 0.02 mg/100g) and Black Soybean (7.5 ± 0.40 mg/100g). This high vitamin C content in Black Mulberry could contribute to its antioxidant properties and potential health benefits. Vitamin E levels are highest in Black Soybean (2.1 ± 0.72 mg/100g), with lower concentrations in Black Mulberry (1.3 ± 0.05 mg/100g) and Corn Silk (0.4 ± 0.05 mg/100g). Vitamin E is a potent antioxidant that may contribute to the overall antioxidant capacity of these products. Vitamin K content is relatively low across all samples, with Black Mulberry containing the highest amount (0.9 ± 0.60 mg/100g), followed by Black Soybean (0.5 ± 0.10 mg/100g) and Corn Silk (0.06 ± 0.30 mg/100g).

The nutritional profiles of Black Mulberry, Black Soybean, and Corn Silk demonstrate their potential as valuable sources of essential nutrients. Black Mulberry stands out for its high calcium, magnesium, and vitamin C content, suggesting potential applications in products aimed at bone health and antioxidant supplementation. Black Soybean's high potassium and zinc content could make it suitable for products targeting cardiovascular health and immune support. Corn Silk's exceptionally high potassium content indicates potential uses in dietary supplements for electrolyte balance and blood pressure regulation.

These findings support the development of value-added products from these agricultural resources. For instance, Black Mulberry could be incorporated into calcium-fortified foods or antioxidant supplements. Black Soybean might be utilized in functional foods targeting heart health or immune support. Corn Silk's high potassium content could be leveraged in natural electrolyte drinks or dietary supplements for hypertension management. The significant variations in nutrient profiles among these three products also highlight the importance of diversifying agricultural resources in value chain development. Combining these materials may create more nutritionally balanced and functionally diverse products, potentially increasing their market value and applications in various industries.

FB 3, due to the higher proportion of black soybean extract (12%), has the higher sodium (309.1mg/100ml), zinc (40.0mg/100ml), vitamin E (18.0mg/100ml), and vitamin K (0.133mg/100ml) content. Black soybeans include a special combination of high sodium, potassium, zinc, and vitamin E, rarely found in a single food source, making them advantageous for those with low blood pressure. Although black soybeans are grown nationwide, their use in beverages is limited due to a lack of knowledge about cultivars suited for manufacturing soy milk and beverages (Patel and Pandya, 2014). Since black soybeans contain a multi-meric iron-store protein called ferritin, which is easily absorbed and accessible, they should be included in the diet of persons who suffer from anaemia. Black soybean extract has platelet aggregation inhibition action (in vitro) produced by collagen (Kim *et al.*, 2017). In Formulated Beverage 2, due to the larger percentage of black mulberry pulp, FB 2 had higher calcium, magnesium, potassium, iron, manganese, and vitamin C content. Black Mulberries are high in calcium, magnesium and iron, which are necessary for bone and muscular formation. Iron is required for the production of haemoglobin. Iron was also detected in significant amounts in all four beverages. Iron is an essential metal for the human body that aids oxygen and electron transmission. These minerals are very good for pregnant women and relieve constipation (Ercisli *et al.*, 2008). Thus, these beverages can ensure women's nutritional security, especially in rural areas. Nutritional anaemia is a major public health problem in Indian women and is primarily due to iron deficiency, which is more common among the rural population. The significant amount of iron in formulated beverages can also pave the way for the Anemia Mukt Bharat programme.

TABLE 4. NUTRITIONAL CHARACTERISTICS OF CORN SILK-MULBERRY FORMULATED BEVERAGES INCORPORATED WITH BLACK-SOYBEAN EXTRACT AT DIFFERENT CONCENTRATIONS

Nutritional Characteristics	Black Mulberry (mg/ 100 g)	Black Soybean (mg/ 100 g)	Corn Silk (mg/ 100 g)	FB 1 (mg/ 100 ml)	FB 2 (mg/ 100 ml)	FB 3 (mg/ 100 ml)
Calcium	444.1 ± 0.88^{a}	42.1 ± 0.56^{b}	70.8 ±0.59^{c}	253.7 ± 0.07^{b}	235.5 ± 0.59^{c}	221.4 ± 0.88^{d}
Magnesium	109.4 ± 0.69^{a}	15.4 ± 0.49^{b}	36.5 ±0.66^{c}	70.0± 0.37^{b}	66.3 ± 0.44^{c}	62.4 ± 1.67^{d}
Sodium	22.4 ± 0.47^{a}	88.3±0.47^{b}	25.4 ± 0.55^{c}	25.2± 0.57^{b}	28.1 ± 0.57^{c}	30.9 ± 0.6^{d}
Potassium	1134.5 ± 0.58^{a}	2055.3± 0.52^{b}	3560.4 ± 0.55^{c}	2005.5 ±0.29^{b}	1962.8 ± 0.57^{c}	1920.1 ± 0.57^{d}
Zinc	8.3 ± 0.88^{a}	11.9±0.24^{b}	4.3 ±0.55^{c}	3.4 ± 0.28^{b}	4.1± 0.37^{c}	4.9± 0.57^{d}
Iron	19.2 ± 0.49^{a}	15.6± 0.26^{b}	0.4 ± 0.27^{c}	1.3 ± 0.28^{b}	1.2± 0.05^{c}	1.1± 0.41^{d}
Manganese	10.4 ± 0.15^{a}	3.7 ± 0.87^{b}	4.0 ± 0.29^{c}	3.6± 0.05^{b}	3.5± 0.30^{c}	3.4± 0.12^{d}
Vitamin C	36.1 ± 0.66^{a}	7.5 ± 0.40^{b}	15.9 ± 0.02^{c}	24.8±0.53^{b}	22.4±0.07^{c}	19.7± 0.57^{d}
Vitamin E	1.3 ± 0.05^{a}	2.1 ± 0.72^{b}	0.4± 0.05^{c}	0.6 ±0.35^{b}	0.8±0.25^{c}	1.4± 0.12^{d}
Vitamin K	0.9 ± 0.60^{a}	0.5 ± 0.10^{b}	0.06 ± 0.30^{c}	0.09±0.06^{b}	0.13±0.00^{c}	0.15± 0.12^{d}

Values are Mean ± SEM of triplicate determinations. Values sharing different superscript letters between columns are significantly different at $p \leq 0.05$

VI

CONCLUSIONS

The comprehensive analysis of black mulberry, corn silk and black soybean and their formulated beverages reveals distinct antioxidant profiles and nutritional characteristics that underscore their potential for sustainable development and the creation of functional foods, nutraceuticals, and pharmaceutical products. Corn silk emerged as a rich source of natural antioxidants, exhibiting the highest total phenolic content (67.6 ± 0.83 mg GAE/ml). This finding suggests that corn silk, often considered an agricultural waste product, could be repurposed for its antioxidant properties, contributing to sustainable agricultural practices and waste reduction. Black soybean demonstrated the strongest overall antioxidant profile, with the highest total flavonoid content (15.8 ± 0.42 mg QCE/ml) and the most potent antioxidant activity in DPPH and FRAP assays. Its high zinc (11.9 ± 0.24 mg/100g) and vitamin E (2.1 ± 0.72 mg/100g) content further enhance its potential in developing functional foods targeting immunity enhancement and antioxidant supplementation. Black mulberry showed a balanced antioxidant profile and stood out for its high calcium (444.1 ± 0.88 mg/100g), magnesium (109.4 ± 0.69 mg/100g), and vitamin C (36.1 ± 0.66 mg/100g) content. This nutritional composition positions black mulberry as a promising ingredient for products aimed at bone health and overall nutritional supplementation. The formulated beverages, particularly FB3 with the highest black soybean content, demonstrated superior anthocyanin content (9070 mgCy-3-G/L) and significant copigmentation effects. This finding highlights the potential for creating functional beverages with enhanced color stability and antioxidant properties. Corn silk, black mulberry, and black soybean present significant potential for developing value-added products with enhanced nutritional and functional properties. The diverse nutritional profiles of these agricultural resources offer opportunities for innovation in the food, nutraceutical, and pharmaceutical industries. Mulberry-based agroforestry systems are also effective in reducing soil erosion on degraded lands. By harnessing the unique properties of these resources, industries can create innovative products that meet the growing consumer demand for natural, health-promoting ingredients while contributing to sustainable development goals. Their incorporation into value chains aligns with sustainable development goals by utilising agricultural by-products like corn silk. It will promote economic growth and women's empowerment in rural areas by creating new market opportunities for these crops. Their utilization of functional foods, nutraceuticals, and pharmaceutical products supports sustainable agricultural practices and offers economic empowerment opportunities, particularly for women in rural areas. Formulated beverages, rich in minerals like calcium, magnesium, potassium, iron, and manganese, are also good for pregnant women. A significant amount of iron in formulated beverages can also pave the way towards the Anemia Mukt Bharat programme in rural areas where these underutilized agricultural resources are abundant. Mulberry-based agroforestry systems also effectively reduce soil erosion on degraded lands and convert wasteland into arable land.

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