Stingless bee honey as functional food - A review

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ABSTRACT Stingless bee honey (SBH) is one of the high value products that have been marketed worldwide. Honey contains unique and distinct compounds of variable nutritional and biological importance. As a natural product harvested from stingless bees, it is rich in bioactive compounds, antioxidants, sugars, amino acids, minerals and vitamins. This review discusses the physicochemical characteristics, nutritional composition, bioactive compounds and functional properties of SBH which contribute to human health. Prospects of SBH are discussed in association to its sustainability and feasibility as a functional food to meet the demands of consumer. It is important that SBH is developed into a sustainable product, providing additional income opportunities for local farmers while ensuring consumer safety and product quality.

KEYWORDS: Stingless bee honey, Physicochemical, Nutritional, Functional food, Health benefits
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Review Article

INTRODUCTION

Stingless bee honey (SBH) is a natural, sweet substance produced by stingless bees. Stingless bee (tribe *Meliponini,* order Hymenoptera) is the largest and most varied corbiculate eusocial bees, with over 60 genera and 600 species documented (Sharin *et al.*, 2021; Zulhendri *et al.*, 2022). They are characterized morphologically by arolia, a jugal lobe on the hind wing, smaller outer grooves on the mandibles, and unique alar venation. Stingless bees are distinguished by their stunted sting, which prevents them from stinging (de Sousa *et al.*, 2022). Stingless bee is known as "kelulut" in Malaysia, "channarong" in Thailand, and "lukot" or "kiwot" in Philippines. The body size of stingless bee ranges from 2 mm (*Trigonisca* spp.) to 15 mm (*Melipona fuliginosa*). Unlike *Apis* bees which store honey in honeycombs, these bees form colonies and store their honey in honey pots (Grüter, 2020). Figure 1 shows the honey pot of stingless bee.

Stingless bees predominantly inhabit tropical regions, where the Meliponini tribe is primarily found in Australia, Southeast Asia, Africa, and Latin America (Brazil and Cuba), while the Trigonini tribe is more common in tropical regions, especially Malaysia (Pimentel *et al.*, 2022). Each colony of stingless bee consist of thousands to tens of thousands of workers which build their nests underground, in termite nests tree cavities, or wall cavities (Bueno *et al.*, 2023). Stingless bees, like other social bees (e.g., honeybees, *Apis* spp.) are frequent visitors to flowers in the ecosystems they inhabit.

Due to the higher demand for raw honey and limited production of SBH, it is priced at approximately USD 100/kg, which is more than double the price of honey from *Apis mellifera*, typically ranging from USD 20 to 40/kg (Gadge *et al.*, 2023). Compared to *Apis* honey, SBH generally exhibits higher levels of acidity, moisture content, and reducing sugars (Souza *et al.*, 2021). Additionally, SBH is characterized by its fluid texture, slow crystallization and a distinctive sweet-sour flavor (Ranneh *et al.*, 2018).

Honey has been valued for its nutritional and therapeutic qualities for over 5500 years (Al-Hatamleh *et al.*, 2020). The unique characteristics of SBH have contributed to its recognition as a possible functional food, owning to its bioactive components and other substances, such as sugars and organic acids, which are associated with many nutraceuticals and medicinal properties (Ali *et al.*, 2020; Biluca *et al.*, 2017; Zawawi *et al.*, 2022). Recent studies highlighted several functional properties of SBH, including wound healing (Esa *et al.*, 2022), anti-microbial (Biluca *et al.*, 2020; Wu *et al.*, 2023), anti-diabetic (Ali *et al.*, 2020) and anti-cancer (Arung *et al.*, 2021). Given the high demands on SBH, this article aims to review relevant literature from reliable sources regarding SBH based on its physicochemical, bioactive compounds and functional properties. This review seeks to provide valuable insights for future researchers to develop functional food products utilizing SBH.

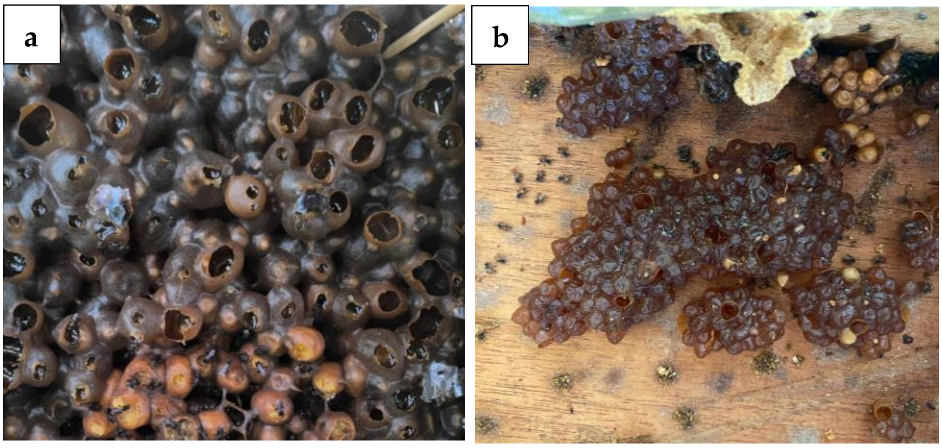

Figure 1. (a) Honey pot of *Heterotrigona itama* and (b) Honey pot of *Tetragonula fuscobalteata*.

PHYSICOCHEMICAL CHARACTERISTICS

Physicochemical properties of SBH are commonly used to measure the quality of the honey. This includes moisture content, reducing sugar and total sugar that are used to measure maturity, and the insoluble solids and ash content to determine the purity of the sample. In contrast, hydroxymethylfurfural (HMF), free acidity and diastase activity are used to indicate the deterioration of stingless bee honey (Ávila *et al.*, 2018). Table 1 summaries the physicochemical and nutritional composition of SBH from different countries.

Water is considered as one of the most important attributes of SBH as it contributes to the viscosity, weight, maturity, flavor and crystallization (Nascimento *et al.*, 2018). As the primary constituent of SBH, moisture content significantly influences its overall quality and shelf life (Braghini *et al.*, 2020). The moisture content of SBH is affected by environmental factors such as temperature, humidity, and rainfall (Manickavasagam *et al.*, 2023). High moisture content in SBH facilitates fermentation and crystallization due to the presence of sugar-tolerant osmophilic yeast. During alcoholic fermentation, undesirable components such as ethanol and carbon dioxide are produced, contributing to an unpleasant flavor (Costa dos Santos *et al.*, 2022; Nordin *et al.*, 2018). The Department of Standards Malaysia has established guidelines for SBH (MS2683:2017) specify that the moisture content of raw SBHs should not exceed 35.0%, while processed SBHs should not surpass 22.0%. Similarly, Thailand and Indonesia have set their maximum moisture content levels for honey higher than international standards, at 21.0% and 27.5%, respectively (Manickavasagam *et al.*, 2023).

Table 1. Physicochemical and nutritional composition of SBH from different countries.

Countries	Parameters/ Species	Moisture (g/100g)	Free acidity (meq/kg)	pH	HMF (mg/kg)	Ash content (g/100 g)	Fructose (g/100g)	Glucose (g/100g)	Reducing sugar (g/100g)	Protein (mg/g)	References
Australia	*Tetragonacarbonaria*	26.50	128.90	4.00	1.20	0.48	24.50	17.50	42.0	2.02	(Oddo *et al.* 2008)
Thailand	*Tetragonula fuscobalteata*	26.00	96.50	3.60	22.0	0.67	23.19	19.44	43.23	-	(Chuttong *et al.*, 2016)
	L. terminata	30.00	194.00	3.50	-	0.25	8.10	4.90	66.00		
Brazil	*Melipona scutellaris* Latrelle	25.50	-	3.95	-	0.16	55.13	41.35	96.47	0.37	(de Sousa *et al.*, 2016)
	M. Subnida Duke	26.40	-	3.95	-	0.19	54.38	42.73	97.10	0.35	
Ecuador	*T. angustula*	25.50	70.55	3.51	27.70	0.69	41.86	30.48	67.40	0.27	(Villacrés-Granda *et al.*, 2021).
	S. polysticta	22.00	63.36	3.55	30.48	0.84	40.54	32.07	73.11	0.18	
	Melipona sp.	27.00	32.08	3.33	7.48	0.29	42.33	38.26	81.08	0.17	
Malaysia	*Geniotrigona thoracica*	28.30	235.6	3.09	-	0.13	16.23	13.37	-	-	(Zawawi *et al.*, 2022)
	Heterotrigona itama	28.16	211.5	3.19	0.11	0.23	4.11	2.90	-	-	
China	*Lepidotrigona arcifera*	25.94	-	3.61	-	0.17	12.26	11.16	-	-	(Zheng *et al.*, 2025)
	Lepidotrigona terminata	26.28	-	3.50	-	0.17	15.27	16.59	-	-	

Free acidity is an important indicator for honey deterioration, which is related to the botanical origin and bee species. Increase in acidity indicates a fermentation process that adversely affects honey quality and sensory attributes (Ávila *et al.*, 2018; Costa dos Santos *et al.*, 2022). Other parameters that are often measured include pH values and color. Study reported that SBH from Southern Brazil exhibited pH values ranging from 3.6 to 5.3 (Marcolin *et al.*, 2021). Color is a physical parameter of honey. Naturally, honey exhibits a wide range of colors, from yellow to amber, dark amber, and even black in some cases (Shamsudin *et al.*, 2019). The color and intensity of SBH are influenced by various factors including phenolic compounds, minerals, pollen types, fermentation, carotenoids, storage time, as well as difference in botanical and geographical origins (Biluca *et al.*, 2014; Shamsudin *et al.*, 2019). Study by Selvaraju *et al.* (2019) suggested that honey darkens more quickly when stored at high temperatures and often darker-colored honey tends to have higher antioxidant activity.

Ash content refers to the minerals and inorganic substances left in the honey after heating to extremely high temperature. Some irregularities in honey, such as lack of hygiene, decantation or filtration of honey by the beekeeper, can be identified based on the ash content (Ávila *et al.*, 2018). The hydroxymethylfurfural (HMF) and diastase activity serve as indicators to evaluate the quality of honey. Formation of HMF indicates potential adulteration with inverted sugar, as it is generated during the sucrose reversal process (Carina *et al.*, 2021), and overheating during dehydration (Ikhsan *et al.*, 2022). Additionally, HMF is used to assess the freshness, degree of deterioration, potential microbial spoilage, and the storage conditions of honey (Negera *et al.*, 2024). Increase in HMF due to the prolong heating accelerates sugar degradation through Maillard reaction (Chen *et al.*, 2021). In fresh honey, HMF is typically absent or present in small amount. The maximum limit for HMF in processed SBH is 30 mg/kg as per Malaysian standard, while the Codex Standard and EU Honey Directive permit up to 80 mg/kg (Malaysian Standard, 2017).

NUTRITIONAL COMPOSITION

Macronutrients

The major carbohydrates in honey are fructose and glucose, which are responsible for the hygroscopicity, viscosity, granulation, and energy value of honey (Biluca *et al.*, 2016; Santos *et al.*, 2021). Sugars such as glucose, fructose, and trehalose are commonly found in SBH where fructose and glucose represent the largest proportion. Study by Biluca *et al.* (2016), reported that the total reducing sugar (fructose and glucose) in SBH ranged from 48.6% to 70.5%, where fructose is the main sugar present. The variation of sugar content can be due to factors such as present of maltose (Chuttong *et al.*, 2016), entomological origins (Sharin *et al.*, 2021), botanical origins and geographical origins (Ramlan *et al.*, 2024).

Recent studies on the sugar content of SBH have focused on trehalulose, a naturally occurring isomer of sucrose that offers significant health benefits. Trehalulose releases monosaccharides into bloodstream slower than sucrose, resulting in low insulinemic index and low glycemic index. It has been identified as a biological active disaccharide with anti-diabetic and acariogenic properties (Fletcher *et al.*, 2020; Zawawi *et al.*, 2022). Zawawi *et al.* (2022) reported trehalulose is the primary sugar in SBH derived from *H. itama, G. thoracica, Tetragonula carbonaria*, and *Tetragonula hockingsi,* sourced from the two geographical regions (Malaysia and Australia).

The protein and amino acid content in honey originates from the secretion of the honeybee's salivary gland and pharynx, as well as from pollen, which serves as the floral sources of these compounds (Machado De-Melo *et al.*, 2018). Study by Villacrés-Granda *et al.* (2021) revealed that the total protein content in SBH varies among species, ranging from 0.02 to 0.37 mg BSA/g. Another study by Biluca *et al.* (2019) reported that the free amino acid in SBH ranged from 51.90 to 2577 mg/kg, with a higher content of proline and phenylalanine. Proline is the major amino acid in honey, accounting for 50% - 85% of the total amino acid (da Costa & Toro, 2021). The International Honey Commission (IHC) recommends a minimum level of 180 mg/kg as an indicator of honey ripeness (Hassan *et al.*, 2023). This makes proline as a quality indicator for SBH, as its level degraded during storage.

Micronutrients

Essential minerals such as calcium (Ca), copper (Cu), iron (Fe), magnesium (Mg), zinc (Zn), potassium (K), sodium (Na), phosphorus (P), selenium (Se), manganese (Mn), chromium (Cr), and iodine (I) are important for human health. Ng *et al.* (2021) reported that Na is the most abundant element in all SBH samples, with concentrations ranging from 223.87 to 326.75 mg/kg. This marks the first report identifying Na as the most abundant mineral in honey, contrary to the previous finding where K was typically the most abundant. Muhammad & Sarbon (2023) reported the total mineral contents of SBH was determined at 562.35 mg/kg, with K, Na, and Ca are the most abundant elements. Similarly, study on stingless bee honeys across the Andes, Amazon, and Pacific regions found that K was the most abundant, ranging from 0.07 to 1.33 mg/g, followed by Ca, which ranged from 0.15 to 0.31 mg/g of honey (Villacrés-Granda *et al.*, 2021). Other trace minerals detected in SBH include Fe, Zn, Mn, and Cr (Biluca *et al.*, 2017; Ng *et al.*, 2021). The mineral composition of honey is primarily influenced by its botanical and geographical origins rather than the bee species (Muhammad & Sarbon, 2023). Nevertheless, the mineral content of honey is highly dependent on the plant uptake from the soils and the environments where the bee collects nectar for honey production (Biluca *et al.*, 2016).

Vitamins are present in small amounts in honey, mostly sourced from the pollen of flowers (Machado De-Melo *et al.*, 2018). Villacrés-Granda *et al.* (2021) reported the present of vitamin C in five out of twelve SBH samples studied, with the highest concentration observed in SBH from *O. mellaria* (63754.04 µg Vit C/g). Similarly, study by Selvaraju *et al.* (2019) found the concentration of vitamin C varied across different locations in Malaysia. The variation of vitamin C content could be attributed to the different geographical and botanical origins. However, the study on vitamin C in honey remained limited due to its instability (Villacrés-Granda *et al.*, 2021).

FUNCTIONAL PROPERTIES

SBH is widely recognised for its functional properties, primarily due to its high phenolic and flavonoid content. This could be due to the present of polyphenolic compounds that neutralise free radicals and prevent oxidative stress. The antioxidant activity of SBH is enhanced by both enzymatic and non-enzymatic compounds. Enzymatic antioxidants, such as superoxide dismutase, and non-enzymatic compounds, including ascorbic acid, tocopherol, and phenolic compounds, work together to neutralize reactive oxygen species (ROS). These compounds interrupt and terminate the damaging chain reactions caused by free radicals (Tuksitha *et al.*, 2018; Esa *et al.*, 2022). Table 2 summaries the biological activities of SBH from different bee species.

Ávila *et al.* (2019) demonstrated that SBH exhibits antioxidant and biological activities that are up to 45% greater than honey from *A. mellifera*. Similarly, result by Nweze *et al.* (2017) suggesting SBH (specifically *Hypotrigona* sp.) a good source of antioxidants. Another study by Mello dos Santos *et al.* (2024) reported that both species of Australia SBH (*Tetragonula carbonaria* and *Tetragonula hockingsi*) have high antioxidant capacity. Given that each phenolic compound has a unique scavenging activity and reducing capacity, the variability in antioxidant activities across the SBH samples may be explained by the different in phenolic content and the types of phenolic compounds present. These compounds are influenced by factors such as botanical origin, geographic location, harvest season, and environmental (Chuah *et al.*, 2023; Mello dos Santos *et al.*, 2024).

Honey has demonstrated its effectiveness as an antibacterial and wound healing agent (Pasupuleti *et al.*, 2017). The low pH and high free acidity of SBH create an unfavourable environment for bacteria, enabling it to inhibit bacteria and pathogenic organisms and accelerate wound healing through epithelization (Esa *et al.*, 2022). Nordin *et al.* (2018) reported that SBH positively affects the cell viability and proliferation of dermal fibroblast, further supporting the capability of SBH in wound management. Rosli *et al.* (2020) revealed the SBH antimicrobial inhibition against five bacteria (*Serratia marcescens*, *Escherichia coli*, *Bacillus subtilis*, *Alcaligenes faecalis* and *Staphylococcus aureus*). Similarly, Tuksitha *et al.* (2018) reported that SBH from *G. thoracica* showed the highest antimicrobial activity against *Staphylococcus xylosus*, *Pseudomonas aeruginosa*, and *Vibrio parahaemolyticus*.

Farida *et al.* (2023) reported that the ethanolic extract of SBH (60.15%) has better inhibition potential on α-glucosidase indicating its anti-diabetic potential. The SBH obtained from different botanical origins (Acacia, coconut, mangrove, starfruit, multifruit and multifloral) showed α-glucosidase inhibition activity with the sample from coconut gave the highest inhibition at 68.32% (100 ug/mL) (Ali *et al.*, 2020). Study by animal model further confirmed the antidiabetic properties of SBH, where a daily oral administration of SBH (*Tetragonula biroi* and *T. laeviceps*) stabilized fasting blood glucose levels and reduced body weight loss (Sahlan *et al.*, 2020). Fadzilah & Omar (2023) reported that SBH from *T. apicalis*, *H. itama*, and *G. thoracica* showed anticancer potential, with SBH from *G. thoracica* demonstrated the highest antiproliferative activity against MCF-7 cells. Similarly, SB products (propolis, honey, and bee pollen) from *H. fimbriata* are better than the positive control, 5-FU, in term of their cytotoxicity against MCF-7, HeLa, and Caco-2 cancer cell lines (Arung *et al.*, 2021). However, more studies should be carried out to verify the therapeutic potential of SBH and the bioactive compounds that are responsible for these functional properties.

Table 2. Biological activities of SBH.

Bioactivities	Stingless bee (species)	References
Antioxidants	*G. thoracica; H. itama; H.erythrogastra*	Tuksitha *et al.* (2018)
	Melipona sp.	Ávila *et al.* (2019)
	H. itama; G.thoracica	Shamsudin *et al.* (2019)
Anti-diabetic	*H. itama*	Ali *et al.* (2020); Cheng *et al.* (2023)
Anti-inflammatory	*G. thoracica*	Badrulhisham *et al.* (2020)
	Melipona sp.	Biluca *et al.* (2020)
	H. itama	Majid *et al.* (2020)
Anti-cancer	*T. apicalis*, *H. itama*, *G. thoracica* and *G. thoracica*	Badrulhisham *et al.* (2020); Fadzilah & Omar (2023)

BIOACTIVE COMPOUNDS IN STINGLESS BEE HONEY

Hundreds of bioactive compounds have been identified in stingless bee honeys from different countries and regions. Since the bee harvest nectar from plants, the bioactive compounds present in SBH are largely influenced by the floral origins (Ávila *et al.*, 2018). Additionally, factors such as bee species, geographical origins, environmental and climatic conditions (including weather, soil type, rainfall, and soil mineral content), and storage conditions also play a significant role in determining the bioactive compounds in SBH (Ávila *et al.*, 2018; Martínez-Puc *et al.*, 2022; Pimentel *et al.*, 2022).

Biluca *et al.* (2017) reported that salicylic acid, p coumaric acid, naringin, and taxifolin were the main phenolic compounds in SBH. This is the first time, mandelic acid, caffeic acid, chlorogenic acid, and rosmarinic acid are reported present in SBH. In another study on stingless bee honeys from Brazil, the most abundance compounds identified were salicylic acid, p-coumaric acid, ferulic acid, aromadendrin, hispidulin and pinocembrin with some phenolic compounds were detected for the first time in SBH (Carina *et al.*, 2021). Majid *et al.* (2020) found 6 phenolic compounds (catechin, chlorogenic acid, epicatechin, protocatechuic acid, p-coumaric acid, and rutin) in SBH from *H. trigona* in Malaysia. In another study, benzoic acid was the most abundant phenolic compound in all honey samples, with concentrations ranging from 738.08 µg/100 g to 12626 µg/100 g in SBH (starfruit). The present of these compounds influenced the antioxidant activities of SBH (Shamsudin *et al.*, 2022).

Ismail *et al.* (2016) found a lower concentration of phenolic compounds in SBH as compared to *Apis* honey due to the seasonal monsoon effect, where the foraging activities of stingless bees are greatly reduced. Study by Ranneh *et al.* (2018) on various SBH from different floral origins (mangrove, *rambutan*, *longan* and starfruits) reported that a total of 13 phenolic compounds namely gallic acid, caffeic acid, caffeic acid phenethyl ester, syringic acid, catechin, apigenin, chrysin, cinnamic acid, 2-hydroxycinnamic acid, kaempferol, p-coumaric acid, quercetin-3-O-rutinosid, and 4-hydroxybenzoic acid have been identified using LC-MS-MS method.

Despite the progress of determining bioactive compounds in SBH continued, recent studies have been focusing on utilising these compounds to discriminate SBHs based on their geographical, botanical and bee species. These studies highlight the influence of seasonal variation on the chemical profile and provide valuable tools for its classification (Sharin *et al.*, 2024). Similarly, Manickavasagam *et al.* (2023) had identified some volatile organic compounds in SBH, including aldehydes, benzene derivatives, esters, hydrocarbons, and terpenoids which could be potential chemical markers for distinguishing honey samples based on their geographical origins.

PROSPECT FOR FUTURE RESEARCH

SBH has gained attention as promising functional food due to its unique nutritional properties and bioactive compounds, including high level of trehalulose, phenolic compounds and antioxidants. However, several challenges must be addressed to fully realize its potential as a sustainable industry-driven commodity. One of the key challenges is the variation in the composition of SBH, which makes it difficult to standardize the processing method required to ensure product stability and quality. Comprehensive research is needed to establish standards that are comply to the international guidelines, such as the Codex. Currently, most SBH producing countries are using Codex Standard for Apis honey while some countries including Malaysia, Indonesia, Argentina and Brazil have introduced their own standards for SBH.

The high moisture content and hygroscopic nature of SBH make it prone to fermentation and spoilage. Therefore, innovative preservation techniques, such as non-thermal dehydration methods or smart packaging technologies, are needed to improve the stability of SBH and expand its market usability. However, the conventional dehydration methods often lead to the formation of Maillard reaction products, such as hydroxymethylfurfural (HMF), acrylamide, heterocyclic amines, and advanced glycation end products, many of which are toxic or potential carcinogens and mutagens. Consequently, developing a simple, cost-effective, and non-destructive processing method is essential to retain the quality and functionalities of SBH.

The safety of SBH must be rigorously evaluated through toxicological assessments and clinical trials, particularly if it is to be marketed as a medicinal food or a therapeutic product aimed for health promotion and disease prevention. Advances in science, increasing consumer awareness on personal health, rising healthcare costs, and modern busy lifestyles have stimulated interest in "designer foods." These are foods that not only provide basic nutrients but also help to prevent degenerative disorders—a significant global issue, especially with an aging population.

Future research could focus on developing SBH as a functional food ingredient by isolating and characterizing its bioactive compounds to create products targeting specific health benefits, such as managing diabetes. SBH's low glycaemic index and antioxidant properties make it particularly appealing to health-conscious consumers. Innovations in product development could lead to its inclusion in beverages, health bars, and dietary supplements. In addition, studying the influence of geographical, botanical, and entomological origins on SBH could enhance its marketability, enable product differentiation, and support the creation of authentic SBH.Promoting high-value SBH products aligns with sustainable agricultural practices, as stingless beekeeping (melliponiculture) supports biodiversity, ecosystems and planetary health. By advancing SBH as a functional food, these efforts can also improve the livelihoods of local communities by creating economic opportunities.

CONCLUSION

SBH has emerged as a promising functional food due to its bioactive compounds which contribute to antioxidants, antimicrobial, anti-inflammatory, anti-diabetic properties, making SBH a valuable natural product. The physicochemical and bioactive compounds of SBH are significantly influenced by its botanical and geographical origins, bee species, and environmental factors, underscoring the importance of these parameters in ensuring its functional properties. As a global shift towards natural, sustainable and health-promoting products, SBH stand out as a promising source. However, challenges such as processing methods, seasonal variation, adulteration and safety must be addressed to unlock its full potential. In conclusion, SBH holds a great promise as potential functional food with health benefits and economic value. Continued research shall be done to pave it way for its global recognition as premium functional food.

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