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Review Article

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Bee Pollen: A Superfood with Health Benefits and Digestibility Challenges

Piyush Agrawal, Jaspreet Kaur* and Prasad Rasane

Department of Food Technology and Nutrition, School of Agriculture, Lovely Professional University, Phagwara, Punjab, India

***Correspondence to:**
Jaspreet Kaur
Department of Food Technology and Nutrition, School of Agriculture,
Lovely Professional University,
Phagwara, Punjab, India.
E-mail: jaspreet11795@gmail.com

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Abstract

For centuries, alternative medicine has used bee products due to their functional properties, identifying their role as a useful aid in diverse treatments. One such valuable product is bee pollen which is gathered by honeybees from different plants. It has a remarkable nutritional profile due to which it is widely used in dietary supplements in the form of granules, capsules, tablets, pellets, and powders. It is loaded with enzymes, amino acids, vitamins, minerals, carbohydrates, proteins, lipids, fiber, and various bioactive compounds including polyphenols, carotenoids, and flavonoids. These bioactive compounds exhibit a wide range of biological properties such as antioxidant, anti-inflammatory, antibacterial, antifungal, hypoglycemic, and anti-cancer. However, the digestibility of the bee pollen is greatly affected due to its robust outer layer which makes it difficult for the digestive enzymes to penetrate the pollen pellets. This significantly reduces the bioavailability of bee pollen by 50% or more. Many processing techniques have been developed to improve the digestibility and bioavailability of nutrients present in bee pollen, for its beneficial impact on human health.

Thus, a comprehensive comprehension of digestibility becomes imperative. This review paper aims to present a comprehensive overview of the nutritional composition of bee pollen and its multiple therapeutic attributes. This article also delves into the digestibility of bee pollen, the factors affecting the bioavailability of its bioactive compounds, and the underlying biomolecular pathways that propel its positive influence on various health conditions.

Keywords

Bee pollen, Nutritional constituents, Bioavailability, Digestibility, Absorption, Fermentation

Introduction

Alternative medicine has long acknowledged the therapeutic potential of bee products due to their functional properties, incorporating them as complementary aids in a multitude of treatment modalities [1]. Pollen grains serve as the male reproductive organs of flowers, carrying male gametes to their progenitor cells as part of the reproductive process of the plants. Bee pollen is formed when worker bees gather harvested pollen grains, bind them together with nectar, honey, and gland secretions, and collect them at the hive entrance [2]. It is renowned for its high concentration of enzymes, amino acids, vitamins, minerals, polyphenols, carotenoids, flavonoids, micronutrients, and physicochemical properties [3]. Studies conducted by Campos et al. [4] demonstrated that bee pollen possesses a varied nutritional profile, including carbohydrates (13 - 55%), proteins (10 - 40%), crude fiber (0.3 - 20%), lipids (1 - 13%), and ash content (2 - 6%). Numerous research revealed that bee pollen encompasses all essential amino acids, fatty acids, free amino acids, vital B-complex vitamins, indispensable minerals, carotenoids, and flavonoids [5].

Among the sugars, fructose is predominantly present, followed by glucose and sucrose, while the remaining 1% includes sugars such as arabinose, isomaltose, melibiose, melezitose, ribose, trehalose, and turanose [6]. Bee pollen is often referred to as "the ultimate complete food" because of its powerful antioxidant properties due to the presence of polyphenols, flavonoids, carotenoids, and vitamins A, C, and E [7]. These qualities have made it a popular choice for dietary supplements, as they offer significant antioxidant benefits. Multiple scientific studies have yielded evidence of the diverse biological properties of bee pollen, which can be attributed to the presence of various bioactive compounds. These compounds encompass antioxidants such as resveratrol and quercetin, hypoglycemic agents like flavonoids, anti-inflammatory constituents such as phenolics, as well as anti-cancerous effects conferred by flavonoids [3, 8].

This paper seeks to provide a comprehensive overview of the nutritional composition and therapeutic properties of bee pollen. Additionally, it aims to uncover the factors that influence its bioavailability, explore processing techniques that can enhance its digestibility, and investigate the biomolecular pathways of the various bioactive bee pollen compounds responsible for improving associated health conditions.

Nutritional Composition and Bioactive Compounds Present in Bee Pollen

Bee pollen is regarded as a magical superfood due to its nutritional profile. These include carbohydrates, lipids, proteins, free amino acids, vitamins, carotenoids, folic acid, and minerals. Flavonoids, phenolic acids, and their derivatives also play a crucial role by contributing to the bioactive properties of bee pollen [9, 10]. This composition of bee pollen varies significantly depending upon factors such as the origin of plants, the time of year the pollen is harvested, and the storage method. Due to this wide variability, extensive research has been conducted to study, summarize, and standardize the nutritional and chemical composition of bee pollen [2]. Carbohydrates are the primary component of bee pollen (13 - 55%) and are primarily composed of polysaccharides and cell wall material [3].

Many studies have reported that glucose and fructose present as monosaccharides comprise most of the sugar fraction [11]. The addition of nectar during the packaging and storage of bee-collected pollen can influence its sugar content [12]. According to the study conducted by Campos et al. [4] total dietary fiber should range between 0.3 and 20 g/100 g of bee pollen dry weight. The dietary fiber content of bee pollen had demonstrated a range of 10 – 21.4 g/100 g dry weight bee pollen with 73-82% of crude fiber [13]. Essential fatty acids, particularly omega-3 fatty acids, have significant biological activity and are crucial for the prevention of inflammatory and cardiovascular diseases as well as hormone-dependent tumors [14]. Bee pollen is an excellent source of these compounds due to its essential role in royal jelly production [3]. Campos et al. [4] reported that the lipid content of bee pollen ranges from 1 to 13 g per 100 g, while De-Melo and Almeida-Muradian demonstrated that the total lipid fraction can reach 22 g per 100 g [14].

Depending upon the origin of bee pollen lipid content varies greatly. For instance, *Brassica napus* bee pollen from Brazil, China, India, and Greece has a total lipid content of 7.4%, 6.6 %, 12.38%, and 7.76% respectively; while *Cocos nucifera* bee pollen from India and Brazil 10.43% and 4.6–5.1% total lipid content [3]. Bee pollen is also rich in protein having significantly varied amounts of protein based on the geographic location and plant species from where it is collected [15], typically ranging between 10 to 40% of the dry weight of pollen [4].

Amino acids

Bee pollen is regarded as the "most natural perfect food" due to its richness of essential amino acids that are vital for both honeybees and humans [16]. The exact composition of these amino acids can vary greatly depending upon the botanical and geographical origin of the pollen, the climate, and the nutrient availability in the plants [17]. Numerous researchers have determined the total amino acid content in bee pollen, typically ranging between 108.1 and 287.7 mg/g [18]. Studies conducted by de Melo et al. [5] identified twenty-five amino acids, eight of which are considered essential (valine, leucine, isoleucine, lysine, phenylalanine, threonine, histidine, and methionine). While the remaining includes non-essential amino acids such as aspartic acid, asparagine, glutamic acid, serine, alanine, glycine, glutamine, arginine, tyrosine, cystine, cysteine, γ-aminobutyric acid (GABA), ornithine, proline, and homoserine [6]. Proline has been found to be the most abundant amino acid in dried bee pollen from various countries, while glutamic acid dominates in freshly collected bee pollen [18].

Minerals

Bee pollen is a valuable source of essential minerals for both bees and humans. It contains about 2-6% minerals, having approximately 25 different elements [4]. One of the key minerals found in bee pollen is potassium (K), with a high concentration ranging from 400-2000 mg/100 g of bee pollen. Phosphorus (P) is another significant element found in bee pollen, ranging from 0.80 to 6 mg per 100 g of bee pollen. Magnesium (Mg) is the third most crucial mineral present in bee pollen, with concentrations ranging from 20 to 300 mg per 100 g of bee pollen. Moreover, bee pollen contains calcium (Ca) in significant amounts, ranging from 20 to 300 mg/100 g of pollen. Bee pollen contains a significant amount of calcium (Ca), ranging from 20 to 300 milligrams per 100 grams of pollen. Additionally, bee pollen is rich in these trace elements, providing substantial portions of their respective RDIs, such as 37% for iron, 79% for zinc, 36% for copper, and 85% for manganese [4]. This mineral profile of bee pollen is recommended as a definite indicator of its quality, floral, and geographical origin [3, 8].

Despite the rich nutritional profile of bee pollen, it may contain antinutritional constituents, such as phytic acid, tannins, and protease inhibitors, which have the potential to impede nutrient absorption and elicit digestive complications in certain individuals. Multiple studies have documented the presence of diverse pyrrolizidine alkaloids in bee pollen, raising concerns about their hepatoxicity and the potential development of lung cancer. The mineral composition of pollen exhibits significant variations attributable to both its botanical and geographical origins, with a pronounced correlation to the soil composition and potential anthropogenic influences. The occurrence of lead, cadmium, aluminum, strontium, arsenic, mercury, nickel, and chromium in pollen is frequently associated with sample contamination. Mycotoxins are the secondary metabolites produced by fungi, particularly those belonging to the *Aspergillus, Penicillium,* and *Fusarium* genera, they have become more prevalent in pollen over recent decades. This trend is attributed to favorable pH and water activity values of pollen, rendering them promising substrates for fungal growth. Among the multitude of mycotoxins, aflatoxins, and ochratoxins stand out as particularly hazardous to human health due to their well-established carcinogenic effects [3, 4, 8].

Factors Affecting Bee Pollen Bioavailability

Earlier research has shown that bee pollen has a wide range of beneficial therapeutic properties [3]. These include improvement of the immune function of the gut barrier in the gastrointestinal tract, reduction of inflammation, and protection against the damage caused by oxidative stress [10, 19]. The efficacy of these bioactive compounds depends on their bioaccessibility, which refers to the amount that is left and absorbed in the small intestine during digestion. Although many studies have highlighted the abundance of bioactive compounds and their beneficial effects, the outer layer of the pollen grain is not easily digested by humans, resulting in a reduced availability of nutrients [7]. The exine layer is made of a biopolymer called sporopollenin, which is chemically inert and provides a solid and flexible structure [20, 21]. The human gastrointestinal tract lacks specific enzymes needed to break down the multiple layers surrounding the pollen grains making its digestion less effective [21].

Moreover, certain bioactive compounds such as phenolics form a complex with plant polysaccharides, which can affect their release and solubility in the chyme. The digestibility of bee products can also be influenced by their botanical origin [3]. Pollen grains that have larger and more pores tend to be easier to digest due to the easy penetration of the cytoplasmic content by the digestive enzymes, leading to a more effective release of the inner content of the pollen grains. Conversely, pollen grains with thinner layers are more susceptible to being broken down by fermentation bacteria thus, improving their degree of bioaccessibility [20, 22]. Studies conducted by Di Cagno et al. [22] demonstrated the highest serum availability implies that fermentation has a positive impact on the bioaccessibility of nutrients compared to Raw-BP, due to the breakdown of pollen walls. This study emphasizes the significance of fermentation conditions and microbial composition during the processing of bee pollen for better absorption of the breakdown products in the intestines [22].

Processing Methods to Enhance the Digestibility of Bee Pollen

The cell wall of bee pollen contains two distinct layers. The outer layer, which is also known as exine, is composed of sporopollenin that contributes to the chemical resistance of bee pollen and also upholds the bioactive compounds in it. Its inner layer, intine has cellulose which is almost like the plant cell wall [23]. To enhance the accessibility of nutrients for intestinal absorption, this cell wall is broken down by utilizing various methods, such as physical, chemical, and biological techniques, along with combinations of these approaches [24]. Numerous biotechnological approaches have been suggested to process bee pollen, with fermentation standing out as the most advantageous method. Through fermentation, bee pollen undergoes a remarkable modification that enhances its content of phenolic compounds, which are readily absorbed by our bodies and known to exhibit beneficial effects [25]. The yeast fermentation process plays a crucial role in elevating the presence of compounds, such as phenolic compounds, nicotinic acid, oligopeptides, nicotinamide, fatty acids, riboflavin, and free amino acids [26].

By the partial breakdown of bee pollen cell walls, and enhanced nutrient composition, the digestibility of fermented bee pollen is increased which enhances its nutritional value [27]. For example, Zhang et al. [10] conducted a study to break the layer of bee pollen through the fermentation process using *Ganoderma lucidum and Saccharomyces cerevisiae* and the findings revealed an impressive yield of approximately 85% for *G. lucidum* and 88% for *S. cerevisiae.* In another intriguing research, the antibacterial, antifungal, and antioxidant properties of BP were observed both before and after fermentation with *Lactococcus lactis* and *Lactobacillus rhamnosus* bacteria. The results demonstrated a significant increase in the total phenolic and flavonoid content after the fermentation process. Consequently, this led to an enhancement in the antioxidant, antibacterial, and antifungal activities of BP [28].

Enzyme hydrolysis is another method that proves to be a safe, cost-effective, and convenient treatment for breaking down the BP cell walls. Pepsin, trypsin, and papain hydrolysates extracted from BP offer remarkable benefits not only in health-conscious diets but also for patients with specific conditions like cancer, cardiovascular issues, and diabetes. When compared to alternative strategies for modifying BP, the use of proteases leads to a substantial improvement in protein content (~13 - 18%), phenolics (83 - 106%), flavonoids (85- 96%), and all essential amino acids, with a significant rise in antioxidant activity of up to 68% [28]. Innovative techniques in physical processing have also proven effective in breaking down the cell walls of BP. The application of ultrasonication and high-shear technology successfully disrupted the cell walls of five different BP species.

This process led to a significant increase in the digestibility of protein, crude fat, amino acids, and reducing sugars, surpassing 80% and reaching approximately 1.5 to 2 times higher levels, respectively [11]. Furthermore, the utilization of ultrasonic temperature difference treatment, under specific conditions such as a water-to-material ratio of 20 mL/g, ultrasonic power of 400 W, temperature difference of 90°C, and an ultrasonic treatment time of 40 minutes, resulted in extracts with potential as effective functional ingredients, particularly in terms of immunomodulatory properties [29] (Figure 1).

Gastrointestinal Digestion of Bee Pollen

When pollen enters the gastrointestinal tract, it absorbs water and causes the grains to swell through the activation of enzymes. The various components of the pollen grain wall, such as pigments, enzymes, and allergens, diffuse in the acidic environment of the stomach. This leads to the outward protrusion of the inner layer of the grain, taking on the shape of a germination tube. As a result, the pollen grains disintegrate and release starch grains that are covered by a protein coating. The digestion of pollen proteins, carbohydrates, and lipids is controlled by various enzymes in the gastrointestinal system. Fatty acids, amino acids, vitamins, and sugars are released through normal processes. It is possible for pollen to directly enter the bloodstream from the gastrointestinal tract [30]. Multiple research studies have reported that BP enhances various aspects of gastrointestinal functions, such as digestion, absorption, secretions, and modulation of microbiota.

For instance, a study conducted by Li et al. [31] a specific extract of *Camellia sinensis* BP was discovered to have a protective effect on the gut in human intestinal cells. It inhibited cell damage caused by dextran-sulfate-sodium, prevented oxidative damage, and reduced the permeability of the epithelial barrier. Additionally, it was found to significantly improve the absorption and metabolism of lipids both across the intestinal lining and within the cells themselves [31]. *In vivo* studies have also shown that BP can have positive effects on digestion-related attributes in the digestive tract. A recent meta-analysis found that supplementation of rabbits with BP not only led to increased activity of digestive enzymes, such as protease, amylase, and lipase, in the intestinal content but also causes improvement in the digestibility of crude proteins, crude fibers, and other organic matter [32].

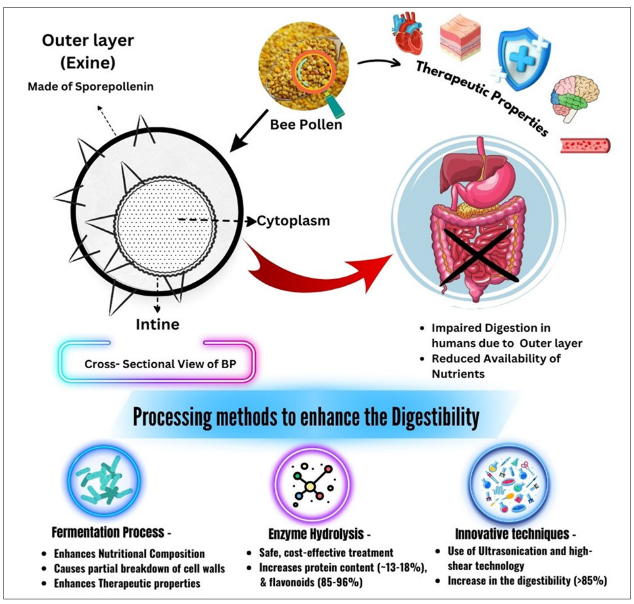

Figure 1: Reduced digestibility of bee pollen due to exine layer and processing methods to improve the digestibility of nutrients.

Furthermore, BP has the potential to increase intestinal absorption and secretory function. When rats were supplemented with *Brassica napus* BP, it was observed that at feed ratios of 0.2% and 0.5% w/w, the depth of intestinal crypts significantly increased, and it was decreased at a ratio of 0.75% w/w. However, the findings demonstrated that all ratios resulted in a significant increase in the depth of intestinal villi. Similar effects were seen in broilers, where a 1.5% supplementation of BP led to increased density and depth of intestinal crypts, as well as longer and thicker villi in the duodenum, jejunum, and ileumm [30]. These findings suggest that BP has the potential to improve the intestinal mucosa by enhancing absorption and secretory functions. Likewise, a study conducted on rodents with high-fat-induced metabolic syndrome found that supplementing with *Brassica campestris* BP had significant effects on the gut microbiota. It resulted in a reduced proteobacteria abundance, restored the disrupted firmicutes and bacteroidetes ratio due to high-fat diet, and enhanced the abundance of *Lactobacillus* and *Lactococcus*. The study also demonstrated that BP which was subjected to yeast fermentation was more effective than regular BP in breaking down its cell walls [33].

Similarly, in rats with hyperuricemia, supplementation with *Camellia japonica* BP extract led to a normalization of the firmicutes-bacteroidetes ratio, as well as levels of bacteroidetes, proteobacteria, and Clostridium. This study also observed a significant increase in the abundance of *Lactobacillus* and *Clostridiaceae*, as well as an increase in short-chain fatty acids [34]. These findings suggest that BP supplementation or the administration of BP extracts can have various preventive and corrective effects on gastrointestinal health.

Digestibility of Protein in BP

Proteins are the major component of bee pollen having a high protein content of (10 - 40%). A study conducted by Aylanc et al. [35] revealed that different phases (oral, gastric, and intestinal) of simulated gastrointestinal digestion have varying protein digestibility rates. In the oral phase of digestion, the percentage of protein in BP samples that is easily digestible was found to be around 24%, which goes up to 69% by the end of the digestion process. The gradual increase in protein digestibility after each digestion phase is due to the continuous release of the inner content of pollen grains. These grains act as natural porous capsules under simulated physiological conditions. This sustained release may contribute to the enhanced digestibility of proteins. Another study conducted by Benavides-Guevara et al. [20] demonstrated that the treatment of bee pollen with the protease enzyme led to a significant increase in protein digestibility, from 62% to 84%, in BP samples. Similar studies on different food matrices have reported digestible protein rates exceeding 80% (such as whey protein: casein) [36]. The relatively lower digestibility of BP compared to other food matrices could be due to the presence of bee pollen outer layer exine (made up of sporopollenin) and intine (cellulose/pectin-based), which are resistant to digestive enzymes and conditions.

Digestibility of BP soluble sugars

Aylanc et al. [35] identified the digestibility rates of individual soluble sugars in BP at each digestion stage for 3 different samples where the digestibility of fructose showed a consistent increase after each digestion phase in all samples, except for BP-A3 and BB-A3. This difference in BP-A3 and BB-A3 could be attributed to the slower release of fructose from these samples or the breakdown of existing fructose in the surrounding environment. On the other hand, glucose, another sugar present in significant amounts in BP, also exhibited an increasing trend in digestibility. By the end of digestion, fructose reached the highest digestibility rate of 19% (BP-A1) among different BP samples. While the maximum digestibility rate for glucose was 37% (BP-A1). These findings revealed that the digestibility rate of glucose was higher than that of fructose. This difference could be attributed to factors such as their stability at different pH levels or synergistic interactions with other compounds based on the chemical composition. Sucrose was only detected in the BP-A2 and BP-A3 samples, it was completely broken down into its individual components, glucose, and fructose in the BP-A3 sample, while sucrose released from BP-A2 continued to be hydrolyzed until the end of digestion. The breakdown of sucrose in the gastric phase can be due to the acidic environment of the stomach, which breaks the glycoside bonds between the monomeric units in the structure of the molecule, rather than digestive enzymes [36]. Additionally, the hydrolysis of sucrose into its monomers has played a major role in increasing the digestibility of fructose and glucose.

Table 1: Effect of microbial fermentation of bee pollen on its bioactive properties

Property	Effect of microbial fermentation	Ref.
Total Phenolic Content (TPC)	The process of fermentation led to a significant increase in the TPC content of BP ranging from 1.07 to 1.92 times, except for one pasteurized sample (SP3).	[37]
	The greatest impact of fermentation was observed in the non-pasteurized samples, increasing the TPC value by 1.27 to 1.92 times. In the pasteurized samples, the increase ranged from 1.07 to 1.43 times.	
	Four out of the five pasteurized samples demonstrated a significant increase of up to 9% in phenolic compounds after spontaneous fermentation.	
Total Flavonoid content (TFC)	The levels of (TFC) in the tested pollen samples showed a significant increase of 1.1 - 1.6 times after fermentation.	[37]
	The highest amount of TFC was found in a pollen sample from Lithuania, with values of 6.26 ± 0.11 mg/g (RUE) before fermentation, 9.67 ± 0.13 mg/g (RUE) after fermentation with lactic acid bacteria, and 8.84±0.18 mg/g (RUE) after spontaneous fermentation.	
	Maltese bee pollen sample demonstrated the lowest TFC values of 3.69 ± 0.11 mg/g (RUE) before fermentation, 5.41±0.05 mg/g (RUE) after fermentation with lactic acid bacteria, and 4.99 ±0.09 mg/g (RUE) after spontaneous fermentation.	
	Similar results were revealed by Latvian pollen after spontaneous and bacterial fermentation where the concentration of TFC enhanced by 1.6-2.1 times after spontaneous fermentation, 1.7 - 2.2 times after fermentation with *L. lactis*, and 1.8-2.4 times after fermentation with *L. rhamnosus*.	
Radical Scavenging Activity (RSA)	The evaluation of RSA demonstrated a significant increase after spontaneous and bacterial fermentation, ranging from 35.3% to 133.5% at a significance level of $p \leq 0.05$.	[20, 37]
	In a study conducted on Indian pollen, the RSA activity increased from 67% before fermentation to 86% after fermentation using *L. lactis* culture for the bioprocess.	
	For the Latvian pollen, the RSA increased by 1.3 - 1.9 times after fermentation with *L. lactis* bacterial culture, 1.5-2.0 times after fermentation with *L. rhamnosus*, and 1.4- 1.7 times after spontaneous fermentation.	
Antibacterial activity	The bee pollen samples demonstrated antimicrobial activity against *M. luteus, S. aureus, E. coli,* and *P. roqueforti* both before and after fermentation.	[37]
	The antibacterial activity increased in all non-pasteurized bee pollen samples after spontaneous fermentation or fermentation with added bacteria.	
	The extent of antibacterial activity was affected by the specific bacteria used in the tests. *E. coli* exhibited the highest resistance to the bee pollen extracts, while *M. luteus* displayed the highest sensitivity among the tested bacteria.	
	The fermentation process was shown to significantly enhance the antibacterial activity, with some cases exhibiting up to a 15-fold increase. These findings highlight the potential of fermentation in augmenting the antimicrobial properties of bee pollen samples.	
Antifungal activity	In addition to enhancing antibacterial activity, fermentation also increased the antifungal activity against *P. roqueforti*.	[37]
	Spontaneously fermented non-pasteurized bee pollen exhibited higher inhibition against the fungi compared to samples fermented with bacteria.	
	Strong correlations were observed between the content of total phenolic compounds, total flavonoids, radical scavenging activity, and antifungal activity.	
	These findings highlight the complex relationship between the chemical composition of bee pollen, its antioxidant activity, and its antifungal properties, which can be influenced by the fermentation process.	
	These findings indicate that fungi and yeast tend to be more resilient to the effects of bee pollen extracts compared to bacteria. Therefore, fermentation presents an intriguing opportunity to enhance the antifungal activity of bee pollen.	

Microbial fermentation of bee pollen

In a study conducted by Kaškonienė et al. [37], five different samples of naturally collected bee pollen were subjected to fermentation using *L. rhamnosus and L. lactis bacteria*, while one sample was left without any bacterial addition. The objective was to understand the changes that the fermented pollen undergoes. Similar studies were conducted with pasteurized bee pollen to ensure that the observed effects were solely due to fermentation and to eliminate the influence of natural microflora present in the bee pollen (Table 1).

Conclusion and Future Perspectives

The therapeutic potential of bee products in alternative medicine has been long recognized due to their functional properties. This review has suggested that bee pollen is renowned for its rich nutritional profile and physicochemical properties. It contains a diverse range of enzymes, amino acids, vitamins, minerals, polyphenols, carotenoids, flavonoids, and micronutrients. These qualities have made it a popular choice for dietary supplements, offering significant antioxidant benefits. Moreover, scientific research has demonstrated that bee pollen exhibits a wide variety of biological properties, including antioxidant, hypoglycemic, anti-inflammatory, antibacterial, and anticancer effects.

These findings highlight its potential as a natural therapeutic agent. The unique pharmacological properties of BP can be attributed to the diverse array of bioactive compounds it contains, such as resveratrol, quercetin, flavonoids, and phenolics. Despite the potential benefits offered by these compounds, the resilience of BP's outer pollen grain layer, composed primarily of sporopollenin, presents a challenge. This chemically inert biopolymer provides structural robustness to the pollen grain, making it resistant to digestion by human enzymes. Numerous methods, including physical, chemical, and biological techniques, have been investigated to overcome this obstacle and enhance nutrient accessibility. Among these methods, fermentation has emerged as a particularly promising biotechnological approach.

However, the lack of standardized composition in BP presents a significant hurdle. This lack of consistency is influenced by factors such as geographical area, climate, plant variations, extraction, and analysis methods, and more. Furthermore, there is limited data available on the safety, potential allergies, toxicity, and therapeutic effectiveness of BP from clinical studies. Therefore, further research is necessary to establish standardized protocols for extraction and analysis, gain a comprehensive understanding of BP's metabolism, and explore its impact on the gut microbiota. Additionally, it is essential to determine safe and toxic dosages, investigate the effects of BP in preclinical and clinical studies, and examine potential synergistic or antagonistic interactions with synthetic drugs. Developing a deeper understanding of these attributes could greatly contribute to the promotion of BP's use in the general population and the exploration of new natural pharmaceutical products for disease treatment in conjunction with traditional therapies.

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Conflict of Interest

None.

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