https://doi.org/10.15407/animbiol28.01.003
UDC 638.178.2
Received 12.01.2026 ▪ Revision 04.05.2026 ▪ Accepted 20.05.2026 ▪ Published online 11.06.2026

Microbial fermentation of bee bread (perga) and its impact on nutrient bioavailability and physiological responses

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Authors' Contributions:
BRO: Conceptualization; Review design; Data curation; Formal Analysis; Writing — original draft, review & editing. The author has read and agreed to the published version of the manuscript.

Declaration of Conflict of Interests:
The author declares no conflict of interest.

Ethical approval:
This article does not contain any studies with animals or human participants performed by the author.

Acknowledgements:
This research received no external funding.

Bee bread (perga) is a fermented bee product resulting from the microbial transformation of collected pollen inside the beehive. This review examines how the microbial fermentation of bee bread enhances the bioavailability of nutrients and explores the physiological responses associated with its consumption. In the hive, lactic acid bacteria and other microbes ferment pollen mixed with nectar and bee enzymes under anaerobic conditions, leading to partial degradation of the pollen cell walls and the synthesis of beneficial metabolites. Compared to raw bee pollen, bee bread contains higher levels of free amino acids, vitamins, including the B-complex group (B_1, B_2, B_3, B_6, B_9) and K, and bioactive compounds, making its nutrients more readily absorbable. The fermentation process increases nutrient digestibility and preserves the pollen by producing organic acids that inhibit spoilage. We discuss the composition differences between pollen and bee bread and how these affect nutritional value and bioavailability. The physiological effects of bee bread consumption are also reviewed: in honey bees, it supports colony health and immunity, while in other animals and humans, bee bread exhibits antioxidant, antimicrobial, and anti-inflammatory activities. Animal studies have demonstrated that dietary bee bread can improve metabolic profiles, alleviate oxidative stress, and protect against certain toxicities. Bee bread thus emerges as a functional food with enhanced nutrient availability and potential health benefits. This article highlights the biological significance of microbial fermentation in converting pollen into bee bread and the consequent implications for nutrition and health.

Keywords: bee bread, perga, lactic acid fermentation, nutrient bioavailability, physiological effects, functional food

Introduction

Bee bread (known as *perga* in Ukrainian beekeeping terminology) is a natural fermented product of the honey bee hive, created by the transformation of flower pollen through microbial activity. Honey bees collect pollen from flowers as a primary source of proteins, lipids, vitamins, and minerals necessary for their growth and colony development. It should be noted, however, that consumption of freshly collected pollen and the storage of pollen for fermentation into bee bread occur in parallel: nurse bees show a clear preference for freshly stored pollen for their immediate nutritional needs, while a substantial part of the collected pollen is simultaneously packed into comb cells for long-term storage as bee bread [8]. A significant fraction of the collected pollen therefore undergoes a process to convert it into bee bread, which involves packing the pollen into comb cells, mixing it with honey or nectar and glandular secretions (including enzymes and beneficial microbes from the bee's saliva), and sealing it under anaerobic conditions with a layer of honey and wax. This sealed pollen undergoes a lactic acid fermentation over several days, resulting in what beekeepers and scientists call bee bread — a brown, compact substance with a sour aromatic taste and high nutritional value [2, 13].

Microbial fermentation is the key distinguishing feature between raw bee pollen and bee bread. In the collected pollen pellets, the outer wall (exine) of pollen grains is largely indigestible; many nutrients remain locked inside the tough pollen coat. The fermentation process initiated by microbes begins to break down these pollen walls and complex nutrients, making them more accessible. Lactic acid bacteria (LAB) are predominantly responsible for this fermentation. Studies have shown that fresh bee pollen is inoculated with a rich community of microorganisms from the honey bee's crop (honey stomach) during collection and packing, including multiple species of *Lactobacillus* and *Bifidobacterium*, as well as yeasts, which start proliferating once the pollen is stored [14]. Under the anaerobic and sugar-rich conditions in the comb cell, these microbes produce lactic acid and other metabolites that preserve the pollen and prevent decay. Within about a week of storage, the pollen is transformed into bee bread through this lactic acid fermentation [2]. The lactic acid lowers the pH, suppressing spoilage bacteria and fungi, thereby naturally conserving the pollen for long-term use by the colony [14].

The importance of bee bread for the honey bee colony cannot be overstated. Bee bread serves as the primary protein and vitamin source for nurse bees and larvae. During periods of brood rearing, bees rely on stored bee bread to meet their nutritional needs, especially when fresh pollen foraging is limited (*e.g.*, in early spring or during dearths) [5]. By fermenting and storing pollen as bee bread, bees ensure a stable, year-round supply of high-quality nutrition. Furthermore, the fermentation process not only preserves the pollen but also enhances its nutritional profile. Bee bread has been found to be more nutritious and digestible for bees than raw pollen, contributing to better growth of larvae and overall colony health [6]. Conversely, a lack of sufficient bee bread in the hive can lead to protein shortages, negatively impacting brood development and the bees' immune functions [11]. Thus, understanding the microbial fermentation of bee bread is essential for appreciating how bees naturally augment their food and how this fermented product can benefit other organisms that consume it.

Beyond its role in the hive, bee bread has attracted attention as a functional food for humans and animals. Traditional apitherapy and modern research both suggest that bee bread consumption can confer health benefits, potentially more so than unfermented bee pollen [5]. This is attributed to the changes brought by fermentation: an increase in bioavailable nutrients, the presence of probiotic microbes or their metabolites, and a broad spectrum of bioactive molecules. Recent years have seen a surge in studies on bee bread's chemical composition and medicinal properties *in vitro* and *in vivo*, aiming to evaluate its antioxidant capacity, antimicrobial effects, and impact on metabolic health [5, 14]. Additionally, there is interest in replicating the natural fermentation process through biotechnological means to produce "artificial" bee bread or fermented pollen for use as dietary supplements [2].

In this review, we will first describe the microbial communities involved in bee bread fermentation and the biochemical transformations that occur during this process. We will then compare the nutrient composition of bee bread with that of fresh pollen, highlighting how fermentation affects macronutrients and micronutrients and improves their bioavailability. Next, we discuss the physiological and health effects observed from bee bread consumption, both in honey bees (*e.g.*, on immunity and longevity) and in other animals or humans (such as antioxidant, anti-inflammatory, and metabolic regulatory effects). Finally, we touch on the potential applications of bee bread and fermented pollen in nutrition and medicine, and outline future research directions for fully elucidating the benefits of this remarkable natural fermentate.

Microbial Fermentation Process of Bee Bread

Microbial Communities in Bee Bread (Perga)

The conversion of pollen into bee bread is primarily a microbiological process. When field bees collect pollen, they moisten it with nectar and salivary secretions to form it into pellets that stick to their hind legs (in the corbiculae, or "pollen baskets"). These salivary secretions are not sterile; they contain a rich microbiota derived from the bee's honey stomach and mouthparts. Research has identified a large and diverse flora of lactic acid bacteria (LAB) in the honey bee's crop which gets introduced into pollen during collection and storage [14]. Vásquez and Olofsson (2009) were the first to demonstrate that bee bread is likely fermented by this endogenous honey bee LAB community. In their study, they isolated numerous LAB strains from fresh bee pollen and bee bread samples, including *Lactobacillus* and *Bifidobacterium* species that matched those found in the bee's honey stomach [14]. They found that shortly after pollen is packed and begins fermentation (within ~2 weeks), these LAB are present in high numbers, actively fermenting the pollen into bee bread. However, in older, fully fermented bee bread (stored for months), the viable counts of these LAB decrease significantly, likely because the fermentation has completed and the environment has stabilized with high acidity [14].

The LAB identified in bee bread and bee pollen belong to several species, often specific to the bee environment. Common examples include *Lactobacillus kunkeei* (reclassified in 2020 as *Apilactobacillus kunkeei* [15], a member of fructophilic lactic acid bacteria, FLAB) and related lactobacilli, as well as *Bifidobacterium asteroides* and other bifidobacteria that are known gut symbionts of bees. These bacteria produce lactic acid (from fermenting sugars in the pollen/honey mixture) and other antimicrobial substances (like bacteriocins, hydrogen peroxide, etc.), contributing to the preservation of bee bread and possibly to disease prevention in the colony [14]. The presence of honey bee LAB and their metabolites in bee bread is thought to help suppress pathogenic microbes (such as *Ascosphaera* fungi that cause chalkbrood, or bacteria that could spoil the pollen), thereby protecting both the food store and the bees that consume it [14]. Indeed, bee larvae and adults consume bee bread containing these LAB and their fermentation products, which might act as a form of probiotic or immune booster for the bees. This symbiotic relationship underscores how bees harness microbial activity for both nutritional and protective advantages.

In addition to LAB, other microorganisms have been detected during the bee bread fermentation process. Yeasts, for example, can be present in stored pollen. Early studies by Gilliam and colleagues isolated yeasts (such as *Saccharomyces* and *Candida* species) from bee bread, although their exact role is less clear compared to bacteria. Some yeasts may participate in fermentation in the initial stages when oxygen is still available or consume by-products of bacterial fermentation. However, the environment in a sealed cell quickly becomes anaerobic and acidic, favoring LAB activity. Some research has also noted *Pseudomonas* and other environmental bacteria in bee bread [2], but these might play a minor role or be transient contaminants. The dominant biochemical activity is attributed to lactic fermentation by LAB, which effectively "outcompetes" other microbes due to acid production and low pH tolerance [2].

It is worth noting that the microbiota of bee bread can vary somewhat depending on the hive and environmental conditions. Factors such as the initial microbial load on the pollen (which can depend on floral source), hive microclimate, and beekeeping practices (*e.g.*, use of antibiotics or other substances) might influence which microbes proliferate. Nonetheless, the core fermentative community — honey bee LAB coming from the bees themselves — appears to be a consistent driver of the process. Modern deoxyribonucleic acid (DNA)-based methods, including amplicon sequencing of the 16S ribosomal ribonucleic acid (rRNA) gene, internal transcribed spacer (ITS) profiling of fungal communities, shotgun metagenomics, and culture-dependent isolation of fermentative strains followed by matrix-assisted laser desorption/ionization time-of-flight mass spectrometry (MALDI-TOF MS) identification, have confirmed that bee bread typically harbors a relatively simple microbial community enriched in lactic acid bacteria, distinct from fresh pollen which may carry more environmental microbes but fewer LAB until bees add them [9]. This illustrates that bee bread fermentation is a controlled, inoculated fermentation orchestrated by the bees through their symbiotic bacteria.

Biochemical Changes During Fermentation

The transformation from raw pollen to bee bread involves significant biochemical changes brought about by the metabolic activities of the microbes and the enzymes added by bees. One of the most important changes is the production of lactic acid from the fermentation of sugars (primarily the simple sugars from nectar/honey added to the pollen). The accumulation of lactic acid drives the pH of the stored pollen down (often to around 4.0), creating an acidic environment [14]. This acidification acts as a natural preservative, inhibiting the growth of spoilage organisms and fungi. It also causes the pollen grains to soften. The acidic conditions, combined with the action of enzymes (such as amylases, proteases) from both bees and microbes, result in partial digestion of the pollen contents. The tough outer exine of pollen, composed of sporopollenin, is not entirely broken down by lactic fermentation, but it can be partially cracked or its contents leached out to some extent. There is evidence that the exine integrity is reduced, and the internal nutrients of pollen become more exposed in bee bread than in fresh pollen [2, 6]. For example, microscopy studies have shown that fermented bee bread pollen grains often have more porous or fractured exines compared to unfermented pollen, indicating that microbial enzymes may perforate the pollen coat. As a result, nutrients like proteins and starches that were inside the pollen are more accessible for digestion when bees (or other animals) consume bee bread [6].

Another key change is in the protein profile. During fermentation, some of the complex proteins from pollen are broken down into smaller peptides and free amino acids by proteolytic enzymes. These enzymes could originate from bee saliva or microbial activity. Bee bread consistently shows a higher content of free amino acids relative to equivalent fresh pollen, implying partial protein hydrolysis has occurred [1, 7]. Bayram et al. (2021), who analyzed bee pollen and bee bread of the same botanical origin, found notable differences in amino acid profiles: bee bread had increased levels of certain free amino acids and smaller peptides, which can be more easily absorbed in the digestive tract [7]. Similarly, enzymes degrade some polysaccharides into simpler sugars. While pollen is already rich in sugars due to added honey, any complex carbohydrates present (for instance, the outer layers of pollen or fiber components) may be partially broken down, potentially improving digestibility.

Vitamin content can also change. Some vitamins are synthesized or augmented by microbial action. A classic example is vitamin K: lactic acid bacteria are known to produce vitamin K (menaquinones) as metabolic by-products. Bee bread has been reported to contain vitamin K, whereas raw pollen typically has minimal vitamin K activity, suggesting microbial synthesis during fermentation [13]. Bee bread also retains water-soluble vitamins such as vitamin C better due to the acidic, low-oxygen environment which can reduce oxidation. Additionally, fermentation may increase levels of certain B vitamins (like folate or riboflavin) through microbial production, though specific data on each vitamin varies with the study. Overall, bee bread tends to have a broader spectrum of vitamins (A, B-complex, C, E, and K) available in bioactive forms [5, 13].

Organic acids besides lactic acid are produced as well. Acetic acid, formic acid, and propionic acid in small quantities have been found in bee bread, contributed by various microbes (for instance, some *Lactobacillus* can produce acetic acid alongside lactic acid in heterofermentation). These acids further contribute to flavor and preservation. The presence of these acids (and the lowered pH) means bee bread is a bit sour to taste in comparison to raw pollen.

Fermentation also influences polyphenolic compounds. Pollen is known to be rich in polyphenols (flavonoids, phenolic acids, etc.), many of which are antioxidants. The fermentation process can cause changes in these compounds: some polyphenols may be freed from bound forms (such as glycosides) into aglycones, potentially increasing their bioavailability or antioxidant activity. Conversely, some sensitive polyphenols might partially degrade in the acidic environment. However, studies generally show that bee bread retains a high polyphenol content and strong antioxidant capacity, often comparable to or even higher than that of fresh pollen from the same source [5]. For instance, one analysis noted that certain flavonoids like quercetin and kaempferol were readily detectable in bee bread, and the total phenolic content remained high, contributing to bee bread's potent ability to scavenge free radicals in assays [5]. This indicates that fermentation does not diminish the antioxidant potential and may in fact render some of these bioactive molecules more accessible.

In summary, the microbial fermentation of bee bread leads to a product that is biochemically distinct from the raw pollen input. Key changes include: a drop in pH due to lactic acid accumulation; partial digestion of proteins into amino acids; possible increase in certain vitamins; preservation of phenolics with potential structural modifications; and overall stabilization of the matrix. These changes collectively enhance the nutritional profile and shelf-life of bee bread, making it a rich, preserved food source for bees and a potentially valuable supplement for other species. The next sections will delve into how these compositional differences translate to improved nutrient bioavailability and physiological effects.

Nutrient Composition and Bioavailability in Bee Bread *vs.* Pollen

Enhanced Nutrient Profile of Bee Bread

Bee bread contains a complex array of nutrients largely derived from pollen, but with notable quantitative and qualitative differences resulting from fermentation. In terms of macronutrients, bee bread is high in proteins (including a range of essential amino acids), carbohydrates (simple sugars primarily, and some polysaccharides), and lipids (especially unsaturated fatty acids from pollen). Additionally, it is a good source of dietary fiber (from pollen grain coats) and is particularly dense in micronutrients like vitamins and minerals. Many analyses of bee bread from various regions have identified over 200–300 different compounds, underlining its richness as a food source [5]. For example, A. Bakour (2022) compiled that bee bread typically contains about 20–25 % proteins, 3–5 % lipids, 30–40 % carbohydrates (including around 15–25 % simple sugars), and significant amounts of minerals such as potassium, magnesium, calcium, iron, and zinc [5]. The exact composition can vary depending on the botanical origin of the pollen and local environmental factors, but generally bee bread is considered a nutritionally complete food for bees, and by extension a concentrated source of nutrients for human diets as well. More recent analytical studies confirm and extend these data: Aksoy (2024) determined detailed profiles of phenolic compounds, free amino acids, sugars, and organic acids in Anatolian bee bread, reporting that gallic acid was the dominant phenolic (up to 39.97 µg/g), aspartic acid the most abundant amino acid, fructose the prevailing sugar, and succinic acid the principal organic acid (up to 73.63 mg/g), with high total phenolic content and strong 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical-scavenging activity [1]. A complementary recent review by Ćirić et al. (2022) additionally emphasises that besides LAB and yeasts, smaller numbers of *Bacillus* spp. (*B. subtilis*, *B. megaterium*, *B. licheniformis*) have also been detected in bee bread, underlining the broader microbial diversity contributing to its functional value [9].

One notable aspect is that bee bread usually has slightly higher moisture content (around 20–30 %) than dried pollen, since it is stored with honey and fermentation produces water. However, the water is partly consumed during fermentation and the final moisture is low enough to prevent spoilage, aided by the high acidity and presence of sugars and antimicrobial compounds. The ash content (mineral content) of bee bread is often around 2–4 %, reflecting its wealth of minerals derived from pollen soil contact and plant origin.

Qualitatively, due to fermentation, bee bread's nutrients are often in a more accessible form. Aylanc et al. (2021) highlighted that bee bread has a higher nutritional value and digestibility than unfermented bee pollen, emphasizing that many dietary phytochemicals and nutrients become more bioavailable after the fermentation process [2]. They noted that processes like the breakdown of pollen walls and partial hydrolysis of biopolymers increase the fraction of nutrients that can be absorbed in the gut. For instance, as mentioned earlier, the free amino acid content is increased. Essential amino acids such as lysine, threonine, and valine, which are present in pollen proteins, appear in higher free concentrations in bee bread [7]. This can be crucial for absorption because free amino acids and small peptides can pass through intestinal walls more easily than complex proteins that require thorough digestion.

In terms of sugars, raw pollen might contain starch or complex carbohydrates that bees cannot directly utilize. Bee bread fermentation can convert these into simpler sugars like glucose and fructose. Moreover, bees often add some honey to the pollen, which introduces readily available sugars that the fermentation does not consume entirely. Thus, bee bread tends to be slightly sweeter and immediately energy-rich compared to plain pollen.

Vitamin content in bee bread is generally reported as equal or higher than in pollen. Bee bread is especially known for its B vitamins content (*e.g.*, bee bread can be a good source of riboflavin, niacin, and folic acid), vitamin C, and vitamin E (tocopherols). The presence of vitamin K2 (menaquinone) produced by LAB fermentation is a unique addition in bee bread. Also, provitamin A carotenoids from pollen (like beta-carotene) remain present and contribute to vitamin A activity. A study on stingless bee bread (by *Heterotrigona* stingless bees) also showed substantial vitamin content, indicating fermentation benefits across bee species [5].

Minerals in bee bread remain largely similar to pollen's mineral profile (since minerals are not destroyed or created by fermentation). However, the relative bioavailability of minerals like iron, zinc, and calcium might increase if fermentation degrades phytic acid or other mineral-binding compounds in pollen. Phytate, which can chelate minerals and reduce their absorption, might be broken down by microbial phytase enzymes during fermentation, as suggested in analogies with other fermented foods. If so, bee bread would have more bioaccessible minerals than raw pollen. While specific data on phytate in bee bread is scarce, the general trend in fermentation of plant seeds (which pollen can be analogous to) is a reduction in phytate content.

Another difference is the presence of unique bioactive compounds produced during fermentation. These include organic acids (lactic, acetic) which not only preserve the food but also can have probiotic benefits in the gut (*e.g.*, supporting beneficial gut flora in consumers). Bee bread may also contain fermentation-derived peptides or polysaccharides that were not present in raw pollen, some of which could have biological activity. For example, certain short peptides might act as antioxidants or signaling molecules in the body.

It should be noted that the exact nutritional composition can vary widely with the botanical origin of the pollen that went into the bee bread. Pollen from different plant species has different protein and lipid contents; thus, bee bread from those pollens will reflect those differences. Moreover, multi-floral (polyfloral) bee bread, which is common in nature, is a mix of pollens, often providing a broad nutritional base and potentially balancing out deficiencies of any single pollen type. Comparative studies have demonstrated that the nutritional composition of stored bee food in honey bee colonies (including bee bread) strongly depends on the diversity of floral sources — colonies with access to diverse flora had bee bread richer in a wide range of amino acids and nutrients, indicating the importance of floral variety for optimal bee nutrition [5]. However, once fermented, even pollen from less nutritious plants can become more beneficial to bees than it was in raw form, thanks to the microbial enrichment and preservation process.

Improved Bioavailability and Digestibility

One of the main advantages of bee bread over unfermented pollen is the improved bioavailability of its nutrients. **Bioavailability** refers to the proportion of nutrients that can be absorbed and utilized by the body. In the context of bee bread, this concept applies both to honey bees (how well bees can digest and use the nutrients) and to other animals or humans who might consume bee bread as a supplement.

For honey bees, studies have long suggested that they derive more nutrition from bee bread than from fresh pollen. This is partly intuitive: the bees themselves evolved this fermentation process presumably to maximize the nutritional extraction from pollen. Bee bread is softer and more easily consumed by nurse bees, who then produce royal jelly and feed larvae. There are indications that when bees are fed only fresh pollen versus bee bread, those on bee bread show better growth or physiological parameters. For example, an early comparative study reported that bees fed stored pollen (bee bread) showed higher hemolymph protein titers and greater hypopharyngeal gland development than those fed an equal amount of freshly collected pollen, underlining that fermented pollen is more efficiently converted into bee tissue and bee brood food [10]. DeGrandi-Hoffman et al. (2013) compared bee bread made by Africanized *vs.* European honey bees and observed that, despite some compositional differences, both types of bee bread supported high protein levels in bee hemolymph, essential for brood rearing, indicating its high nutritional efficacy [10].

In terms of human or animal digestion, the breaking down of pollen walls and large molecules by fermentation is crucial. Human digestive enzymes are not very effective at breaking the sporopollenin coat of pollen; thus, if one consumes raw pollen granules, a significant fraction may pass through the gut undigested, with nutrients still trapped inside intact pollen grains. Bee bread mitigates this problem. As fermentation breaches the pollen walls and pre-digests some content, it effectively "unlocks" the nutrients. Habryka et al. (2016) (as cited in other works) reported that bee bread has a higher assimilation rate and is absorbed better at the human intestinal level than plain pollen [6]. In practice, this means that consuming bee bread could result in more proteins, amino acids, and vitamins entering the bloodstream than the same amount of raw pollen would yield.

In vitro digestibility tests provide evidence for this. For instance, simulated gastric and intestinal digestion models have shown that bee bread releases more soluble protein and peptides compared to unfermented pollen under the same conditions [2]. Other experimental processing studies on bee pollen have similarly demonstrated that fermentation significantly improves the digestibility of pollen proteins and carbohydrates, making more of these nutrients available for absorption [2, 13]. Additionally, Kieliszek et al. (2018) in their review noted that fermentation increased the bioaccessibility of certain micronutrients and phytochemicals — for example, some antioxidant compounds become more active or more easily absorbable after the fermentation breaks them from complex structures [13].

Another aspect of bioavailability is how bee bread's nutrient profile can influence gut microbiota in larger animals. Because bee bread contains lactic acid bacteria (either live or inactivated, but their cell components remain) and fermentation metabolites, it can act somewhat like a probiotic or prebiotic. For example, lactic acid and short-chain fatty acids present in bee bread can lower intestinal pH and promote beneficial microbes in the gut if consumed, potentially aiding overall nutrient absorption and gut health. While direct studies on humans are limited, analogous effects are known from fermented foods like yogurt or sauerkraut, and bee bread might have similar mild probiotic effects.

In summary, bee bread offers improved digestibility because:

- The mechanical barrier of pollen exine is partially overcome.
- Proteins and carbs are pre-digested into smaller forms.
- Anti-nutritional factors (like enzyme inhibitors or phytates) are reduced.
- It comes naturally loaded with digestive aids (enzymes and organic acids from the fermentation).

For these reasons, bee bread's nutrients are more bioavailable. This underlies many of the reported physiological benefits, as a greater fraction of nutritional and bioactive compounds can enter an organism's metabolism when consuming bee bread as opposed to raw pollen.

Physiological and Health Effects of Bee Bread

Effects on Honey Bee Physiology and Colony Health

Within the bee colony, bee bread is fundamentally important for various physiological processes of individual bees and the overall health of the colony. Nurse bees, which are young worker bees, consume large amounts of bee bread to develop their hypopharyngeal glands (which produce royal jelly for feeding the queen and larvae). The high protein and vitamin content of bee bread is critical in this regard. Adequate consumption of nutrient-rich bee bread allows nurse bees to secrete quality royal jelly, directly influencing the growth and immune strength of bee larvae. If bee bread is in short supply or of poor quality, nurse bees exhibit underdeveloped glands and cannot rear brood optimally, leading to weaker or fewer new bees.

Protein is a limiting nutrient for bee colony growth; thus the role of bee bread in supplying digestible protein translates to faster brood development and greater brood rearing capacity. Colonies provided with high-quality bee bread (either by natural foraging or beekeepers supplementing with collected bee bread) often show increased brood area and higher young bee populations. This is partly because bee bread's enhanced digestibility means each unit consumed yields more nutrients, effectively boosting the colony's nutritional status [11]. Conversely, bees forced to subsist on only fresh pollen (for instance, in experiments) often cannot derive nutrition as efficiently, which can slow brood rearing.

Bee bread also impacts the immunocompetence of bees. A well-fed bee (with ample bee bread in diet) can maintain stronger immunity. Pollen/bee bread contains important amino acids like arginine and phenylalanine that are precursors for immune-related compounds (*e.g.*, enzymes like phenoloxidase in insect immunity). Additionally, certain components in bee bread, such as flavonoids and vitamins, have antioxidant and antimicrobial properties that can reduce oxidative stress and pathogen load in bees. There's evidence that colonies with good pollen stores (thus likely good bee bread stores) have lower incidences of diseases like *Nosema*, possibly because the bees' improved nutrition and the presence of beneficial microbes in bee bread help stave off infections [11]. For example, one study found that adding fermented pollen (bee bread analog) to diets reduced the proliferation of *Nosema* microsporidia in experimentally infected bees, suggesting a protective effect, although more research is needed for confirmation.

Energy provision is another physiological aspect. Bee bread's carbohydrates (mostly glucose and fructose from honey) supply energy for daily activities. While nectar/honey is the primary energy source for foragers, inside the hive, the mixture of honey in bee bread provides energy for house bees involved in brood care and other tasks. Additionally, the fermentation process may produce small amounts of ethanol (though typically minimal, not enough to intoxicate bees, but detectable) and CO_2. These by-products are usually not harmful; CO_2 dissipates and ethanol is either evaporated or present in trace that bees can metabolize.

Furthermore, bee bread consumption by nurse bees triggers vitellogenin production — vitellogenin is a key egg yolk protein and also serves as an antioxidant and longevity protein in worker bees. High vitellogenin levels, supported by good nutrition (especially protein and fat intake from bee bread), correlate with longer-lived worker bees and better overwintering survival of colonies. Thus, bee bread indirectly influences bee lifespan and stress resistance through hormonal/nutritional pathways. Dolezal and Toth (2018) review highlights the feedback between nutrition and disease: well-nourished bees (plentiful bee bread) can better tolerate pathogens and stress, whereas malnourished bees are more susceptible to parasites and have shorter lifespans [11]. They emphasize that improving pollen nutrition (*e.g.*, through diverse, abundant bee bread) is a key aspect of maintaining colony health in the face of challenges like viruses, *Nosema*, and pesticides.

Finally, an interesting physiological response is how bees self-regulate their intake of bee bread. Some observations suggest bees prefer fermented pollen (bee bread) to unfermented pollen if given a choice, possibly because they instinctively sense its higher nutritional payoff or better taste (due to lactic acid making it more palatable in moderate amounts). This feeding preference indicates that from an evolutionary perspective, bees are adapted to rely on fermented pollen for optimal health, and direct consumption of raw pollen might be a fallback only when bee bread isn't yet available (like during heavy foraging days, newly collected pollen might be partially eaten but generally bees pack most of it away to ferment).

In summary, the physiological responses of honey bees to bee bread are overwhelmingly positive: improved growth and development of brood and glands, enhanced immune function, and possibly extended longevity and better stress tolerance. Adequate bee bread stores are one indicator of a thriving colony, while colonies lacking in bee bread often exhibit signs of nutritional stress such as cannibalism of brood or poor brood viability. The fermentation of pollen into bee bread is thus a crucial natural strategy bees use to maintain their health and ensure the success of the colony.

Health Benefits and Functional Properties for Other Animals and Humans

While bee bread's primary consumers are honey bees, there is a growing body of research examining its effects when consumed by other animals, including humans. Bee bread can be considered a functional food — it not only provides basic nutrition but also confers additional health benefits due to its bioactive components. A number of *in vitro* and *in vivo* studies have explored these benefits:

Antioxidant Activity. Bee bread is rich in antioxidants such as polyphenols (flavonoids like quercetin, kaempferol, naringenin, etc., and phenolic acids like caffeic and ferulic acid) as well as vitamins C and E. These contribute to a high radical-scavenging capacity. In lab assays, bee bread extracts have demonstrated strong antioxidant activity, often comparable to or higher than that of propolis or bee pollen extracts [5]. This antioxidant property is significant because oxidative stress is a component of many chronic diseases and aging processes. By neutralizing free radicals, bee bread could help reduce oxidative damage in tissues.

Anti-Inflammatory and Immunomodulatory Effects. Some studies suggest that bee bread can modulate inflammatory responses. The presence of flavonoids and other components that inhibit pro-inflammatory enzymes (like cyclooxygenase-2 (COX-2)) or cytokines may explain this. For instance, in animal models of induced inflammation, supplementation with bee bread or its extracts was associated with reduced markers of inflammation (such as lower C-reactive protein (CRP) levels and inflammatory cytokines) [5]. Bakour et al. (2017), in their study with aluminum-intoxicated rats, noted that bee bread not only ameliorated oxidative stress but also lowered inflammatory markers (like CRP and white blood cell counts that were elevated due to toxicity) [3]. This indicates bee bread's anti-inflammatory potential.

Metabolic and Cardiovascular Effects. Bee bread seems to have beneficial effects on metabolic parameters in animal studies. For example, experiments have been done where bee bread is given to rodents on high-fat or otherwise unhealthy diets. Eleazu et al. (2020) reported that administering bee bread to rats on a high-fat diet attenuated negative changes in their metabolism — specifically, bee bread helped prevent renal pathology linked to obesity and improved antioxidant indices in those animals [12]. Similarly, bee bread supplementation has been associated with improved blood lipid profiles (lower total cholesterol, low-density lipoprotein (LDL), and triglycerides, and higher high-density lipoprotein (HDL)) in some models, as well as better blood glucose control. In one study with diabetic or hyperglycemic rats, adding bee bread to their diet led to reduced blood glucose levels and improved pancreatic function compared to controls, suggesting an anti-diabetic effect (likely due to its antioxidant and perhaps insulin-sensitizing components) [8]. These findings point to a role for bee bread in managing metabolic syndrome aspects, though human data are needed for confirmation.

Hepatoprotective and Renal Protective Effects. Research by Bakour et al. (2017) demonstrated that bee bread could protect the liver and kidneys from certain toxic insults. In their experiment, rats exposed to aluminum (which causes oxidative damage and functional impairment in liver and kidney) showed much less damage when they were treated with bee bread extract concurrently. Liver enzymes (alanine aminotransferase, ALT; aspartate aminotransferase, AST) and kidney function markers (urea, creatinine) were closer to normal in the bee bread group versus the toxin-only group [3]. Histological examinations supported that bee bread reduced tissue damage. This suggests that bee bread's combination of nutrients and antioxidants can strengthen the body's resilience against toxic chemicals or stressors.

Antimicrobial Properties. Bee bread displays antimicrobial activity, likely owing to the presence of acids (lactic, etc.), hydrogen peroxide (produced by some LAB), and polyphenols. *In vitro* tests have found that bee bread extracts can inhibit the growth of various pathogenic bacteria and fungi. For example, ethanol extracts of bee bread have shown activity against *Staphylococcus aureus*, *Escherichia coli*, *Candida albicans*, among others [4, 5]. Bakour et al. (2019) examined bee bread's bioactive properties and found it had notable antibacterial effects against Gram-positive bacteria and also antifungal effects, which align with traditional uses of bee bread for supporting immune health [4]. The concentrations required in lab tests were moderate, indicating bee bread is not as potent as specialized antibiotics, but it can contribute to reducing microbial growth. This antimicrobial trait, combined with bee bread's probiotic LAB content (if consumed fresh), might benefit gut health by suppressing harmful microbes and supporting beneficial ones.

Anti-Tumor Potential. Preliminary research has even looked at bee bread in the context of cancer. Some cell culture studies suggest that bee bread extracts might inhibit proliferation of certain cancer cell lines or induce apoptosis (cell death) in tumor cells [5]. These effects are usually attributed to polyphenols and other antioxidants that can interfere with cancer cell metabolism or protect healthy cells from DNA damage. While these findings are interesting, they are at an early stage. Bee bread is not a cure for cancer, but its components could be complementary in a health-promoting diet that lowers cancer risk.

Energy and Stamina. From a nutritional standpoint, bee bread provides a quick energy boost due to its simple sugars, and sustained energy and recovery support due to its proteins and vitamins. Some anecdotal reports and non-clinical trials have claimed that bee bread supplementation can improve vitality, reduce fatigue, and enhance athletic recovery in humans, presumably because it supplies easily assimilable nutrients and antioxidants that reduce exercise-induced oxidative stress.

Allergenic Considerations. It should be mentioned that like pollen, bee bread can cause allergic reactions in sensitive individuals. Fermentation might reduce some allergenic proteins, but people with pollen allergies should exercise caution when consuming bee bread. On the other hand, there are claims that consuming bee products like bee bread in small amounts can help build tolerance to pollen allergens (similar to immunotherapy), although this is anecdotal and individual-dependent.

In conclusion, the physiological responses to bee bread in non-bee organisms appear generally positive: antioxidant, anti-inflammatory, metabolic regulation, and protective effects have been documented in various studies [3, 5, 12]. These results position bee bread as a potent functional food supplement. However, most of these findings come from animal studies or *in vitro* experiments. Human clinical data are relatively scarce, with a few studies or traditional usage reports suggesting benefits such as improved blood health and immunity. Given its rich composition, it is reasonable that adding bee bread to the diet could help address nutritional gaps and improve overall health resilience. It is also worth noting that because bee bread is a natural product, its composition can vary, so standardizing dosages for therapeutic effects is challenging. Nonetheless, moderate consumption of authentic bee bread is generally considered healthful as part of a balanced diet.

Applications and Future Perspectives

The recognition of bee bread's enhanced nutritional qualities and health benefits has led to increasing interest in its applications beyond the hive. In apiculture, some advanced beekeeping practices involve harvesting bee bread from frames and selling it as a high-value product for human consumption. Beekeepers must balance this with the needs of the bees, often only taking surplus bee bread or providing alternative protein feeds to colonies if they remove too much. Bee bread is marketed as a dietary supplement in various forms — raw granules, capsules of dried powder, or mixed into honey/pastes. Consumers seeking natural and nutrient-dense foods use bee bread for general wellness, to boost immunity, or for specific goals like improving athletic performance or aiding recovery from illness.

The pharmaceutical and nutraceutical industries are also exploring bee bread. Its content of antioxidants and vitamins makes it a candidate for inclusion in supplements aimed at anti-aging or immune support. Some preliminary research is directed towards isolating compounds from bee bread that could be used in medicines — for example, if a specific peptide or polyphenol with strong bioactivity is identified, it might be concentrated and tested as a therapeutic agent.

One emerging area is the biotechnological production of "artificial" bee bread. Since natural bee bread is limited by what bees produce and is labor-intensive to harvest, scientists are investigating how to ferment pollen in a controlled way to mimic bee bread. Barta et al. (2022) discuss advances in simulating the natural fermentation by using selected starter cultures (like LAB strains isolated from bee bread) to ferment collected pollen in the lab or factory settings [6]. The goal is to produce a bee bread-like product that has the same enhanced bioavailability and stability, which could then be used as livestock feed supplement (for example, in poultry or aquaculture) or as a human superfood ingredient. Early trials have shown that inoculating pollen with certain *Lactobacillus* strains under anaerobic conditions can indeed yield a fermented pollen very similar in composition to naturally occurring bee bread, including the production of lactic acid and increased free amino acids [6]. If scaled up, this could make the benefits of bee bread more accessible and affordable, and reduce pressure on harvesting from bee hives.

From a research perspective, future studies are needed to fully map the nutritional changes and health outcomes related to bee bread. Some questions include: Which specific microbial species contribute most to fermentation and are they all necessary? How does each major compound class (proteins, lipids, polyphenols) change quantitatively during fermentation for various pollens? What are the long-term health effects of consuming bee bread in humans (*e.g.*, could it help in managing certain chronic conditions or improving gut microbiota composition)? Additionally, standardization of bee bread quality is an issue — developing quality control measures, such as defining the minimum content of lactic acid or particular nutrients, would help in ensuring consistency for consumers and researchers.

Finally, the role of bee bread in sustainable agriculture is noteworthy. By emphasizing bee nutrition (such as planting diverse flora for good pollen sources, or providing supplemental bee bread), beekeepers can strengthen colonies, which in turn improves pollination services for crops. A healthy colony with ample bee bread is more robust against stressors, which is crucial in an era where bee populations face challenges from pesticides, diseases, and climate change. There is a virtuous circle here: diverse, pesticide-free forage leads to high-quality bee bread; high-quality bee bread leads to healthy bees; healthy bees ensure good pollination and agricultural productivity.

In summary, microbial fermentation of bee bread significantly elevates the nutritive and medicinal value of pollen, with wide-ranging implications. Bee bread stands out as a naturally derived functional food that benefits bees and shows promise for human and animal health. Ongoing research and development may further unlock its potential, whether by harnessing it directly from hives or reproducing the fermentation process industrially. The study of bee bread exemplifies how symbiosis between insects and microbes can be leveraged to enhance nutrition — a concept that might inspire novel approaches in food science and technology.

Bee bread (perga) is a remarkable example of nature's fermentation processes yielding a product with superior nutritional qualities. Through the activity of lactic acid bacteria and other symbiotic microbes, raw pollen is transformed within the hive into a stable, enriched food source that sustains honey bee colonies and offers intriguing benefits for other consumers. The microbial fermentation breaks down pollen's physical and chemical barriers, enhancing the bioavailability of proteins, amino acids, vitamins, and minerals. As a result, bee bread provides honey bees with more efficient nutrition, directly supporting their physiological needs, immune function, and colony vitality.

For humans and other animals, bee bread represents a potent functional food with diverse bioactive components. Scientific studies have begun to validate a range of health-promoting effects attributed to bee bread, including antioxidant, anti-inflammatory, metabolic, and antimicrobial properties. When included as a supplement, bee bread has shown the capacity to ameliorate oxidative stress, improve lipid and glucose metabolism, and protect organs against toxin-induced damage in experimental models. While further research, especially clinical trials in humans, is needed to fully substantiate these benefits, the existing evidence underscores bee bread's potential as a natural nutraceutical.

In addition to direct health implications, the study of bee bread has broader significance. It highlights how fermentation — a process widely used by humans in food preservation — is employed by bees to ensure their survival, drawing parallels that can inspire novel biotechnological approaches. Efforts to artificially ferment pollen are already underway, which could expand the availability of "bee bread-like" products for use in nutrition and medicine. Moreover, understanding bee bread encourages better beekeeping and agricultural practices by emphasizing the importance of pollen diversity and quality in maintaining healthy pollinator populations.

In conclusion, microbial fermentation of bee bread substantially increases the nutritional and physiological value of pollen. Bee bread serves as a crucial nutrient reservoir for bees and a promising supplement for human health. Embracing this natural ferment could contribute to improved dietary options for people and the wellbeing of honey bees alike. By learning from the bees' example of fermentation, we not only gain a powerful health food but also deepen our appreciation of the intricate connections between microbiology, nutrition, and the health of ecosystems.

References

1. Aksoy A, Sandıkçı Altunatmaz S, Aksu F, Tokatlı Demirok N, Yazıcı K, Yıkmış S. Bee bread as a functional product: phenolic compounds, amino acid, sugar, and organic acid profiles. *Foods*. 2024; 13 (5): 795. DOI: 10.3390/foods13050795.
2. Aylanc V, Falcão SI, Ertosun S, Vilas-Boas M. From the hive to the table: Nutrition value, digestibility and bioavailability of the dietary phytochemicals present in bee pollen and bee bread. *Trends Food Sci Technol.* 2021; 109: 464–481. DOI: 10.1016/j.tifs.2021.01.042.
3. Bakour M, Al-Waili NS, El Menyiy N, Imtara H, Figuira AC, Al-Waili T, Lyoussi B. Antioxidant activity and protective effect of bee bread (honey and pollen) in aluminum-induced anemia, elevation of inflammatory markers and hepato-renal toxicity. *J Food Sci Technol.* 2017; 54 (13): 4205–4215. DOI: 10.1007/s13197-017-2889-9.
4. Bakour M, Fernandes Â, Barros L, Soković M, Ferreira ICFR, Lyoussi B. Bee bread as a functional product: Chemical composition and bioactive properties. *LWTFood Sci Technol.* 2019; 109: 276–282. DOI: 10.1016/j.lwt.2019.02.008.
5. Bakour M, Laaroussi H, Ousaaid D, El Ghouizi A, Es-Safi I, Mechchate H, Lyoussi B. Bee bread as a promising source of bioactive molecules and functional properties: An up-to-date review. *Antibiotics.* 2022; 11 (2): 203. DOI: 10.3390/antibiotics11020203.
6. Barta DG, Cornea-Cipcigan M, Margăoan R, Vodnar DC. Biotechnological processes simulating the natural fermentation process of bee bread and and therapeutic properties — an overview. *Front Nutr.* 2022; 9: 871896. DOI: 10.3389/fnut.2022.871896.
7. Bayram NE, Gerçek YC, Çelik S, Mayda N, Kostić AŽ, Dramićanin AM, Özkök A. Phenolic and free amino acid profiles of bee bread and bee pollen with the same botanical origin — similarities and differences. *Arab J Chem.* 2021; 14 (11): 103004. DOI: 10.1016/j.arabjc.2021.103004.
8. Carroll MJ, Brown N, Goodall C, Downs AM, Sheenan TH, Anderson KE. Honey bees preferentially consume freshly stored pollen. *PLoS ONE.* 2017; 12 (4): e0175933. DOI: 10.1371/journal.pone.0175933.
9. Ćirić J, Haneklaus N, Rajić S, Baltić T, Branković Lazić I, Đorđević V. Chemical composition of bee bread (perga), a functional food: a review. *J Trace Elem Med Biol.* 2022; 2: 100038. DOI: 10.1016/j.jtemin.2022.100038.
10. DeGrandi-Hoffman G, Eckholm BJ, Huang MH. A comparison of bee bread made by Africanized and European honey bees (*Apis mellifera*) and its effects on hemolymph protein titers. *Apidologie.* 2013; 44 (1): 52–63. DOI: 10.1007/s13592-012-0154-9.
11. Dolezal AG, Toth AL. Feedbacks between nutrition and disease in honey bee health. *Curr Opin Insect Sci.* 2018; 26: 114–119. DOI: 10.1016/j.cois.2018.02.006.
12. Eleazu C, Suleiman JB, Othman ZA, Zakaria Z, Nna VU, Hussain NHN, Mohamed M. Bee bread attenuates high fat diet induced renal pathology in inflammation and Bax signalling. *Arch Physiol Biochem.* 2020; 128 (4): 276–283. DOI: 10.1080/13813455.2020.1752258.
13. Kieliszek M, Piwowarek K, Kot AM, Błażejak S, Chlebowska-Śmigiel A, Wolska I. Pollen and bee bread as new health-oriented products: A review. *Trends Food Sci Technol.* 2018; 71: 170–180. DOI: 10.1016/j.tifs.2017.10.021.
14. Vásquez A, Olofsson TC. The lactic acid bacteria involved in the production of bee pollen and bee bread. *J Apic Res Bee World.* 2009; 48 (3): 189–195. DOI: 10.3896/IBRA.1.48.3.07.
15. Zheng J, Wittouck S, Salvetti E, Franz CMAP, Harris HMB, Mattarelli P, O'Toole PW, Pot B, Vandamme P, Walter J, Watanabe K, Wuyts S, Felis GE, Gänzle MG, Lebeer S. A taxonomic note on the genus *Lactobacillus*: description of 23 novel genera, emended description of the genus *Lactobacillus* Beijerinck 1901, and union of *Lactobacillaceae* and *Leuconostocaceae*. *Int J Syst Evol Microbiol.* 2020; 70 (4): 2782–2858. DOI: 10.1099/ijsem.0.004107.

Мікробна ферментація бджолиного хліба (перги) і її вплив на біодоступність поживних речовин та фізіологічні реакції

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Бджолиний хліб (перга) — це природний ферментований продукт, який утворюється в результаті мікробної трансформації зібраного пилку всередині вулика. У огляді проаналізовано, як мікробна ферментація перги підвищує біодоступність її поживних речовин, а також розглянуто фізіологічні реакції, пов'язані зі споживанням перги. У вулику молочнокислі бактерії та інші мікроорганізми ферментують пилок, змішаний з нектаром і ферментами бджіл, в анаеробних умовах, що призводить до часткового руйнування оболонок пилкових зерен та синтезу корисних метаболітів. Порівняно зі свіжим пилком, перга містить більше вільних амінокислот, вітамінів (зокрема групи B та K) і біологічно активних сполук, завдяки чому її поживні компоненти легше засвоюються. Процес ферментації підвищує перетравність поживних речовин і консервує пилок шляхом утворення органічних кислот, що гальмують псування. Обговорено відмінності в складі поживних речовин між пилком і пергою та їхній вплив на поживну цінність і біодоступність. Розглянуто також фізіологічні ефекти споживання перги: для медоносних бджіл вона сприяє зміцненню здоров'я сім'ї та імунітету, а для інших тварин і людей перга проявляє антиоксидантні, протимікробні, протизапальні властивості. Наведено дані дослідів на тваринах, що демонструють, як додавання перги в раціон поліпшує обмін речовин, знижує оксидативний стрес та захищає від деяких токсичних чинників. Отож, перга постає як функціональний продукт із підвищеною доступністю поживних речовин та потенційною користю для здоров'я. Огляд підкреслює біологічне значення мікробної ферментації пилку в пергу і відповідні наслідки для харчування та здоров'я.

Ключові слова: бджолиний хліб, перга, молочнокисла ферментація, біодоступність поживних речовин, фізіологічні ефекти, функціональний продукт

Bondarenko RO. Microbial fermentation of bee bread (perga) and its impact on nutrient bioavailability and physiological responses. *Bìol Tvarin*. 2026; 28 (1): 3–12. DOI: 10.15407/animbiol28.01.003.