Journal of Functional Foods 49 (2018) 472–484

Contents lists available at ScienceDirect

Journal of Functional Foods

journal homepage: www.elsevier.com/locate/jff

Nutrient-rich bee pollen: A treasure trove of active natural metabolites

Qiang-Qiang Li[a], Kai Wang[a,*], Maria Cristina Marcucci[b], Alexandra Christine Helena Frankland Sawaya[c], Lin Hu[d], Xiao-Feng Xue[a], Li-Ming Wu[a,*], Fu-Liang Hu[e]

[a] Institute of Apicultural Research, Chinese Academy of Agricultural Sciences, Beijing, China
[b] Laboratory of Natural Products, Pharmacy and Biotechnology Department, University Anhanguera of São Paulo, SP, Brazil
[c] Faculty of Pharmaceutical Science, Universidade Estadual de Campinas, UNICAMP, Campinas, Brazil
[d] Institutes of Biology and Medical Sciences, Soochow University, Suzhou, China
[e] College of Animal Sciences, Zhejiang University, Hangzhou, China

ARTICLE INFO

Keywords:
Bee pollen
Phytometabolites
Nutrition
Therapeutic benefits
Food safety

ABSTRACT

Bee pollen is a mixture of plant pollen pellet with nectar and honeybee secretions. Due to its active natural metabolites with extensive nutritional and therapeutic properties, it is recommended as a treasure trove of human nutrition. The nutritional components in bee pollen include carbohydrates, proteins, lipids, vitamins, minerals, polyphenols, and a small percentage of other components. Previous studies demonstrated that bee pollen exhibit antioxidant, antibacterial, anti-inflammatory, anticarcinogenic, and antiallergic properties. This comprehensive review focused on the nutritional properties and potentially active phytometabolites (polyphenolic acids and flavonoids) of bee pollen and its therapeutic health benefits. We also covered the food safety and guidelines for the consumption with future industrial challenges of bee pollen.

1. Introduction

Honey bees collect the pollen and agglutinate to fill their baskets from the flowers using their hind legs to make bee pollen. This process involves the moistening of flowers with bee oral secretions and allows forming the pellet and sticking to the specific baskets (corbiculae) (Fig. 1A) (Campos et al., 2008). Beekeepers use pollen traps at the entrance of their hives to collect raw bee pollen, which makes easy to collect bee pollen for commercial uses possible (Fig. 1B and C). The different nutritional components of bee pollen confer to various valuable therapeutic properties (Denisow and Denisow-Pietrzyk, 2016; Kieliszek et al., 2017). Bee pollen is widely recognized as the potential for medical or nutritional applications since early times. Previous literature showed women who had bee pollen in their diet in ancient time's maintained health, beauty, and strong human body (Graham, 2015 (Chapter 23)). The chemical composition of bee pollen differs based on the variety of factors, including botanical origins, bee species, and geographic origins. The palynology analysis is the most representative method for identifying the botanical origins of bee pollen (Almaraz et al., 2004; Da Silva, da Natividade, Camara, da Silva, & Silva, 2014; Nogueira, Iglesias, Feás, & Estevinho, 2012; Saa-Otero, Díaz-Losada, & Fernández-Gómez, 2000; Szczesna, 2006; Yang et al., 2013). Recent days, a wide variety of bee pollen products have been formulated as granules, tablets, candy bars, oral liquids, and tonics for

Abbreviations: GC–MS, gas chromatography-mass spectrometry; LC-ESI/MS, liquid chromatography-electrospray ionization mass spectrometry; TLC, thin layer chromatography; HPLC-DAD-ESI/MS, high-performance liquid chromatography-diode array detection-electrospray ionization mass spectrometry; HPLC-DAD-APCI/MS, high-performance liquid chromatography-diode array detection-atmospheric pressure chemical ionization mass spectrometry; UHPLC-LTQ-orbitrap/MS, ultra-performance liquid chromatography with a linear ion trap high-resolution orbitrap mass spectrometry system; UPLC-Q-Exactive orbitrap/MS, ultra-performance liquid chromatography in tandem with hybrid quadrupole-orbitrap mass spectrometry system; NMR, nuclear magnetic resonance; ICP-OES, inductively coupled plasma-optical emission spectrometry; TXRF, total reflection X-ray fluorescence; ICP-AES, inductively coupled argon plasma-atomic emission spectrometry; ASS, atomic absorption spectrometry; SGLT1, sodium-dependent glucose transporter 1; MRP2, multidrug resistance-associated protein 2; BSβG, broad-specific-β-glucosidase; LPH, lactase phlorizin hydrolase; UGT, UDP-glucuronosyltransferase; ROS, reactive oxygen species; MDA, malondialdehyde; SOD, superoxide dismutase; CAT, catalase; GSH-Px, glutathione peroxidase; ABTS, 1, 2, 2′-azino-bis (3-ethylbenzothiazoline-6-sulfonic acid); DPPH, 1-diphenyl-2-picrylhydrazyl radical; COX-2, cyclooxygenase-2; NO, nitric oxide; PGs, prostaglandins; IFN-γ, interferon-γ; TNF-α, tumor necrosis factor-α; IgE, immunoglobulin E; IgG1, immunoglobulin G1; MRL, maximum residue limits; ELISA, enzyme-linked immune-sorbent assay

* Corresponding authors.
E-mail address: kaiwang628@gmail.com (K. Wang).

https://doi.org/10.1016/j.jff.2018.09.008
Received 25 June 2018; Received in revised form 31 August 2018; Accepted 9 September 2018

Fig. 1. Bee pollen raw materials collection process, including gathering pollen by bees (A), intercepting pollen grains by pollen traps (B), collecting the intercepted bee pollen grains (C), drying bee pollen (D), and packaging bee pollen (E). F shows the micromorphology of the bee pollen grains, using Scanning Electron Microscope (SEM) technology. The bee pollen shown in A, B, C is from *Camellia sinensis* L. in Zhejiang province of China, and the bee pollen shown in D, E, F comes from coconut palms (*Cocos nucifera* L.) in the province of Sergipe, Brazil. Figures A, B and C were provided by Prof. Zhongyin Zhang, from Henan Institute of Science and Technology, Xinxiang, China. Figures D and E were taken by Dr. Kátia Peres Gramacho from Universidade Federal Rural do Semi-Árido, Mossoró, RN, Brazil. Figure F were taken by Dr. Maria de Fatima Brito Souza Sundin, Department of Analytical Chemistry, Chemical Institute of Campinas State University (UNICAMP), Campinas, SP, Brazil.

human consumption (Bogdanov, 2012 (Chapter 2); Campos, Markham, Mitchell, & Cunha, 2015).

Improved techniques and methods for comprehensive composition profiling of bee pollen from various origins are necessary for understanding their variety of nutrients varying from different origins, as well as the potential bioactivities that are beneficial to human health. Recently, specific techniques like gas chromatography (GC), liquid chromatography (LC), gas chromatography-mass spectrometry (GC–MS), liquid chromatography in tandem with mass spectrometry (LC-MS), and high-resolution mass spectrometry have been used to analyze the composition of bee pollen to facilitate the quality control, nutrient profiling, as well as metabolism and bioactivity mechanisms investigations (Campos et al., 2008). According to previously published reviews, Puerto, Prieto, and Castro (2015) summarized the chemical composition of bee pollen, and some phenolic compounds that cause its antioxidant activity; Denisow and Denisow-Pietrzyk (2016) mainly introduced its biological and therapeutic properties; Ares, Valverde, Bernal, Nozal, and Bernal (2017) reported the extraction and determination techniques of some nutrients (carbohydrates, proteins, amino acids, lipids, phenolic compounds, vitamins and minerals) in bee pollen. However, the nutrient profile of samples of bee pollen with different botanical and geographic origins has been insufficiently studied. Although the studies on compositional profiling, a systematic classification of bee pollen lacks traceability of sample sources. Moreover, the studies on the metabolism of active natural plant metabolites from bee pollen after consumption, as well as the food safety of bee pollen are both unsatisfactory.

Therefore, the purpose of this review is to provide a comprehensive overview of recent studies regarding the nutrient profile of bee pollen with various botanical and geographic origins, as well as to give recent updates on nutritional properties of bee pollen and its potential bioactivities for human health. Additionally, the *in vivo* metabolic pathways of various potential active natural plant metabolites (mainly phenolic acids and flavonoids) from the different origin of bee pollen are highlighted. Moreover, this review also covers the food safety, essential guidance for the consumption of bee pollen, as well as a brief overview of several challenges and the future outcomes, which can facilitate its industrial development and wide-ranging applications.

2. Nutrients and nutritional properties

2.1. Essential nutrients

2.1.1. Carbohydrates

Carbohydrates are the major class of components and comprised of approximately 40–85% (W/W) of dry bee pollen (Table 1). Fructose is abundant, followed by glucose and sucrose compared to other carbohydrate components of bee pollen (Table 2). Oligosaccharides and polysaccharides are also very important ingredients in bee pollen which help to regulate various biological functions. Moreover, these compounds are regarded as characteristic markers for discriminating the botanical origin of bee pollen. However, it's difficult to detect them both by GC and high-performance liquid chromatography (HPLC) due to their highly hydrophilic nature, high molecular weight, and very similar polarity among these sugars (Martins, Morgano, Vicente, Baggio, & Rodriguez-Amaya, 2011; Qian, Khan, Watson, & Fearnley, 2008; Serra & Jorda, 1997). Therefore, it needs an attention to develop proper, innovative and effective methods for oligosaccharide and polysaccharide detection in bee pollen.

2.1.2. Protein and amino acids

The second most abundant components are protein, making up approximately 14–30% (W/W) with the total of 20 essential amino acids in dry bee pollens (Da Silva et al., 2014; González-Paramás, Bárez, Marcos, García-Villanova, and Sánchez, 2006; Serra & Jorda, 1997; Szczesna, 2006; Yang et al., 2013). HPLC and ion exchange