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Research progress on nutritional functional ingredients and biological activity of edible flowers

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Abstract
Edible flowers have a long history of development, rich in a variety of nutrients and functional ingredients, and have great market development potential. Based on the latest research results on edible flowers at home and abroad, the nutrients of common edible flowers and functional ingredients such as anthocyanins, carotenoids, flavonoids, phenolic acids, and plant essential oils are reviewed, and the biological activities of edible flowers are summarized and analyzed in order to provide a reference for the product development and deep processing and utilization of edible flowers.

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1. Introduction

Edible flowers are a class of flowers and plants that can be eaten directly. Edible bits include flowers, stems, leaves, etc. [1]. Edible flowers are rich in nutrients and functional ingredients, and there are currently more than 180 kinds reported. With people's pursuit of a healthy and green diet, edible flowers are gradually becoming a new hot topic in the field of food science [2]. According to the botanical classification, edible flowers can be divided into three categories: fruit flowers, vegetable flowers, and medicinal and food flowers [3]. Fruit flowers mainly refer to the flowers of fruit trees, such as peach blossoms, pear blossoms, etc. Common vegetable flowers include western blue flowers, rapeseed flowers, etc., chrysanthemums, lilies, honeysuckle, etc. Are often used as medicinal and food flowers, many of which belong to traditional Chinese medicine raw materials, with unique aromas and medicinal properties [4]. There are many varieties of edible flowers and rich resources in our country. The development of the flower food industry can promote the diversification of food resources and drive the upgrading of the flower industry chain, which is of positive significance for improving people's health and increasing farmers' incomes [5].

2. Overview of Edible Flowers

From the perspective of the world, the development of edible flowers has a long history. There are records of chrysanthemum foods in the spring and Autumn Warring States Period. There are already edible flower verses in the masterpiece "Chu Ci·Lixiao" by our great poet Qu Yuan [6]. There is literature on the use of various flowers as food ingredients in Mexico and Peru in the American continent and ancient Greece, Rome, France, etc. in Europe [7]. The classification of common edible flowers and the parts and methods of consumption are shown in Table 1.

Table 1: Classification and edible use of common edible flowers

Category	Name	Edible Parts	How to Eat
medicinal and food flowers	*Lilium brownii* var. *viridulum* Baker	Bulb	Medicine, stir-fried food, tea
	Camellia petelotii (Merr.) Sealy	flower	Tea, tea, soup
	Lonicera japonica Thunb.	Stem, leaf, flower	Medicine, tea
	Calendula officinalis L.	Petals, leaves	Medicine
	Chrysanthemum × *morifolium* Ramat	Petals	Medicine, tea, wine making
	Hibiscus syriacus L.	Buds, flowers	Medicine, porridge, tea
	Paeonia × *suffruticosa* Andr.	Petals, buds	Pastries, tea, porridge
	Paeonia lactiflora Pall.	Petals	Tea, porridge, pastries
	Tagetes erecta L.	flower	Medicine, fresh food, noodles
	Rosa chinensis Jacq.	Petals	Take medicine, fry, and make porridge
	Gardenia jasminoides J. Ellis	flower	Medicine, food dyes
fruits and flowers	*Malus spectabilis* (Ait.) Borkh.	Petals, fruit	Tea, medicine
	Pyrus spp.	Flowers and fruits	Winemaking
	Cerasus pseudocerasus	Flowers, leaves, fruits	Medicine
	Crataegus	Flower buds, tender stems	Stir-fried food, tea
	P*unicagranatum*	Male flower	Stir-fried food, cold salad, porridge,
	Prunus persica	Flower, fruit	Tea drinking, brewing, sauce making
vegetables and flowers	*Cucurbita moschata*	Male flower	Pastry, stuffing, salting
	Luffacylindric	Male flower	Fried food
	Brassica oleracea L. var. *italica* Plenck	Flower bud	Stir-fried food, cold salad
	Brassica campestris	Flowers and leaves	Fried food
	Cucurbita pepo L.	Male flower	Frying, baking, stuffing

As a newly developed food resource, edible flowers have relatively little research literature, and relevant laws and standards are not yet perfect. The development of flower food has certain safety risks. Not all flowers meet the basic requirements for consumption. Many types of flowers contain toxic substances and anti-nutrient factors, such as trypsin inhibitors, hemagglutinin, oxalic acid, cyanosides and alkaloids. Excessive intake may cause food safety accidents [8]. In addition to naturally occurring anti-nutrient factors and toxins, pollution in the planting process cannot be ignored. The European RASFF system (Food and feed rapid warning system) has reported a number of pollution incidents related to edible flowers, including cases of pathogenic microorganisms and chemical pollution have been reported [9]. So far, the food regulatory authorities have not stipulated the maximum daily intake value of each edible flower, especially for wild edible flowers that may have toxic compounds and anti-nutrient factors. Only the European regulation N258/97 (EC) relates to flower safety issues related to the development of new foods and ingredients [10]. For the development of floral foods, attention should be paid to natural toxins and pollution issues, as food ingredients are added, the amount of addition should be controlled and toxicological experiments should be improved [7].

Although there are certain safety risks in the processing and utilization of edible flowers, due to their natural, green and healthy characteristics, they are more and more sought after and loved by people. Consumption trends have increased significantly. The number of edible flower recipes, flower cooking articles and media reports is increasing. It is expected to grow further in the next few years. The annual growth rate of global edible flower product development in 2021 and 2022 is 4.24% and 4.40%, respectively, and it is expected that it will be as high as 4.85% in 2026, with a cumulative growth rate of 31.17% in ten years [7], with broad future market prospects.

3. Nutrition and functional ingredients of edible flowers

For the analysis of the nutrition and functional composition of flowers, the number of domestic literature is relatively small compared to foreign reports. From a nutritional point of view, edible flowers can be divided into pollen, nectar, petals and other parts. Pollen contains a lot of protein, carbohydrates, fats and carotenoids; petals are a good source of vitamins, antioxidants and minerals; and nectar contains high concentrations of sugars, such as fructose, sucrose and glucose [10].

3.1 Nutrients

Edible flowers are similar to other plants, with a higher water content, generally more than 70%. The overall water content of vegetable flowers such as broccoli and cauliflower is more than 92%, and the water content of the petal tissues of aromatic flowers such as marigold is also close to 90% [11]. Calories are relatively low, and carbohydrates are the most important nutrients in edible flowers, with a content of about 40 to 90 mg/100 g dry weight. Judging from the current published literature, the carbohydrate content of rose petals is 90.2 mg/100g, which is the highest among existing edible flowers [12], while the carbohydrate content detected in Xilan flowers is low, about 10.0 g/100 g dry weight [11], and the research by Yan Zixi *et al*. shows the carbohydrate gap between different varieties of roses. Not significant [13], its content is similar to the reported data of foreign roses. The cellulose content varies significantly between different flowers. The crude fiber content of Mexican marigold is about 55.4 mg/100 g, which is the type with a higher cellulose content in edible flowers. The crude fiber content of pansy flowers is only 6.1 mg/100 g [14]. It is speculated that in addition to the differences in varieties, it is also related to the differences in the determination methods of cellulose. The protein content of vegetable flowers is generally higher than that of other edible flowers. The protein content of western blue flowers is as high as 52.3 mg/100 g, while the protein content of begonia petals is only 2mg/100g. The protein content of other common flowers such as chrysanthemums and roses is below 20 mg/100g, and its amino acid composition is mainly phenylalanine, leucine and valine [8].

In terms of fat content, the content of different types of edible flowers is also relatively different, about 0.1%-10%, rich in α-linolenic acid and linoleic acid [15]. In terms of mineral content, potassium, phosphorus, magnesium and calcium are the main minerals found in edible flowers. The potassium content of mint flowers is 30.03g kg-1 dry matter, which is currently the highest potassium content in known edible flowers, and the iron content reaches 154.93 mg kg-1 dry matter in peony flowers [16]. The above research results show that edible flowers, as an emerging food resource, are rich in nutrients, have good development value and potential, and have the potential to become a part of functional food raw materials.

3.2. Anthocyanins

Anthocyanins are flavonoids. They can be expressed in various forms such as red, blue, and purple due to differences in structure and pH in flowers. Their anabolism is affected by various factors such as genes, light, and temperature [17]. Anthocyanins in edible flowers exist in the structure of anthocyanin glycosides and are water-soluble polyphenols. They mainly include geranium pigment, cornflower, anthocyanin, peony anthocyanin ligand, petunia glycoside ligand and mallow pigment 6 non-glycosides [18]. Anthocyanins are important physiological substances in flowers. They have antioxidant and antibacterial functions. The basic structure is connected by a ring of 2 benzene rings and 3 carbon. Because they can form glycosides with different sugars, anthocyanins have been reported so far. More than 700 different structures have been reported [19]. The content and types of anthocyanins will affect the color of flowers. Spectrophotometer and high-performance liquid chromatography can be used for quantitative determination [20]. Among edible flowers, peony, pansy, chrysanthemum, hibiscus and rose are typical anthocyanin-rich edible flowers.Cui Huliang and others studied the anthocyanin content and structure of different varieties of peony petals, and found that they showed dynamic changes in different periods anthocyanin glycosides continued to accumulate from the bud stage to the decaying stage, and the total anthocyanin content continued to increase. Luoyang red varieties reached 340 μg·g-1 in the decaying stage anthocyanin glycoside content [21], which shows that the use of edible flowers in the decaying stage to extract anthocyanins is a feasible solution to achieve its comprehensive utilization. The structure of anthocyanins in different flowers is different. Natural anthocyanins in nature are actually complex mixtures of multiple glycosylations. For example, the anthocyanins in bauhinia, azalea, chrysanthemum, and geranium are mainly cornflower-3-O-glucoside [22], while the anthocyanins in roses are mainly cornflower-3-O-Sambu disaccharide and anthocyanin-3-O-Sambu disaccharide [23]. Even between different subspecies of the same variety, the types of anthocyanins may be different. For example, in Cui Huilang's study, 6 different varieties of peony flowers, only geranium-3-glucoside was detected in the Yingrihong variety, while other varieties were not detected [21]. Generally speaking, edible flowers rich in anthocyanins have a relatively good aroma, taste and appearance, which are more attractive to consumers [24].

3.3. Carotenoids

Carotenoids are another important pigment substance in edible flowers in addition to anthocyanins. They have the appearance of yellow, orange, and red. Their molecular structure is characterized by a long-chain polyolefin structure with conjugated double bonds. The number of conjugated double bonds directly affects its physical and chemical properties and physiological functions [25]. So far, more than 700 kinds of carotenoids have been isolated from natural animals and plants, the most common are lutein, zeaxanthin, β-cryptaxanthin, α-carotene, β-carotene and lycopene [26]. Carotenoids play a vital role in human and animal nutrition. Studies have shown that carotenoids can reduce the risk of vitamin A deficiency, senile macular degeneration (AMD), cataracts, cancer, and cardiovascular disease [27]. Carotenoids in animals cannot be synthesized from scratch, so they must be absorbed from foods and supplements. The composition of carotenoids varies greatly between edible flower types and varieties. Marigold is an edible flower rich in lutein. The carotenoid content of different varieties of marigold in France has reached 5.0 to 7.8 mg/g (dry weight) [28], The composition analysis of the yellow and brown-orange petals of the plantagenet was carried out by HPLC-PDAD-MS method, and the results showed that they contained 450±60 μg/g and 350±50 μg/g lutein (fresh weight), respectively, while the content of β-cryptaxanthin, α-carotene, β-carotene, zeaxanthin and lycopene was very low [29].The carotenoid spectrum of roses shows the presence of lutein, lutein, zeaxanthin, β-carotene, lutein epoxide, lutein, lutein, neoflavin, etc. The highest concentration of total carotenoids in different flowering periods is 142.71μg/g (fresh weight), and several different geometric configurations of lutein are the main carotenoid components [30]. The content and types of carotenoids between different varieties of calendula are also more significant. Kishimoto *et al*. extracted and isolated the carotenoids of the orange and yellow varieties of calendula. 19 types of carotenoids were identified from the petal extract of the orange blossom variety, while only 9 types were identified in the petal extract of the yellow flower variety. The total fresh weight content of carotenoids ranges from 48μg/g for yellow-orange flowers to 2760 μg/g for dark orange flowers [31]. Saffron is a relatively special class of carotenoids. It is currently only found in saffron. Its chemical structure is a diester compound formed by the esterification of saffron acid and longcholine disaccharides. Saffron also contains saffron glycosides including saffron acid, bitter saffron and saffron aldehyde, which are derivatives of zeaxanthin [32]. The carotenoid content of edible flowers is related to the location of the origin. The content of saffron in saffron flowers is about 100 mg to 360 mg/g (dry weight). Judging from the comparison of data from all over the world, the content of high-altitude areas is higher than that of low-altitude areas [33]. In addition, studies have shown that light and temperature also have an impact on the content of carotenoids. For example, at a low temperature of 10℃, the carotenoid content of "cold moon" ginger flower has decreased compared to the high temperature environment, while the "cold moon" ginger grown in low light has decreased. The content of carotenoids in flowers also showed a downward trend compared to strong light irradiation. The mechanism may be that temperature and light affect the vitality of the sac-like membrane and related enzymes [34].

3.4. Flavonoids

Edible flower flavonoids mainly include flavonoids, flavonols and flavanols. Flavonoids are present in edible flowers in different forms, such as acacia, chrysanthemum,

celery, luteolin and glucosides. Expressed in mg rutin (RE)/g extract, the flavonoid content of Tangniu flower and Mimeng flower collected from Yunnan reached 586 RE/g and 442.32RE/g, and daily consumption has certain health value[1].Studies have also found more types of flavonoids in chrysanthemums, such as acacia, acacia-7-O-β-glucoside, celery, celery-7-O-β-glucoside, luteolin and luteolin-7-O-β-glucoside [35].Pansy has analgesic, antitussive, antipyretic, hypnotic, analgesic and anti-inflammatory effects. Its main flavonoids are celery glycosides, and the content of other flavonoids is low [36].Catechins, epicatechins, epicatechin gallate and epicatechin gallate derivatives are the main flavanols found in edible flowers [37].Relevant studies have confirmed that roses are edible flower varieties with rich content of flavanols, mainly catechins, epicatechins, epicatechins gallate, etc. [38], yellow cauliflower and chrysanthemum also contain a large number of flavanols [39].Flavonols include myricetin, quercetin, is of lavones and kaempferol. In most edible flowers, the content of flavonols is relatively high compared with other flavonoids. A study published in the Journal of Medicinal Plant Research reported that flavonols were found in chrysanthemums as the main component of flavonoids, and one or more flavonols were also found in roses, lilies, Hangzhou white chrysanthemum, magnolia, and honeysuckle [39].There are as many as 19 types of flavonols identified in peony flowers, including kaempferol-3-o-malondienylglucoside-7- o-glucoside, kaempferol dihexose, isoamnosin-3-o-glucoside and quercetin-3-o-galactoside are the main flavonols in peony petals [40]. Analyzing the flavonoids of different varieties of crape myrtle, it was found that the content and types of flavonoids in the petals of different colors are different. The content of flavonoids of the genus Crape myrtle is much higher than that of the genus Crape myrtle. The flavonols are mainly kaempferol–7-O–glucoside, while the flavonols in the white flowers of the genus Crape myrtle are mainly quercetin [41]. Through the study of the changes in the content of flavonoids in petals in different flowering periods, it was observed that the total content of flavonols showed a trend of increasing first and then decreasing. The main components are quercetin 7-O-rhamnoside and kaempferol [42]. Wu Qian and others used ultra-high performance liquid chromatography and mass spectrometry to analyze and identify the flavonoids of different varieties of lotus pollen. A total of 15 types of flavonoids were identified, of which 13 were flavonols, quercetin 3-O-glucuronide, quercetin 3-O-new orange peel glycoside content is high [43]. These results show that flavonols are widely present in a variety of edible flowers. In the study of the flavonoid content of five edible flowers, osmanthus, marigold, gardenia, purple magnolia, and hibiscus, it was found that osmanthus has the highest flavonoid content, measured in catechin concentration (mg CE/g), reaching 74.476 mg CE/g, followed by hibiscus (23.202 mg CE/g), purple magnolia has the lowest content, only 12.249 mg CE/g, but in the simulated digestion experiment, it was found that the release of marigold is five. The highest among flowers [44], which shows that the absolute content of flavonoids in edible flowers has no absolute relationship with the value of biological activity.

3.5. Phenolic acids

Phenolic acid is another important natural chemical substance found in edible flowers and belongs to aromatic organic acid compounds. Using metabolomics techniques, Li Yonghui and others identified a total of 271 phenolic acid metabolites in the root system of peony, which provided a reference for the medicinal value of peony flowers [45]. Studies have analyzed the phenolic acid substances of yellow cauliflower buds. The main components are chlorogenic acid, lilac acid, vanillic acid, coumaric acid, ferulic acid, gallic acid, etc. [46]. Juárez-Trujillo *et al*. found that 4-coumaric acid, rutin, ferulic acid, 4-hydroxybenzoic acid, coffee acid, and trans cinnamic acid are present in elephant leg yucca orchids [47], while coffee acid, 4,5-di-coffee acylquinine, chlorogenic acid and 3,5-di-coffee acylquinine are the main phenolic acids found in honeysuckle, and chlorogenic acid is the most abundant [48]. Traditional edible flowers such as roses and chrysanthemums, as well as ornamental flowers, are also rich in phenolic acids, mainly coffee acid derivatives, vanillic acid, etc. [49]. The above results show that the phenolic acid substances of different flowers differ greatly in terms of type and content, while the phenolic acid substances have antioxidant and anti-inflammatory functions, which provide a theoretical basis for the development of health foods for flowers.

3.6. Aromatic ingredients and essential oils

The aromatic components of flowers are a complex mixture formed by a combination of many volatile substances. Each type is manifested in a specific and unique way, exuding a specific aroma and fragrance. So far, more than 1,700 kinds of volatile components have been identified, and many biologically active compounds have been found in the floral components, mainly composed of terpenes, phenylpropyl/ benzene compounds and fatty acid derivatives [7]. Terpenoids are defensive substances of plants. They are synthesized and stored in plant trichomes (secretory glands of plants). So far, about 556 terpenoids have been identified. They are the volatiles with the richest content and variety of flowers. They are divided into semiterpenoids, monoterpenoids, sesquiterpenoids, diterpenoids, triterpenoids, tetriterpenoids and polyterpenoids [50]. The terpenoids of lilies are linalool, (E)-β-basilene, and Laurene. The fragrance substances of the moonlight season are mainly linalool, citronella, geraniol, orange blossom tertiary alcohol, etc. The floral components of osmanthus are violet ketone and linalool, while the fragrance of peony is composed of linalool, citronella, orange blossom tertiary alcohol, and β-caryophyllene. It can be seen that there are certain differences in the aromatic composition of different types of flowers [51]. Because terpenoids have a variety of biological activities, the nutritional and health functions of edible flowers have good commercial value. Phenylpropyl compounds and benzoic acid compounds are the second most common volatiles in flowers. They contain three subclasses, namely phenylpropyl (C6-C3), benzene (C6-C1) and phenylpropyl related compounds (C6-C2) [52], among which phenylpropyl/benzoic acid compounds have certain antibacterial functions. The third type of volatiles in flowers is fatty acids. According to relevant literature, 35 kinds of fatty acids have been identified from flowers, mainly unsaturated fatty acids, of which linolenic acid and linoleic acid are the most representative, but the fatty acid content of most edible flowers is not high [7].

Essential oils are complex mixtures with volatile aromatic compounds commonly found in plants. They are secondary metabolites and are present in roots, stems, leaves, flowers, etc. They have certain antibacterial effects and can be used as food green preservatives [53].Through the analysis of the

composition of plant essential oils, known plant essential oils are generally composed of 20-60 kinds of ingredients, mainly represented by the terpene group, among which linalool, α-pinene, 1,8-eucalyptus alcohol, eugenol, camphor and camphor are the most common monomer compounds [54], the specific composition may vary depending on the species or ecological type, edible flower essential oils of different sources due to genetic factors, growth environment, developmental stage and plant parts and other reasons, the chemical composition of essential oils has been significantly affected [15].In recent years, there have been many research results on flower essential oils, mainly focusing on the optimization of extraction methods, composition analysis, and antibacterial properties [55, 56], but the commercial application of flower essential oils is still relatively small, and there are currently no cases of food development of flower essential oils.

4. Research on the biological activity of edible flowers

Many studies have shown that edible flowers have certain preventive and therapeutic effects on many diseases, such as vascular diseases, cancer, diabetes, microbial infections, colds, coughs, jaundice, etc. [57]. Roselle flower petals are rich in flavonoids, can be used as food antioxidants, and have a cytotoxic effect on T47D breast cancer cells, so it is possible to play an important role in the pathophysiology of cancer. In addition, quercetin, quercetin and 6-hydroxycannabinol commonly contained in edible flowers have growth inhibition and cytotoxic effects on human liver cancer cell lines (HepG2) and lung cancer cell lines (A549). Hibiscus extract can inhibit the activity of α-amylase, thereby preventing the absorption of sugar and starch, thereby inhibiting fat production and inhibiting lipid accumulation. Used to develop diet foods [39]. Yamamoto *et al*. used 70% ethanol to extract six local edible flowers in Japan and evaluated their physiological functions *in vitro*, including antioxidant activity, anti-allergic activity, antidiabetic activity (based on amylase reducing ability) and anti-obesity activity (based on lipase inhibitory activity). It was found that the antioxidant activity is 2-3 times higher than α-tocopherol, and it also has good biological value in terms of antidiabetic, anti-allergic and anti-obesity activities. It can be speculated that edible flowers are a potential source of natural antioxidants, and adding edible flowers to the human diet has antioxidant and anti-aging effects [58]. It is reported that chrysanthemum extract is very effective for acute oxidative tissue damage, liver enzyme balance, and preventing histopathological changes (such as tissue necrosis, fat changes, etc.). Therefore, chrysanthemum is a liver-protecting drug in China's traditional Chinese medicine system. Studies have found that chrysanthemum contains a high concentration of chlorogenic acid, an antioxidant and anti-inflammatory biologically active substance, which clarifies its medicinal basis and pharmacological properties [59]. Abdel Hafez *et al*. studied the liver protection potential of mallow flower for carbon tetrachloride-induced hepatotoxicity in rats. The results showed that mallow can significantly reduce liver damage in rats, which is manifested by a decrease in the levels of alanine aminotransferase, total bilirubin, aspartic acid aminotransferase, malondialdehyde and alkaline phosphatase [60]. Neuronal degeneration is highly related to aging, Alzheimer's disease and Parkinson's disease. These diseases are common causes of dementia. Flowers such as marigold, lavender, arnica, and daisy can be used as substitutes for sedative drugs to treat patients with Alzheimer's disease. In addition, they are also rich in carotenoids, triterpenoids and other anti-hyperglycemic substances for the prevention and treatment of diabetes [61].In terms of antibacterial, calendula extract exhibits antibacterial activity against gram-negative and gram-positive bacteria, hibiscus flower extract has antibacterial activity against several foodborne bacterial pathogens [39], pomegranate flower extract extracorporeal antibacterial experiments have shown that pomegranate flower polysaccharides, polyphenols, and flavonoids can inhibit the growth of Staphylococcus aureus [62], studies have shown that the ethanol extract of hibiscus flower and cassia seed flower has significant antibacterial activity against several foodborne bacterial pathogens and has the application prospects of natural food preservatives [63].

5. Summary

As a class of emerging food resources, edible flowers are rich in nutrients and functional ingredients such as anthocyanins, flavonoids, phenolic acids, and plant essential oils. They have various effects such as hypoglycemia, anti-cancer, anti-inflammatory, antibacterial, liver protection, and dementia prevention, and have attracted more and more attention. Edible flowers can be used as functional food raw materials, and their extracts can be used to prepare natural food preservatives. Although edible flowers are still in their infancy and there are relatively few mature commercial products, with the deepening of research on edible flowers, flowers with the characteristics of ornamental, medicinal and food use have great market development potential and are very likely to become a new hot spot for the development of natural and healthy foods.

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