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*Review*

# Phytochemicals and Antioxidant Properties of Edible Flowers

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**Abstract:** Nowadays there is a growing interest among consumers for functional food products, and edible flowers could be a solution to fulfill this demand. Edible flowers have been used throughout the centuries for their pharmaceutical properties, but also in some areas for culinary purposes. There is a great variety of edible flowers, and numerous studies are available regarding their chemical composition and potential antioxidant and functional characteristics. Therefore, the present work focuses on gathering a vast amount of data regarding edible flowers. Phytochemical content, total phenolic content, total flavonoid content and antioxidant activity (DPPH, FRAP, ABTS, etc.) of more than 200 edible flowers are presented. The main phytochemicals belong to the groups of phenolic acids, flavonoids, carotenoids and tocols, while great variability is reported in their content. The present study could be a useful tool to select the edible flowers that can be served as sources of specific phytochemicals with increased antioxidant activity and evaluate them for their safety and potential application in food industry, during processing and storage.

**Keywords:** edible flowers; phytochemicals; antioxidant; total phenolic content; total flavonoid content; DPPH; FRAP; ABTS

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## 1. Introduction

The word phytochemicals is derived from two Greek words "φυτό" and "χημικά", which mean plants and chemicals, respectively. Therefore, phytochemicals are chemical compounds that are derived from plants. According to the most common definition, *phytochemicals are defined as bioactive non-nutrient plant compounds in fruits, vegetables, grains, and other plant foods that have been linked to reducing the risk of major chronic diseases* [1]. However, in plants they are produced through secondary biochemical pathways due to environmental stimulations and as a response to various challenges. They play several roles during all stages of plant growth and are essential for their survival (Figure 1) [2]. These roles may explain several characteristics and properties of phytochemicals such as their taste, color or even aroma. In the case of taste, phytochemicals may be bitter or even toxic (in interactions with nervous systems of animals) in order to limit their consumption from herbivores. Some of them present characteristic colors and aromas in order to attract the necessary pollinators or the enemies of herbivores by producing a mixture of phytochemicals as a response to tissue damage [2].

Flowers are parts of plants that also contain amounts of several phytochemicals, and therefore they have been used since ancient times for their potential therapeutic properties in medicine or for culinary purposes [3]. Nowadays, the results of several research studies support these potential health properties of edible flowers, known since ancient times. In addition, these studies concluded that it is mainly the antioxidant activities of such compounds that are responsible for these health benefits, since they are linked with the prevention of several diseases (Figure 2). Therefore, various recent review articles are available reporting the potential health benefits of phytochemicals from edible flowers [3–6].

Edible flowers are sources of a variety of bioactive compounds, and the most common include phenolic acids, flavonoids, carotenoids, tocols and terpene compounds. However, some other compounds in lower concentrations may also be detected, such as alkaloids, nitrogen-containing compounds and organosulfur compounds [7,8].

As already mentioned, there are several works available regarding the functional characteristics of edible flowers; however, the majority of them focus on the health benefits, and in some of them a brief description of the main compounds is presented [3–8]. The aim of the present study is to provide a detailed presentation of the main compounds detected in edible flowers and the possible antioxidant activity. In the present work, more than 200 edible flowers, analyzed in different studies, have been collected and presented.

This comprehensive review was based on a search in electronic databases such as Scopus and Google Scholar and related articles regarding edible flowers, as well as their total phenolic content and antioxidant activity. The keywords used were 'edible flower' and each one of the terms 'antioxidant', 'total phenolic content', 'total flavonoid content', 'phenolic acids', 'flavonoids', 'carotenoids', 'tocols' and 'terpenes', found in the title/abstract/keywords. Subsequently, a systematic review related to the phenolic compounds of edible flowers and their antioxidant properties was performed. An attempt was made to mainly include works from the last 5–10 years.

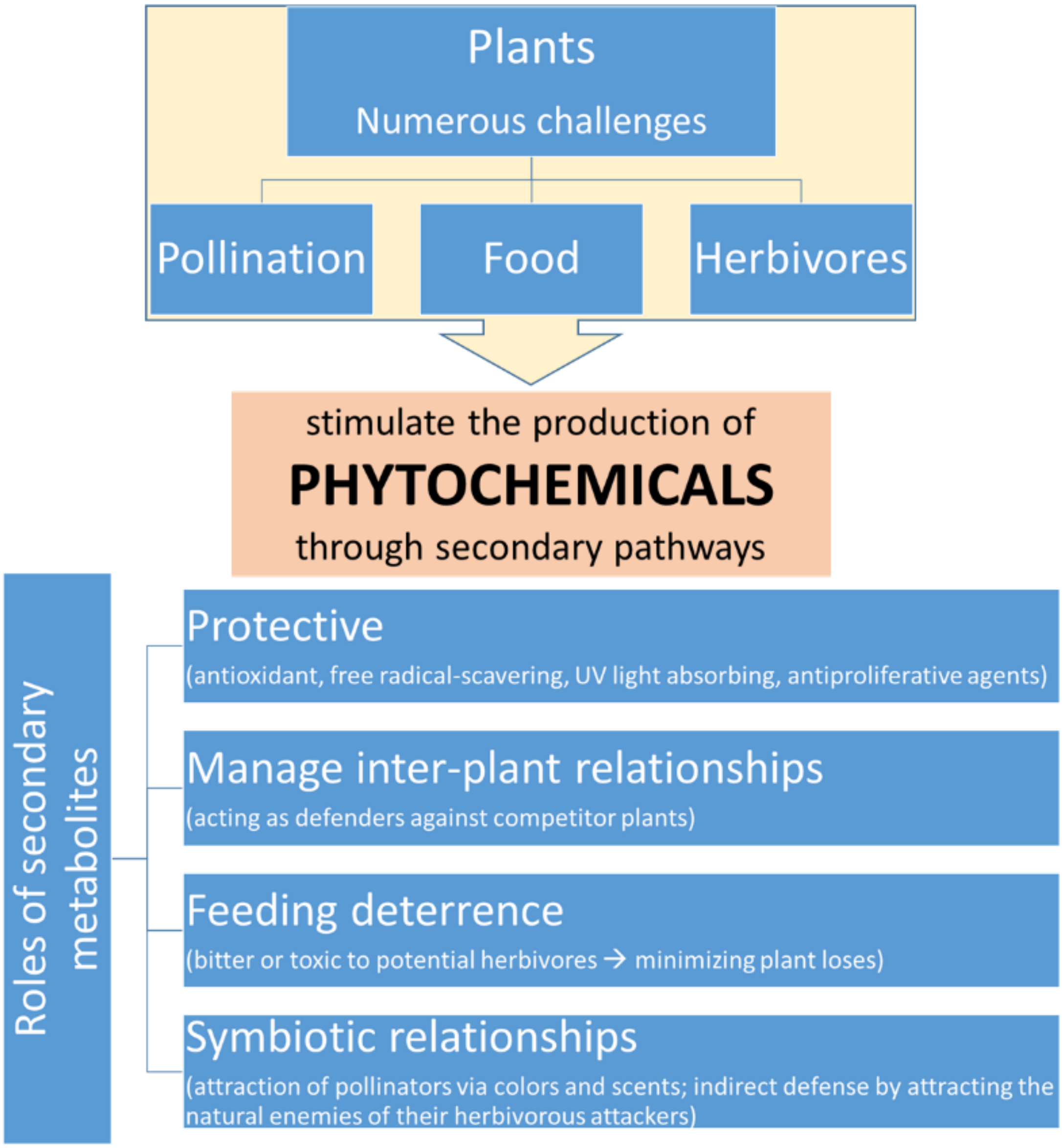



**Figure 1.** Phytochemicals and their role in plants.

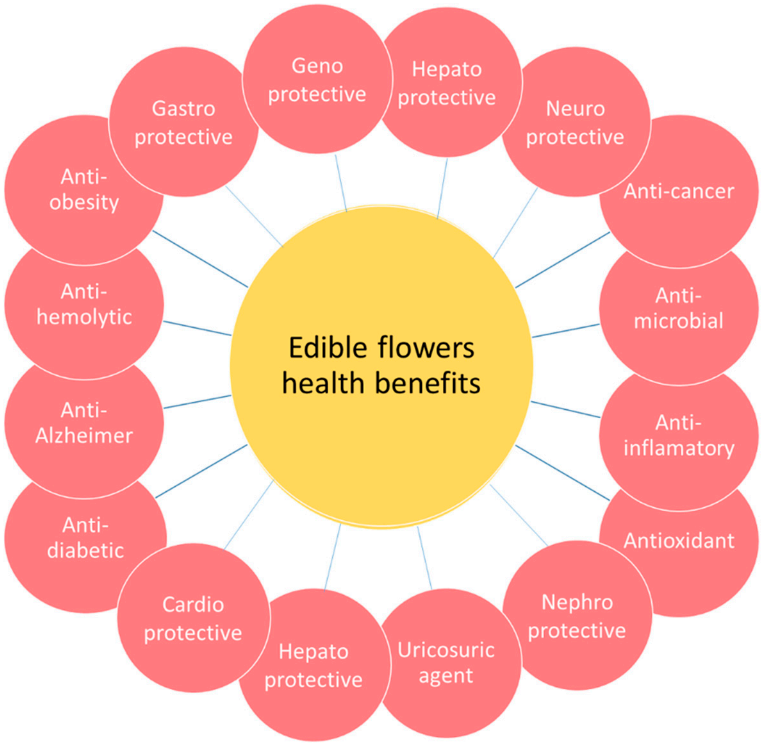



**Figure 2.** Potential health benefits linked with edible flowers.

## 2. Phytochemicals

### *2.1. Phenolic Compounds*

From a chemical point of view, phenolic compounds, or simply polyphenols, are compounds that possess at least an aromatic ring containing one or more hydroxyl groups and/or their functional derivatives such as esters, methyl esters, glycosides, etc. In edible flowers and in plants in general, they are mainly found as a conjugated form with one or more glucose residues joined to the hydroxyl groups or directly to an aromatic carbon resulting to glycosides (the main form found in nature) [9]. Phenolic compounds have numerous actions in the plant, participating in the mechanisms of growth, reproduction and plant protection [10]. However, they are well-known for their antioxidant activities in humans after consumption. In edible flowers, two main groups of phenolics are usually highlighted due to their bioactive potential and their content, namely phenolic acids (hydroxycinnamic and hydroxybenzoic acids) and flavonoids (flavones, flavanones, flavonols, flavanols and antocyanins) [4,6–8].

#### 2.1.1. Total Phenolic Content

The most common and simple method for the estimation of total phenolic content (TPC) is the colorimetrical assay based on Folin–Ciocalteu reagent. However, this method usually overestimates the TPC of samples since all the compounds with an active hydroxyl group(s) may react with the reagent and give a positive result [11,12]. Such compounds, apart from the phenolics, include reducing sugars, ascorbic acid and others. Despite that, this method is the most commonly used, and therefore is the same method used for the extracts of edible flowers. The TPC of more than 200 edible flowers, expressed as mg gallic acid equivalents (GAE) per g in dry weight (DW) or fresh weight (FW), are presented in Tables 1 and 2 [13–21].

In studies where TPC was expressed in DW, the highest values were reported for *Rosa rugosa* (312 mg GAE/g DW), *Carpobrotus edulis* (299 mg GAE/g DW), *Rosa chinensis* (285 mg GAE/g DW) and *Rhododendron simsii* Planch (250 mg GAE/g DW), while the lowest were reported for *Agave salmiana* and *Aloe vera* (4.6 mg GAE/g DW). In studies where TPC was expressed in FW, the highest values were reported for *Rosa hybrid* (35.8 mg GAE/g FW) and

*Limonium sinuatum* (34.2 mg GAE/g FW), while the lowest were reported for *Iris japonica* (0.6 mg GAE/g FW) and *Lilium candidum* L. (0.9 mg GAE/g FW).

The results in Tables 1 and 2, also revealed the main problem of TPC estimation through Folin–Ciocalteu reagent. This method is highly affected by the raw material, extraction method and duration of reaction for color development. Therefore, in some cases, almost identical results were obtained for the same flower, such as *Matricaria recutita* (26.5 mg GAE/g DW [20] and 26.4 mg GAE/g DW [18]); in other cases, a small difference occurred, such as *Siraitia grosvenorii* (12.8 mg GAE/g DW [20] and 22.2 mg GAE/g DW [18]); but completely different values may also be reported, such as *Lavandula angustifolia* Mill. (36.9 mg GAE/g DW [18] and 7.4 mg GAE/g DW [16]) and *Tropaeolum majus* (62.7 mg GAE/g DW [18] and 11.8 mg GAE/g DW [16]).

**Table 1.** Total phenolic content (mg GAE/g DW) of several edible flowers.

| Flower | TPC | Flower | TPC | Flower | TPC |
|---|---|---|---|---|---|
| *Agave salmiana* | 4.6 [d] | *Dianthus caryophyllus* | 30.8 [a] | *Myosotis sylvatica* | 64.0 [a] |
| *Aglaia odorata* | 55.5 [a] | *Dianthus* L. | 15.9 [b] | *Myrtillocactus geometrizans* | 28.7 [d] |
| *Albizzia julibrissin* | 14.2 [a] | *Epipremnum aureum* | 12.9 [a] | *Nelumbo nucifera* | 54.5 [a] |
| *Allium schoneoprasum* L. | 7.2 [b] | *Eriobotrya japonica* | 21.6 [a] | *Nymphaea stellata* | 69.6 [a] |
| *Aloe vera* | 4.6 [d] | *Erythrina americana* | 7.8 [d] | *Oroxylum indicum* | 46.0 [a] |
| *Amygdalus persica* | 51.2 [a] | *Florists chrysanthemum* (yellow) | 32.5 [a] | *Osmanthus fragrans* | 134.0 [a] |
| *Armeniaca mume* | 54.6 [a] | *Florists chrysanthemum* (white) | 23.2 [a] | *Osmanthus fragrans* (Thunb.) Lour. | 68.2 [c] |
| *Bauhinia variegata* | 48.0 [a] | *Gomphrena globosa* | 11.1 [a] | *Paeonia lactiflora Pall.* | 222.0 [c] |
| *Begonia tuberhybrida* Voss. | 33.0 [b] | *Gomphrena globosa* Linn. | 4.8 [c] | *Paeonia suffruticosa* | 240.0 [a] |
| *Bombax ceiba* | 21.6 [a] | *Hedychium coronarium* | 14.2 [a] | *Panax pseudoginseng* | 7.7 [a] |
| *Calendula officinalis* | 17.4 [a] | *Helichrysum bracteatum* | 72.4 [a] | *Perennial chamomile* | 28.5 [c] |
| *Calendula officinalis* L. | 17.2 [b] | *Hemerocallis citrina* | 8.7 [a] | *Plumeria rubra Acutifolia* | 20.4 [a] |
| *Calendula officinalis* L. | 13.0 [c] | *Hemerocallis hybrida hort* | 15.7 [b] | *Plumeria rubra Linn.* Sp. | 56.0 [a] |
| *Camellia azalea* | 61.5 [a] | *Hibiscus sabdariffa* L. | 21.1 [c] | *Prunella vulgaris* | 9.5 [a] |
| *Camellia japonica* | 22.0 [a] | *Hibiscus sabdariffa* | 16.4 [a] | *Punica granatum* | 245.8 [a] |
| *Campsis grandiflora* | 29.6 [a] | *Hylocereus undatus* | 9.7 [a] | *Radix Gentianae* | 25.1 [c] |
| *Canna edulis* | 18.0 [a] | *Jasminum sambac* | 20.6 [a] | *Redartfulplum tea* | 8.6c |
| *Carpobrotus edulis* | 299.0 [e] | *Jasminum sambac* (L.) Ait | 12.7 [c] | *Rhododendron simsii* Planch | 249.8 [a] |
| *Centaurea cyanus* L. | 7.3 [b] | *Lavandula angustifolia* | 50.8 [a] | *Rosa centifolia* | 108.9 [a] |
| *Chamomilia* | 30.2 [c] | *Lavandula angustifolia* Mill. | 36.9 [c] | *Rosa chinensis* | 284.8 [a] |
| *Chimonanthus praecox* | 33.9 [a] | *Lavandula angustifolia* Mill. | 7.4 [b] | *Rosa gallica* | 111.3 [a] |
| *Chimonanthus praecox* | 25.8 [c] | *Lilium brownie* | 34.8 [a] | *Rosa rugosa* (rose) | 312.2 [a] |
| *Chrysanthemum indicum* | 36.0 [a] | *Lilium brownii var. viridulum* | 18.4 [c] | *Rosa rugosa* (white-rose) | 39.5 [a] |
| *Chrysanthemum indicum* | 55.0 [a] | *Lilium bulbiferum* | 12.1 [a] | *Rosa rugosa Thunb* (pink) | 25.8 [c] |
| *Chrysanthemum lavandulifolium* | 39.4 [a] | *Lonicera japonica* | 87.5 [a] | *Rosa rugosa Thunb* (purple) | 57.8 [c] |
| *Chrysanthemum morifolium ramat* | 33.6 [a] | *Magnolia denudate* | 19.6 [a] | *Rosa rugosa* | 56.2 [b] |
| *Chrysanthemum morifolium* | 24.6 [c] | *Magnolia grandiflora* | 10.4 [a] | *Rosmarinus officinalis* L. | 24.9 [c] |
| *Citrus aurantium* | 62.5 [a] | *Malus pumila* | 60.6 [a] | *Sambucus nigra* L. | 14.4 [b] |
| *Coreopsis tinctoria* | 92.9 [a] | *Malus spectabilis* | 8.2 [a] | *Siraitia grosvenorii* | 12.8 [a] |
| *Crocus sativus* L. | 21.4 [a] | *Matricaria recutita* | 26.5 [a] | *Siraitia grosvenorii* | 22.2 [c] |
| *Cucumis sativus* Linn. | 5.5 [a] | *Matricaria recutita* | 26.4 [c] | *Sophora japonica* L. | 84.2 [a] |
| *Cucurbita pepo* L. | 13.0 [b] | *Matthiola incana* | 43.3 [a] | *Tagates* L. | 89.2 [b] |
| *Cymbidium sinense* | 23.3 [a] | *Michelia alba* | 18.9 [a] | *Tropaeolum majus* | 62.7 [a] |
| *Dendranthema morifolium* | 20.8 [c] | *Myosotis sylvatica* | 25.9 [c] | *Tropaeolum majus* | 11.8 [b] |
| *Dianthus caryophyllus* | 27.9 [c] | | | *Viola tricolor* L. | 46.8 [b] |

a, [20]; b, [16]; c, [18]; d, [14]; e, [21].

**Table 2.** Total phenolic content (mg GAE/g FW) of several edible flowers.

| Flower | TPC | Flower | TPC | Flower | TPC |
|---|---|---|---|---|---|
| *Ageratum conyzoides* | 4.6 [a] | *Flos chrysanthemi* | 3.8 [a] | *Oxalis corymbosa* | 2.2 [a] |
| *Allamanda cathartica* | 4.2 [a] | *Geranium sylvaticum* | 12.7 [d] | *Paeonia officinalis* | 19.3 [d] |
| *Allium ursinum* | 1.8 [d] | *Gerbera jamesonii Bolus* | 4.9 [a] | *Pelargonium hortorum* | 25.7 [a] |
| *Antirrhinum majus* L. | 1.0 [b] | *Gladiolus hybrids* | 2.3 [a] | *Phaseolus vulgaris* | 1.9 [a] |
| *Antirrhinum majus* L. | 2.7 [c] | *Helianthus annuus* | 1.9 [a] | *Platycodon grandiflorus* | 4.6 [a] |
| *Bauhinia purpurea* | 6.1 [a] | *Hemerocallis × hybrida Hort.* | 2.1 [c] | *Plumbago auriculata* Lam. | 6.3 [b] |
| *Bellis perennis* | 4.0 [d] | *Hibiscus rosa-sinensis* | 6.8 [a] | *Primula veris* | 10.4 [d] |
| *Bidens pilosa* | 8.1 [a] | *Hibiscus rosa-sinensis* L. (red) | 4.3 [b] | *Primula vulgaris* | 6.0 [d] |
| *Bombax malabaricum* | 3.9 [a] | *Hibiscus rosa-sinensis* L. (white) | 4.2 [b] | *Rhapniolepis indica* | 8.0 [a] |
| *Borago officinalis* | 1.6 [d] | *Impatiens walleriana* | 7.6 [a] | *Rhododendron simsii* Planch | 6.8 [a] |
| *Bougainvillea spectabilis* | 6.9 [a] | *Ipomoea cairica* | 1.8 [a] | *Rhododendron simsii* Planch | 1.8 [b] |
| *Brassica campestris* | 3.3 [a] | *Iris japonica* | 0.6 [a] | *Rhoeo discolor* | 2.6 [a] |
| *Brassica compestris* | 4.4 [a] | *Jasminum officinale* L. | 4.6 [b] | *Robinia pseudoacacia* | 2.0 [d] |
| *Brunfelsia acuminate* | 4.1 [a] | *Jasminum nudiflorum* | 3.1 [a] | *Rosa canina* | 14.0 [d] |
| *Calendula officinalis* | 1.9 [d] | *Jatropha integerrima* | 17.2 [a] | *Rosa chinensis Jacq.* | 18.6 [b] |
| *Calliandra haematocephala* | 14.4 [a] | *Lantana camara* | 3.5 [a] | *Rosa hybrida* | 35.8 [a] |
| *Camellia japonica* | 5.1 [a] | *Lantana camara* L. (white) | 1.7 [b] | *Rosa pendulina* | 17.7 [d] |
| *Catharanthus roseus* L. G. Don | 3.5 [b] | *Lantana camara* L. (pink) | 1.4 [b] | *Ruellia simpex C. Wright* | 4.3 [b] |
| *Centaurea cyanus* | 3.8 [d] | *Lantana camara* L. (yellow) | 2.6 [b] | *Salvia pratensis* | 3.1 [d] |
| *Chaenomeles sinensis* | 13.9 [a] | *Lavandula angustifolia* | 4.0 [d] | *Salvia splendens* | 2.6 [a] |
| *Chrysanthemum coronarium* | 3.8 [a] | *Leucanthemum vulgare* | 4.5 [d] | *Sambucus nigra* | 5.1 [d] |
| *Chrysanthemum indicum* L. (purple) | 2.1 [b] | *Ligustrum sinense* | 6.2 [a] | *Strelitzia reginae Aiton* | 9.4 [a] |
| *Chrysanthemum indicum* L. (dark-red) | 1.9 [b] | *Lilium candidum* L. | 0.9 [b] | *Tagetes erecta* L. | 7.6 [b] |
| *Cichorium intybus* | 6.2 [d] | *Lilium brownie* | 1.3 [a] | *Tagetes patula* | 4.7 [d] |
| *Cyclamen hederifolium Aiton* (fuchsia) | 5.5 [b] | *Limonium sinuatum* | 34.2 [a] | *Taraxacum officinale* | 1.6 [d] |
| *Cyclamen hederifolium Aiton* (white) | 6.4 [b] | *Lorpetalum chindense var.rubrum* | 11.5 [a] | *Tecomaria capensis* (Thunb.) *Spach* | 2.5 [b] |
| *Cyclamen repandum Sm* | 7.4 [b] | *Magnolia soulangeana* | 5.3 [a] | *Thunbergia alata Bojer ex Sims* | 2.0 [b] |
| *Dianthus caryophyllus* | 5.5 [a] | *Malvaviscus arboreus* | 3.1 [a] | *Trifolium alpinum* | 4.6 [d] |
| *Dianthus caryophyllus* L. | 1.3 [b] | *Malvaviscus arboreus Cav.* | 2.3 [b] | *Tropaeolum majus* | 3.6 [d] |
| *Dianthus carthusianorum* | 9.4 [d] | *Matthiola incana* | 1.7 [a] | *Viola tricolor* L. (pink) | 6.9 [b] |
| *Dianthus chinensis* | 5.3 [a] | *Mentha aquatica* | 10.6 [d] | *Viola tricolor* L. (yellow) | 7.2 [b] |
| *Dianthus chinensis* L. | 12.3 [c] | *Mimulus × hybridus* L. | 4.3 [c] | *Viola odorata* | 4.3 [d] |
| *Dianthus pavonius* | 7.5 [d] | *Monarda didyma* L. | 10.6 [c] | *Wedelia trilobata* | 3.8 [a] |
| *Ericaceae rhododendron* | 6.3 [a] | *Oncidium varicosum* | 4.5 [a] | *Youngia japonica* | 1.1 [a] |
| *Erythrina variegata* | 3.9 [a] | *Orostachys fimbriatu* | 12.4 [a] | *Zantedeschia aethiopica Spreng* | 3.1 [a] |
| *Erythronium dens-canis* | 3.6 [d] | *Osmanthus fragrans* | 16.0 [a] | | |

a, [13]; b, [19]; c, [15]; d, [17].

In the abovementioned studies, Rosa species are in the top five edible flowers with the highest TPC. Similar results with high TPC of Rosa species are also reported in other studies with edible flowers [22,23]. It is also interesting that the TPC of some edible flowers is higher than vegetables, common edible fruits and nontraditional tropical fruits reported in the literature [24,25].

### 2.1.2. Phenolic Acids

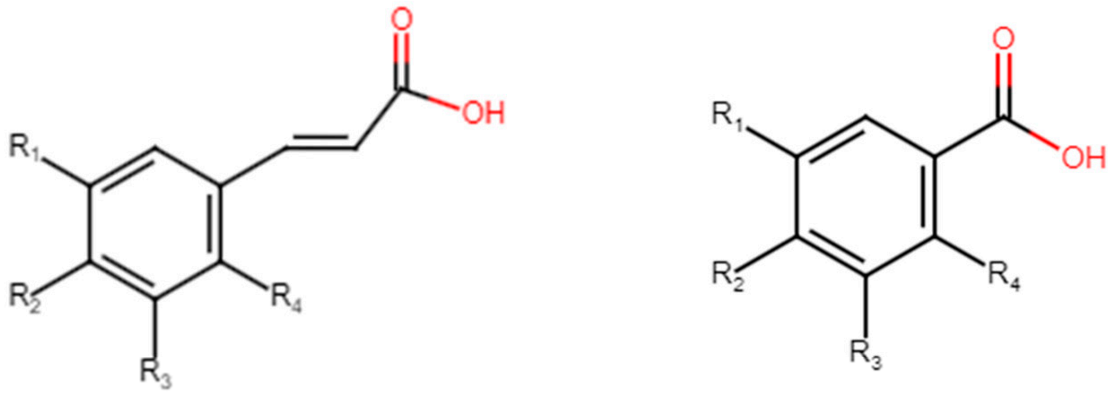
Phenolic acids can be divided into two groups: the hydroxycinnamic acids, comprising a three-carbon side chain (C6–C3) structure (Table 3); and hydroxybenzoic acids, comprising a C6–C1 structure (Table 4), which can be found as free substances or conjugated (Figure 3) [10]. Hydroxycinnamic acid derivatives include p-coumaric, caffeic, ferulic, sinapic and chlorogenic (5-O-caffeoylquinic acid) acids [1,8]. In the group of hydroxybenzoic acid derivatives belong, among others, p-hydroxybenzoic, protocatechuic, vanillic, syringic, ellagic and gallic acids [1,8]. They are usually part of a complex structure such as lignins and hydrolyzable tannins, but they can also be found in the form of sugar derivatives and organic acids [1]. Homogentisic acid has been detected in several edible flowers such as *Bidens pilosa*, *Brunfelsia acuminata*, *Calliandra haematocephala*, *Chaenomeles sinensis*, *Dianthus caryophyllus*, *Dianthus chinensis*, *Flos chrysanthemi*, *Gerbera jamesonii* Bolus, *Gladiolus hybrids*, *Helianthus annuus*, *Hibiscus rosa-sinensis*, *Ipomoea cairica*, *Jatropha integerrima*, *Lantana camara*, *Limonium sinuatum*, *Magnolia soulangeana*, *Malvaviscus arboreus*, *Orostachys fimbriatu*, *Osmanthus fragrans*, *Pelargonium hortorum*, *Rhapniolepis indica*, *Rhododendron simsii* Planch, *Rhoeo discolor*, *Rosa hybrid*, *Salvia splendens* and *Strelitzia reginae* Aiton [13].

**Table 3.** Major hydroxycinnamic acid derivatives detected in some edible flowers.

| Flower |
|---|
| p-coumaric |
| • *Aloe vera*, *Erythrina americana*, *Myrtillocactus geometrizans* [14]<br>• *Allium schoenoprasum* L., *Begonia × tuberhybrida* Voss., *Calendula officinalis* L., *Centaurea cyanus* L., *Cucurbita pepo* L., *Hemerocallis hybrida* hort, *Lavandula angustifolia* Mill., *Rosa rugosa* Thunb, *Sambucus nigra* L., *Tagates* L., *Tropaeolum majus*, *Viola tricolor* L. [16]<br>• *Allium ursinum*, *Bellis perennis*, *Cichorium intybus*, *Erythronium dens-canis*, *Geranium sylvaticum*, *Mentha aquatica*, *Sambucus nigra* L., *Trifolium alpinum*, *Viola odorata* [17]<br>• *Chimonanthus praecox*, *Dianthus caryophyllus*, *Gomphrena globosa* Linn., *Lavandula angustifolia* Mill., *Lilium brownii* var. *viridulum*, *Osmanthus fragrans*, *Paeonia lactiflora* Pall., *Perennial chamomile*, *Radix Gentianae*, *Redartfulplum tea*, *Rosmarinus officinalis* L. [18]<br>• *Allium schoenoprasum* L., *Viola arvensis* [26] |
| Caffeic |
| • *Agave salmiana*, *Myrtillocactus geometrizans* [14]<br>• *Allium schoneoprasum* L., *Begonia × tuberhybrida* Voss., *Calendula officinalis* L., *Centaurea cyanus* L., *Cucurbita pepo* L., *Hemerocallis hybrida* hort, *Lavandula angustifolia* Mill., *Rosa rugosa* Thunb, *Sambucus nigra* L., *Tagates* L., *Tropaeolum majus*, *Viola tricolor* L. [16]<br>• *Bellis perennis* L., *Dianthus carthusianorum*, *Erythronium dens-canis*, *Mentha aquatica*, *Paeonia officinalis*, *Primula veris*, *Primula vulgaris*, *Sambucus nigra* L., *Taraxacum officinale*, *Tropaeolum majus*, *Viola odorata* [17]<br>• *Calendula officinalis* L., *Chamomilia*, *Chimonanthus praecox*, *Chrysanthemum morifolium*, *Dendranthema morifolium*, *Dianthus caryophyllus*, *Gomphrena globosa* Linn., *Hibiscus sabdariffa* L., *Lavandula angustifolia* Mill., *Lilium brownii* var. *viridulum*, *Matricaria recutita*, *Paeonia lactiflora* Pall., *Perennial chamomile*, *Radix Gentianae*, *Rosa rugosa* Thunb, *Rosmarinus officinalis* L. [18]<br>• *Bellis perennis* L., *Cichorium intybus* L., *Sambucus nigra* L., *Taraxacum officinale*, *Trifolium repens* L. [26] |
| Ferulic |
| • *Agave salmiana*, *Aloe vera*, *Erythrina americana*, *Myrtillocactus geometrizans* [14]<br>• *Allium schoneoprasum* L., *Begonia × tuberhybrida* Voss., *Centaurea cyanus* L., *Cucurbita pepo* L., *Hemerocallis hybrida* hort, *Lavandula angustifolia* Mill., *Tagates* L., *Tropaeolum majus* [16]<br>• *Allium ursinum*, *Erythronium dens-canis*, *Paeonia officinalis*, *Primula veris*, *Primula vulgaris*, *Trifolium alpinum*, *Viola odorata* [17]<br>• *Calendula officinalis* L., *Chamomilia*, *Chimonanthus* praecox, *Dendranthema morifolium*, *Dianthus caryophyllus*, *Gomphrena globosa* Linn., *Hibiscus sabdariffa* L., *Lavandula angustifolia* Mill., *Lilium brownii* var. *viridulum*, *Osmanthus fragrans*, *Paeonia lactiflora* Pall., *Perennial chamomile*, *Radix Gentianae*, *Redartfulplum tea*, *Rosa rugosa* Thunb, *Rosmarinus officinalis* L., *Siraitia grosvenorii* [18]<br>• *Allium schoneoprasum* L., *Bellis perennis* L., *Cichorium intybus* L., *Tragopogon pratensis* L. [26] |
| Sinapic |
| • *Begonia × tuberhybrida* Voss., *Dianthus* L. [16]<br>• *Cichorium intybus* L., *Rumex acetosa* L., *Taraxacum officinale*, *Tragopogon pratensis* L. [26] |
| Chlorogenic |
| • *Agave salmiana*, *Aloe vera*, *Erythrina americana*, *Myrtillocactus geometrizans* [14]<br>• *Cichorium intybus*, *Erythronium dens-canis*, *Geranium sylvaticum*, *Mentha aquatica*, *Rosa canina*, *Taraxacum officinale*, *Tropaeolum majus* [17] |

**Table 4.** Major hydroxybenzoic acid derivatives detected in some edible flowers.

| **Flower** |
| --- |
| p-hydroxybenzoic |
| • *Aloe vera*, *Myrtillocactus geometrizans* [14] |
| • *Begonia × tuberhybrida* Voss., *Cucurbita pepo* L., *Dianthus* L., *Lavandula angustifolia* Mill., *Tropaeolum majus* [16] |
| Protocatechuic |
| • *Ageratum conyzoides*, *Allamanda cathartica*, *Bidens pilosa*, *Brassica campestris*, *Camellia japonica*, *Chrysanthemum coronarium*, *Dianthus caryophyllus*, *Ericaceae rhododendron*, *Erythrina variegate*, *Gerbera jamesonii* Bolus, *Gladiolus hybrids*, *Impatiens walleriana*, *Jasminum nudiflorum*, *Ligustrum sinense*, *Matthiola incana*, *Osmanthus fragrans*, *Oxalis corymbosa*, *Phaseolus vulgaris*, *Platycodon grandiflorus*, *Rhapniolepis indica*, *Rosa hybrid*, *Salvia splendens*, *Zantedeschia aethiopica* Spreng [13] |
| • *Allium schoneoprasum* L., *Begonia × tuberhybrida* Voss., *Centaurea cyanus* L., *Cucurbita pepo* L., *Lavandula angustifolia* Mill., *Tagates* L., *Tropaeolum majus*, *Viola tricolor* L. [16] |
| • *Calendula officinalis* L., *Chamomilia*, *Chimonanthus praecox*, *Chrysanthemum morifolium*, *Dianthus caryophyllus*, *Hibiscus sabdariffa* L., *Jasminum sambac*, *Lavandula angustifolia* Mill., *Matricaria recutita*, *Myosotis sylvatica*, *Osmanthus fragrans*, *Paeonia lactiflora* Pall., *Perennial chamomile*, *Radix Gentianae*, *Redartfulplum tea*, *Rosa rugosa Thunb*, *Siraitia grosvenorii* [18] |
| Vanillic |
| • *Agave salmiana*, *Aloe vera*, *Erythrina americana*, *Myrtillocactus geometrizans* [14] |
| • *Cucurbita pepo* L. [16] |
| • *Bellis perennis* L., *Rumex acetosa* L., *Sambucus nigra* L., *Taraxacum officinale* [26] |
| Syringic |
| • *Erythrina americana*, *Myrtillocactus geometrizans* [14] |
| • *Calendula officinalis* L., *Tagates* L., *Viola tricolor* L. [16] |
| • *Calendula officinalis* L., *Chimonanthus praecox*, *Dianthus caryophyllus*, *Hibiscus sabdariffa* L., *Myosotis sylvatica*, *Osmanthus fragrans*, *Paeonia lactiflora* Pall., *Radix Gentianae*, *Rosa rugosa* Thunb, *Rosmarinus officinalis* L. [18] |
| Ellagic |
| • *Allium ursinum*, *Bellis perennis*, *Borago officinalis*, *Calendula officinalis*, *Centaurea cyanus*, *Cichorium intybus*, *Dianthus carthusianorum*, *Dianthus pavonius*, *Erythronium dens-canis*, *Geranium sylvaticum*, *Lavandula angustifolia*, *Leucanthemum vulgare*, *Mentha aquatica*, *Paeonia officinalis*, *Primula veris*, *Primula vulgaris*, *Robinia pseudoacacia*, *Rosa canina*, *Rosa pendulina*, *Salvia pratensis*, *Sambucus nigra*, *Tagetes patula*, *Taraxacum officinale*, *Trifolium alpinum*, *Tropaeolum majus*, *Viola odorata* [17] |
| Gallic |
| • *Ageratum conyzoides*, *Allamanda cathartica*, *Bauhinia purpurea*, *Bidens pilosa*, *Bombax malabaricum*, *Bougainvillea spectabilis*, *Brassica campestris*, *Chrysanthemum coronarium*, *Ericaceae rhododendron*, *Jasminum nudiflorum*, *Ligustrum sinense*, *Lorpetalum chindense* var.*rubrum*, *Magnolia soulangeana*, *Oncidium varicosum*, *Phaseolus vulgaris*, *Platycodon grandiflorus*, *Rhoeo discolor*, *Youngia japonica*, *Zantedeschia aethiopica* Spreng [13] |
| • *Aloe vera*, *Myrtillocactus geometrizans* [14] |
| • *Begonia × tuberhybrida* Voss., *Cucurbita pepo* L., *Hemerocallis hybrida* hort, *Lavandula angustifolia* Mill., *Sambucus nigra* L., *Tagates* L., *Tropaeolum majus*, *Viola tricolor* L. [16] |
| • *Borago officinalis*, *Cichorium intybus* L., *Dianthus carthusianorum*, *Paeonia officinalis* [17] |
| • *Chamomilia*, *Dianthus caryophyllus*, *Hibiscus sabdariffa* L., *Myosotis sylvatica*, *Paeonia lactiflora* Pall., *Rosa rugose* Thunb [18] |
| • *Allium schoenoprasum* L., *Bellis perennis* L., *Cichorium intybus* L., *Salvia pratensis* L., *Sambucus nigra* L., *Taraxacum officinale*, *Tragopogon pratensis* L., *Trifolium repens* L., *Viola arvensis* [26] |




**Hydroxycinnamic acids**

| $R_1$ | $R_2$ | $R_3$ | $R_4$ | Name |
|---|---|---|---|---|
| H | OH | H | H | **p-coumaric** |
| OH | OH | H | H | **Caffeic** |
| $OCH_3$ | OH | H | H | **Ferulic** |
| $OCH_3$ | OH | $OCH_3$ | H | **Sinapic** |

**Hydroxybenzoic acids**

| $R_1$ | $R_2$ | $R_3$ | $R_4$ | Name |
|---|---|---|---|---|
| H | OH | H | H | **p-hydroxybenzoic** |
| OH | OH | H | H | **Protocatechuic** |
| $OCH_3$ | OH | H | H | **Vannilic** |
| $OCH_3$ | OH | $OCH_3$ | H | **Syringic** |
| OH | OH | OH | H | **Gallic** |

**Figure 3.** The major hydroxycinnamic and hydroxybenzoic acids.

#### 2.1.3. Flavonoids

Flavonoids, a class of low-molecular-weight phenolic compounds, are an important group of natural products, which are characteristic compounds and the largest group of secondary metabolites in plants [27]. In plants, flavonoids, as all the phenolic compounds, participate in the mechanisms of growth and protection. Many flavonoids are the main flower pigments in most plants. Flavonoids can be easily divided in several subgroups; however, this review will be focus on anthocyanins, flavones and flavanones, and flavanols and flavonols.

The total flavonoid content (TFC) of more than 100 edible flowers is presented in Tables 5 and 6. The TFC of 65 edible flowers showed a wide variation from 0.7 to 85.3 mg CAE (catechin equivalents)/g DW, with a more than 120-fold difference. The highest TFC was reported in flowers of *Osmanthus fragrans* (85.3 mg CAE/g DW), *Lonicera japonica* (52.5 mg CAE/g DW), *Coreopsis tinctoria* (29.3 mg CAE/g DW), *Helichrysum bracteatum* (28.59 mg CAE/g DW) and *Armeniaca mume* (28.50 mg CAE/g DW). On the other hand, the lowest TFC was reported in *Cucumis sativus* Linn. (0.7 mg CAE/g DW), *Hylocereus undatus* (0.8 mg CAE/g DW) and *Hemerocallis citrina* (0.9 mg CAE/g DW). This study concluded that Chrysanthemum species may contain higher flavonoids than Rosa species [20].

The TFC of 23 edible flowers, expressed as mg rutin equivalents per gram of dry weight (mg RE/g DW) varied from 0.5 to 71.5 mg RE/g DW with a 159-fold difference. *Osmanthus fragrans* (Thunb.) Lour had the highest total flavonoid content (71.5 mg RE/g DW), followed by *Lavandula angustifolia* Mill (27.4 mg RE/g DW), *Rosmarinus officinalis* L. (18.8 mg RE/g DW), *Perennial chamomile* (16.0 mg RE/g DW) and *Chamomilia* (15.7 mg RE/g DW). *Gomphrena globose* Linn had the lowest TFC (0.5 mg RE/g DW), followed by *Redartfulplum tea* (0.7 mg RE/g DW) [18].

**Table 5.** Total flavonoid content (mg CAE/g DW) of several edible flowers [20].

| Flower | TFC | Flower | TFC | Flower | TFC |
|---|---|---|---|---|---|
| *Aglaia odorata* | 3.85 | *Epipremnum aureum* | 1.6 | *Michelia alba* | 5.6 |
| *Albizzia julibrissin* | 3.78 | *Eriobotrya japonica* | 9.6 | *Myosotis sylvatica* | 11.1 |
| *Amygdalus persica* | 16.9 | *Florists chrysanthemum* (yellow) | 15.2 | *Nelumbo nucifera* | 7.8 |
| *Armeniaca mume* | 28.5 | *Florists chrysanthemum* (white) | 11.2 | *Nymphaea stellata* | 8.8 |
| *Bauhinia variegata* | 6.62 | *Gomphrena globosa* | 1.2 | *Oroxylum indicum* | 3.0 |
| *Bombax ceiba* | 5.76 | *Gomphrena globosa* | 2.2 | *Osmanthus fragrans* | 85.3 |
| *Calendula officinalis* | 6.82 | *Hedychium coronarium* | 2.0 | *Paeonia suffruticosa* | 19.2 |
| *Camellia azalea* | 8.76 | *Helichrysum bracteatum* | 28.6 | *Panax pseudoginseng* | 1.4 |
| *Camellia japonica* | 4.36 | *Hemerocallis citrina* | 0.9 | *Plumeria rubra* Acutifolia | 3.8 |
| *Campsis grandiflora* | 9.76 | *Hibiscus sabdariffa* | 2.9 | *Plumeria rubra* Linn. Sp. | 15.7 |
| *Canna edulis* | 6.67 | *Hylocereus undatus* | 0.8 | *Prunella vulgaris* | 3.6 |
| *Chimonanthus praecox* | 6.93 | *Jasminum sambac* | 4.4 | *Punica granatum* | 25.0 |
| *Chrysanthemum indicum* | 20.45 | *Lavandula angustifolia* | 12.3 | *Rhododendron simsii* planch | 20.0 |
| *Chrysanthemum indicum* | 25.39 | *Lilium brownie* | 7.2 | *Rosa centifolia* | 10.9 |
| *Chrysanthemum lavandulifolium* | 19.19 | *Lilium bulbiferum* | 1.6 | *Rosa chinensis* | 24.1 |
| *Chrysanthemum morifolium ramat* | 18.73 | *Lonicera japonica* | 52.5 | *Rosa gallica* | 13.4 |
| *Citrus aurantium* | 2.96 | *Magnolia denudate* | 2.3 | *Rosa rugose* (rose) | 23.6 |
| *Coreopsis tinctoria* | 29.3 | *Magnolia grandiflora* | 2.6 | *Rosa rugose* (white-rose) | 2.5 |
| *Crocus sativus* L. | 2.57 | *Malus pumila* | 16.9 | *Siraitia grosvenorii* | 2.9 |
| *Cucumis sativus* Linn. | 0.67 | *Malus spectabilis* | 1.6 | *Sophora japonica* L. | 18.2 |
| *Cymbidium sinense* | 4.06 | *Matricaria recutita* | 10.2 | *Tropaeolum majus* | 24.7 |
| *Dianthus caryophyllus* | 2.45 | *Matthiola incana* | 7.5 | | |

CAE: catechin equivalents; DW: dry weight.

**Table 6.** Total flavonoid content (mg RE/g DW or mg QE/g DW) of several edible flowers.

| Flower | TFC | Flower | TFC | Flower | TFC |
|---|---|---|---|---|---|
| mg RE/g DW [18] | | | | | |
| *Calendula officinalis* L. | 3.0 | *Jasminum sambac* (L.) Ait | 3.8 | *Perennial chamomile* | 16.0 |
| *Chamomilia* | 15.7 | *Lavandula angustifolia* Mill. | 27.4 | *Radix Gentianae* | 6.9 |
| *Chimonanthus praecox* (L.) Link | 6.0 | *Lilium brownii* var. *viridulum* | 1.9 | *Redartfulplum tea* | 0.7 |
| *Chrysanthemum morifolium* | 10.4 | *Matricaria recutita* | 17.6 | *Rosa rugosa* Thunb (pink) | 3.4 |
| *Dendranthema morifolium* | 9.6 | *Myosotis sylvatica* | 4.3 | *Rosa rugosa* Thunb (purple) | 6.6 |
| *Dianthus caryophyllus* | 1.4 | *Osmanthus fragrans* (Thunb.) Lour. | 71.5 | *Rosmarinus officinalis* L. | 18.8 |
| *Gomphrena globosa* Linn. | 0.5 | *Paeonia lactiflora* Pall. | 13.8 | *Siraitia grosvenorii* | 4.5 |
| *Hibiscus sabdariffa* L. | 1.9 | | | | |
| mg QE/g DW [14] | | [14] | | [16] | |
| *Allium schoneoprasum* L. | 4.6 | *Hemerocallis hybrida* hort | 9.6 | *Agave salmiana* | 4.6 |
| *Begonia tuberhybrida* Voss. | 22.0 | *Lavandula angustifolia* Mill. | 2.1 | *Aloe vera* | 7.8 |
| *Calendula officinalis* L. | 7.8 | *Rosa rugosa* | 14.4 | *Erythrina Americana* | 25.3 |
| *Centaurea cyanus* L. | 4.8 | *Sambucus nigra* L. | 2.1 | *Myrtillocactus geometrizans* | 72.4 |
| *Chrysanthemum* | 5.7 | *Tagates* L. | 14.7 | | |
| *Cucurbita pepo* L. | 3.6 | *Tropaeolum majus* | 0.8 | | |
| *Dianthus* L. | 11.9 | *Viola tricolor* L. | 1.5 | | |

RE: rutin equivalents; QE: quercetin equivalent; DW: dry weight.

Anthocyanins

Anthocyanins and their derivatives are water-soluble flavonoids and natural pigments that are responsible for the color of flowers. Their color depends mainly on pH, but metal ion and copigments may also affect it. They are responsible mainly for the red, blue and purple color of flowers. The term anthocyanins is derived from two Greek words, anthos (flower) and cyano (blue), and therefore its meaning is "blue from flowers". Anthocyanins and their color in flowers play a significant role in plants since they are responsible for the correct pollination. The color of flowers is necessary to attract the pollinators (birds and insects). In addition, for humans, anthocyanins have been correlated with plants with increased antioxidant activity and therefore with high nutritional value. Anthocyanins are present in nature mainly in their aglycon form, also called anthocyanidin. There are six common anthocyanidins, namely pelargonidin, cyanidin, delphinidin, peonidin, petunidin and malvidin, which are linked to one or more glycosidic units [28].

The variations in qualitative and quantitative composition of anthocyanidins are responsible for the variations of colors in flowers, even among the different cultivars of the same species [5,7]. In general, specific anthocyanidins have been correlated with specific colors in flowers. For example, pelarginidin is scarlet and delphinidin is more bluish. Therefore, the anthocyanidins of pink, scarlet, red, red-purple and magenta flowers are cyanidin and/or pelargonidin with or without peonidin, while in cyanic flowers, which are purple, violet and blue, mainly the anthocyanidins, delphinidin and its methylated derivatives, petunidin and malvidin are present [29]. In addition, regarding the total anthocyanin content (TAC), there is a small correlation with the flower color (blue = red > rose > yellow = orange > white) [30]. In the case of *Hibiscus syriacus* L., the red flowers presented higher TAC than purple and pink, with values of 3.2 mg/g, 1.87 mg/g and 1.61 mg/g (DW), respectively [31]. Benvenuti et al. [30] studied twelve species of cultivated edible flowers and reported the presence of a high TAC up to 14.4 mg cyn-3-glu eq./100 g FW and large variation from 0.35 to 14.4 mg cyn-3-glu eq./100 g FW. The highest concentrations (as mg cyn-3-glu eq./100 g FW) were reported for flowers from *Petunia* × *hybrid* (red 14.4 mg/100 g; rose 12.9 mg/100 g), *Viola* × *wittrockiana* (blue 13.6 mg/100 g; red 12.4 mg/100 g), *Dianthus* × *barbatus* (red 13.4 mg/100 g; rose 10.6 mg/100 g), and *Pelargonium peltatum* (red 12.5 mg/100 g), while the lowest were reported in white or orange flowers such as *Tagetes erecta* (orange 0.75 mg/100 g), *Viola* × *wittrockiana* (white 0.35 mg/100 g), *Dianthus* × *barbatus* (white 0.73 mg/100 g) and *Calendula officinalis* (orange 0.47/mg 100 g). In addition, Janarny et al. [32] studied twenty-eight species of fresh edible flowers from Sri Lanka using the pH differential method. Concentrations higher than 100 mg cyn-3-glu eq./100 g DW were reported for flowers from *Hibiscus rosa-sinensis* (200 mg/100 g), *Carrica papaya* (140 mg/100 g), *Punica granatum* (118 mg/100 g) and *Ixora coccinea* (157 mg/100 g), while the lowest concentrations below 3 mg cyn-3-glu eq./100 g DW were reported for flowers from *Cassia auriculata*, *Duriozibethinus*, *Calendula officinalis* (2 mg/100 g), *Musa* spp (0.8 mg/100 g) and *Madhuca longifolia* (0.6 mg/100 g).

Some extracts from edible flowers presented important contents of total anthocyanins, and therefore they have been proposed for potential applications in the food industry both for natural colorants and antioxidants. The ethanolic extract (0.01% HCl in 50% ethanol) of Titanbicus (a hybrid of *Hibiscus moscheutos* × *H. coccineus* (Medic.) Walt.) flowers presented total monomeric anthocyanin content (mg Cy3-G/g extract) of 2.7 mg/g for Artemis (white/pink), 6.0 mg/g for Rhea (pink) and 47.1 mg/g for Adonis (red) [33]. Furthermore, the ethanolic extracts of *Viola wittrockiana* and *Antirrhinum majus* flowers were 5.7 and 0.3 (µg/mg DW), respectively [34].

Flavones and Flavanones

Flavones and flavanones are two classes of flavonoids present in edible flowers. Flavanones have the structure of 2,3-dihydroflavone, but without a double bond between C2 and C3, making C2 chiral. On the other hand, flavones contain the double bond between C2 and C3 [8]. In edible flowers, flavanones such as hesperidin, naringenin, isosacuratenin, heridictol and their derivatives and flavones such as luteolin, apigenin, acacetin, chrysoeriol and their glucosides have been detected (Table 7).

Flavones, in addition to their functions to help plants to adapt to their surrounding environment, have been also correlated with numerous health benefits in humans, including antioxidant, antimicrobial and anticancer activities [35]. Among 70 edible flower samples in China, flavones were only detected in seven, and mainly apigenin [36]. The highest content was detected in *Tropaeolum majus* (53.6 µg/g DW apigenin), followed by *Helichrysum bracteatum* (10.4 µg/g DW apigenin and 7.4 µg/g DW chrysin) and *Matthiola incana* (10.9 µg/g DW apigenin). Flavanones derived from edible flowers have been correlated with potential antiaging properties. More specifically, flavanones such as hesperetin, hesperidin, neohesperidin and naringin have been extensively studied for their antiaging properties [37]. In general, flavanones, and especially hesperidin and hesperetin, have been correlated with several health benefits [38]. In a study of the phenolic composition of edible flowers of distinct colors used in foods and drinks, hesperidin and naringenin were the main flavanones [39]. The highest content of flavanones was detected in *Cosmos sulphureus* Cav. (yellow color and 1661 µg/g FW) and the lowest in *Begonia* × *tuberhybrida* Voss. (light red color and 3.7 µg/g FW). *Cosmos sulphureus* Cav., *Clitoria ternatea* L. and *Dianthus chinensis* L. were the edible flowers with the highest content of both flavanones (hesperidin and naringenin). However, the same study reported a low bioaccessibility of these flavanones compared to other phenolic compounds, with the highest value of 11% detected in *Dianthus chinensis* L. It is well-known that hesperidin, as a rutinoside, is more difficult to be absorbed, compared to hesperitin, which can be absorbed directly in the small intestine. Hesperidin should be first fermented by the intestinal microorganisms in order to become more easily absorbed. The flavanone composition of 70 edible flowers from China revealed mainly hesperitin (up to 2162 µg/g DW), naringin (up to 28,001 µg/g DW) and naringenin (up to 1187 µg/g DW) [36]. Hesperitin was detected in the majority of edible flowers, followed by naringin and naringenin. However, among the 70 flower samples, hesperitin was only detected in seven, naringin in four, and naringenin in three.

**Table 7.** Major flavones and flavanones detected in several edible flowers.

| Flavones/Flavanones (and Their Derivatives) | Flower | Reference |
|---|---|---|
| Acacetin | *Chrysanthemum morifolium* | [40] |
| Apigenin | *Chrysanthemum indicum* L., *Chrysanthemum lavandulifolium*, *Chrysanthemum morifolium*, *Clitoria ternatea* L., *Florists chrysanthemum*, *Helichrysum bracteatum*, *Matthiola incana*, *Nelumbo nucifera* Gaertn., *Rosa rugose*, *Tagetes erecta* L., *Tropaeolum majus* | [36,41,42] |
| Chrysoeriol | Tree peony flowers, *Hemerocallis fulva* | [43,44] |
| Chrysin | *Chrysanthemum morifolium*, *Helichrysum bracteatum* | [36] |
| Eriodictyol | *Fengdan Bai* (tree peony), *Impatiens walleriana*, *Chrysanthemum morifolium* | [45–47] |
| Hesperetin | *Amygdalus persica*, *Chrysanthemum indicum*, *Chrysanthemum lavandulifolium*, *Chrysanthemum morifolium*, *Citrus aurantium* L., *Gomphrena globose*, *Hylocereus undatus*, *Musa basjoo* Sieb. et Zucc. | [36,48] |
| Hesperidin | *Citrus aurantium* L., *Rosa chinensis*, *Torenia fournieri*, *Clitoria ternatea* L. | [39,48] |
| Luteolin | *Chrysanthemum indicum* L., *Chrysanthemum morifolium*, *Glycyrrhiza glabra*, *Lonicera japonica* Thunb., *Viburnum inopinatum* | [41,47,49,50] |
| Naringenin | *Amygdalus persica*, *Helichrysum bracteatum*, *Nymphaea hybrid*, *Begonia* × *tuberhybrida* Voss., *Rosa chinensis*, *Torenia fournieri*, *Clitoria ternatea* L. | [36,39] |
| Naringin | *Citrus aurantium*, *Rhododendron simsii planch*, *Rosa chinensis*, *Nymphaea hybrid* | [36] |

Flavonols

Flavonols are usually the group of flavonoids with the higher content in edible flowers, even among total phenolic compounds [7,51]. This group of flavonoids has a double bond between C2 and C3 and a carbonyl at C4. Glycosylation normally occurs at C3 as mono-, di-, or triglycosides, while there is also the possibility for glucuronidation [10]. The most frequently determined flavonols in edible flowers are quercetin, quercitrin and isoquercitrin, hyperoside, rutin and other quercetin derivatives, kaempherol and its derivatives, isorhamnetin and its derivatives and myricetin and its derivatives (Table 8). Although almost all flowers present high (>2200 mg/100g *Dianthus pavonius*) or low concentrations of flavonols (<1 mg/100 g), according to Demasi et al., [17], flowers of *Centaurea cyanus* (0.9 mg/100 g), *Taraxacum officinale* (1.8 mg/100 g), *Tagetes patula* (0.5 mg/100 g) and *Calendula officinalis* (1.7 mg/100 g), are very poor in flavonols, while in flowers of *Bellis perennis*, *Salvia pratensis* and *Borago officinalis*, flavonols are lacking completely. In the same study, quercitrin was the main flavonol in *Rosa pendulin*, *Robinia pseudoacacia* and *Tropaeolum majus*; quercetin in *Leucanthemum vulgare*, *Paeonia officinalis* and *Rosa canina*; and isoquercitrin in *Dianthus pavonius*, *Geranium sylvaticum*, *Lavandula angustifolia*, *Leucanthemum vulgare*, *Mentha aquatic* and *Rosa canina*.

**Table 8.** Major flavonols detected in some edible flowers.

| Flavonols | Flower | Reference |
| --- | --- | --- |
| Quercetin | *Bauhinia variegata* L., *Capparis spinose*, *Chrysanthemum morifolium*, *Coreopsis tinctoria* Nutt., *Hedysarum coronarium*, *Matthiola incana* (L.) R.Br., *Paeonia suffruticosa*, *Prunus persica*, *Rhododendron indicum* var. *simsii*, *Rosa brunonii*, *Rosa centifolia* L., *Rosa gallica* L., *Sambucus nigra*, *Styphnolobium japonicum* (L.) Schott, *Tibouchina urvilleana*, *Tibouchina mollis*, *Tulbaghia violacea* | [18,23,36,52–54] |
| Quercitrin (quercetin 3-rhamnoside) and isoquercitrin | *Chamomilia*, *Chrysanthemum morifolium*, *Dendranthema morifolium*, *Matricaria recutita*, *Osmanthus fragrans*, *Paeonia lactiflora* Pall., *Perennial chamomile*, *Rosa brunonii*, *Rosa bourboniana*, *Rosa damascene* | [54,55] |
| Hyperoside (quercetin-3-galactoside) | *Chrysanthemum morifolium*, *Chrysanthemum indicum*, *Prunus mume* | [56–58] |
| Rutin (quercetin 3-rutinoside) | *Calendula officinalis* L., *Capparis spinose*, *Chamomilia*, *Cichorium intybus*, *Dahlia mignon*, *Dendranthema morifolium*, *Flos lonicerae*, *Hedysarum coronarium*, *Osmanthus fragrans*, *Paeonia suffruticosa*, *Prunus persica*, *Robinia pseudoacacia*, *Rosmarinus officinalis*, *Sambucus nigra*, *Tulbaghia violacea* | [18,23,53,55,59] |
| Other quercetin derivatives | *Agave durangensis*, *Calendula officinalis* L., *Cyanus segetum* Hill, *Rosa gallica* L., *Tibouchina urvilleana*, *Tibouchina mollis*, *Tulbaghia violacea*, *Tropaeolum majus* L. | [52,53,59–61] |
| Kaempherol | *Anchusa azurea*, *Anchusa azurea* Mill., *Antigonon leptopus* Hook. & Arn., *Bauhinia variegata* L., *Bougainvillea glabra* Choisy, *Capparis spinose*, *Coreopsis tinctoria* Nutt., *Flos rosae rugosae*, *Hedysarum coronarium*, *Malva sylvestris*, *Matthiola incana* (L.) R.Br., *Nymphaea nouchali* Burm. f., *Paeonia x suffruticosa* Andrews, *Prunus persica*, *Robinia pseudoacacia*, *Rosmarinus officinalis*, *Rhododendron indicum* var. *simsii*, *Rosa centifolia* L., *Rosa gallica* L., *Styphnolobium japonicum* (L.) Schott | [23,36,55,62] |
| Kaempherol derivatives | *Agave durangensis*, *Calendula officinalis* L., *Crocus sativus*, *Cyanus segetum* Hill, *Dahlia mignon*, *Rosa gallica* L., *Tibouchina urvilleana*, *Tibouchina mollis*, *Tulbaghia violacea*, *Tropaeolum majus* L. | [52,53,59–61,63] |
| Isorhamnetin and its derivatives | *Rosa gallica* L., *Tibouchina urvilleana*, *Tibouchina mollis*, *Prunus mume* | [52,58,59] |
| Myricetin and its derivatives | *Anchusa azurea* Mill., *Antigonon leptopus* Hook. & Arn., *Bauhinia variegata* L., *Bougainvillea glabra* Choisy, *Capparis spinose*, *Cichorium intybus*, *Malva sylvestris*, *Rosmarinus officinalis*, *Rosa damascene*, *Rosa brunonii*, *Rosa bourboniana*, *Sambucus nigra*, *Tibouchina urvilleana*, *Tibouchina mollis* | [36,52,54,55,62] |

Flavanols

The major flavanols detected in edible flowers are catechin, epicatechin, epigallocatechin, epicatechin gallate and epigallocatechine gallate. There is no double bond in flavanols between C2 and C3 and no carbonyl in the ring C (C4), resulting in two chiral carbons (C2 and C3), and therefore four possible diastereomers: (+)-catechin (2R,3S), (-)-catechin (2S,3R), (+)-epicatechin (2R,3R) and (-)-epicatechin (2S,3S) [10]. Flavanols are the compounds that have been detected in the majority of edible flowers and especially the two main representatives of the group catechin and epicatechin (Table 9). In a study with 26 edible flowers, only 5 presented very low content of flavanols, namely *Dianthus carthusianorum*, *Leucanthemum vulgare*, *Taraxacum officinale*, *Trifolium alpinum* and *Calendula officinalis*, while in *Borago officinalis* no flavanols were detected [17]. In addition, in the majority of cases, epicatechin prevailed on catechin. Among the health benefits that have been associated with the consumption of these two flavanols are the decrease in body mass index [64], the prevention of metabolic and cardiovascular diseases by improving the blood flow and the exertion of antimicrobial, anti-inflammatory and antidiabetic properties [65].

**Table 9.** Edible flowers with important content of catechin and epicatechin [13,17,18].

| Flower |
|---|
| Catechin |
| *Bauhinia purpurea*, *Bombax malabaricum*, *Bougainvillea spectabilis*, *Brunfelsia acuminate*, *Calendula officinalis* L., *Calliandra haematocephala*, *Camellia japonica*, *Chaenomeles sinensis*, *Chamomilia*, *Chimonanthus praecox*, *Chrysanthemum morifolium*, *Cichorium intybus*, *Dendranthema morifolium*, *Dianthus caryophyllus*, *Dianthus chinensis*, *Dianthus pavonius*, *Erythrina variegate*, *Flos chrysanthemi*, *Geranium sylvaticum*, *Gomphrena globosa* Linn., *Helianthus annuus*, *Hibiscus rosa-sinensis*, *Hibiscus sabdariffa* L., *Jasminum sambac* (L.) Ait, *Iris japonica*, *Lantana camara*, *Lavandula angustifolia*, *Lilium brownii*, *Limonium sinuatum*, *Lorpetalum chindense* var. *rubrum*, *Malvaviscus arboreus*, *Matricaria recutita*, *Mentha aquatic*, *Myosotis sylvatica*, *Oncidium varicosum*, *Osmanthus fragrans*, *Oxalis corymbosa*, *Paeonia lactiflora* Pall., *Paeonia officinalis*, *Pelargonium hortorum*, *Perennial chamomile*, *Radix Gentianae*, *Redartfulplum tea*, *Rhododendron simsii* Planch, *Rhoeo discolor*, *Rosa canina*, *Rosa rugosa* Thunb, *Rosmarinus officinalis* L., *Siraitia grosvenorii*, *Strelitzia reginae* Aiton, *Wedelia trilobata* |
| Epicatechin |
| *Ageratum conyzoides*, *Allamanda cathartica*, *Allium ursinum*, *Bellis perennis*, *Bougainvillea spectabilis*, *Brassica campestris*, *Calendula officinalis* L., *Camellia japonica*, *Centaurea cyanus*, *Chaenomeles sinensis*, *Chimonanthus praecox*, *Chrysanthemum coronarium*, *Chrysanthemum morifolium*, *Cichorium intybus*, *Dendranthema morifolium*, *Dianthus caryophyllus*, *Dianthus chinensis*, *Dianthus pavonius*, *Erythrina variegate*, *Erythronium dens-canis*, *Flos chrysanthemi*, *Geranium sylvaticum*, *Gladiolus hybrids*, *Gomphrena globosa* Linn., *Helianthus annuus*, *Hibiscus sabdariffa* L., *Jasminum nudiflorum*, *Jasminum sambac* (L.) Ait, *Jatropha integerrima*, *Impatiens walleriana*, *Lavandula angustifolia*, *Ligustrum sinense*, *Lilium brownii*, *Limonium sinuatum*, *Lorpetalum chindense* var. *rubrum*, *Malvaviscus arboreus*, *Matricaria recutita*, *Mentha aquatic*, *Myosotis sylvatica*, *Orostachys fimbriatu*, *Osmanthus fragrans*, *Oxalis corymbosa*, *Paeonia lactiflora* Pall., *Paeonia officinalis*, *Perennial chamomile*, *Platycodon grandifloras*, *Primula veris*, *Primula vulgaris*, *Radix Gentianae*, *Redartfulplum tea*, *Rhapniolepis indica*, *Rhododendron simsii* Planch, *Robinia pseudoacacia*, *Rosa hybrid*, *Rosa canina*, *Rosa pendulina*, *Rosa rugosa* Thunb, *Rosmarinus officinalis* L., *Salvia pratensis*, *Sambucus nigra*, *Siraitia grosvenorii*, *Strelitzia reginae* Aiton, *Tagetes patula*, *Tropaeolum majus*, *Viola odorata*, *Wedelia trilobata*, *Zantedeschia aethiopica* Spreng |

### *2.2. Carotenoids*

Carotenoids are the most widely distributed pigments in nature, with yellow, orange, red and even purple colors. They are lipophilic isoprenoid pigments that are synthesized by photosynthetic organisms (algae, plants, cyanobacteria) but are also present in some bacteria, fungi and animals. They are present in leaves, but they observed mainly in autumn when chlorophylls are degraded, providing the orange-like color to them. Humans, like the majority of animals, cannot synthesize them, and therefore they take them through their diet by consuming plants. The Carotenoids Database [66] currently provides information on 1204 natural carotenoids in 722 source organisms, and these numbers continuously increase. The majority of them, based on C number, belong to the C40 group (>93%), although carotenoids with C30, C45 and C50 also occur. Carotenoids are classified into two main groups: the carotenes that are formed exclusively by carbon and hydrogen atoms, and the xanthophylls that contain oxygen. Some characteristic examples of the first group are α-carotene, β-carotene and lycopene, while in the latter are lutein, zeaxanthin, astaxanthin, fucoxanthin and peridinin [67,68]. In plants, carotenoids play essential roles in photosynthesis and photoprotection. In humans, their consumption is very important since they are precursors of vitamin A and they have been linked with several beneficial functions in human health such as eye, brain and heart health, cancer prevention, maternal and infant nutrition, skin-UV protection, fertility, immune modulation/stimulation, etc. [69].

In the case of *U. leptophylla* from Costa Rica, petioles presented the highest content of carotenoids (16.1 mg/100 g DW) followed by stems (14.9 mg/100 g DW) and flowers (12.4 mg/100 g DW). In the case of flowers, lutein was the major compound (9.3 mg/100 g DW) followed by β-carotene (1.8 mg/100 g DW), but zeaxanthin, β-cryptoxanthin and α-carotene were also detected in lower concentrations [70]. In a recent study with flowers of *Helichrysum italicum* subsp. *Picardii* Franco, a carotenoid content of 6.79 mg/100 g DW was reported [71]. Similar values (5.8 mg/100 DW) were reported in the case of *Centaurea cyanus* [72]. Higher values (24.7 mg/100 g DW) were reported for the flowers of *Camellia japonica*, and even higher (181.4 mg/100 g DW) for *Borago officinalis* [72]. Finally, a correlation between color of flower and total carotenoid content was reported in the case of flowers of *Viola × wittrockiana* (pansies; white 21.6, yellow 58.0 and red 109.2 mg/100 g DW) [72].

### *2.3. Tocols*

Tocols are a group of compounds that includes tocopherols (α-, β-, γ-, and δ-tocopherol) and tocotrienols (α-, β-, γ-, and δ-tocotrienol) and they are synthesized only by plants and photosynthetic microorganisms. They are well-known for their antioxidant activity and their linkage with vitamin E. Although all of them are considered part of the vitamin E group [73], only α-tocopherol has been tested and shown to prevent vitamin E deficiency disease, and therefore only α-tocopherol can be called vitamin E [74]. They contain a polar chromanol ring linked to an isoprenoid-derived hydrocarbon chain, and the presence of the phenolic hydroxyl group provides their antioxidant activity [75]. This antioxidant activity is based on the ability to stop the propagation phase of the oxidative chain reaction through the donation of a phenolic hydroxyl group of the chromanol ring to free radicals in order to stabilize them [76]. Therefore, the main function of these compounds is to act as a lipid-soluble antioxidant protecting photosynthetic membranes from oxidative stress.

Edible flowers contain tocols, some of them in significant amounts (Table 10). However, these concentrations are affected by the method of extraction. Moreover, in some cases, the tocol content is higher in petals than stems or petioles [70]. Flowers with the highest content of tocols are *Calendula officinalis* L. (60.9 mg/100 g DW), *Viola × wittrockiana* (yellow) (24.9 mg/100 g DW), *Moringa oleifera* Lam. (21.0 mg/100 g DW) and *Urtica leptophylla* (11.1 mg/100 g DW) [70,72,77,78]. It is mainly tocopherols that are detected, but in some cases, a small quantity of tocotrienols is also present in dried flowers such as *Urtica leptophylla* (1.1 mg/100 g DW) and *Borago officinalis* L. (0.5 mg/100 g DW) [70,79]. Usually, α-tocopherol is the dominant compound, ranging from 52 to 93 % of total tocopherol content, followed by γ-tocopherol. In the cases of *Amaranthus caudatus* L. and *Juglans regia* L., where low concentrations of tocopherols were detected, β-tocopherol and δ-tocopherol were the dominant compounds, respectively [80,81].

**Table 10.** Total tocopherol content of several edible flowers from recent studies.

| Flower | Total Tocopherol (mg/100 g DW) | α-Tocopherol (% of Total) | Reference |
|---|---|---|---|
| *Calendula officinalis* L. | 60.9 | 93 | [77] |
| *Viola × wittrockiana* (yellow) | 24.9 | 89 | [72] |
| *Moringa oleifera Lam.* (Quinhamel) | 21.0 | 90 | [78] |
| *Moringa oleifera Lam.* (Bissau) | 19.9 | 87 | [78] |
| *Viola × wittrockiana* (white) | 11.3 | 77 | [72] |
| *Urtica leptophylla* | 11.1 | 63 | [70] |
| *Camellia japonica* | 10.9 | 85 | [72] |
| *Lactuca canadensis* L. | 9.7 | 63 | [82] |
| *Rosa damascene/R. gallica* | 9.3 | 88 | [77] |
| *Dahlia mignon* | 7.3 | 60 | [77] |
| *Aloe vera* | 4.7 | - | [83] |
| *Borago officinalis* L. | 3.2 | 69 | [79] |
| *Juglans Regia* L. | 2.9 | 7 | [81] |
| *Centaurea cyanus* L. | 2.4 | 52 | [79] |
| *Amaranthus caudatus* L. | 2.0 | 24 | [80] |
| *Centaurea cyanus* L. | 1.3 | 78 | [84] |
| *Viola × wittrockiana* (white) | 1.1 | 63 | [72] |
| *Centaurea cyanus* L. | 0.8 | 65 | [77] |
| *Narcissus poeticus* L. | 1.5 [1] | - | [85] |
| *Cynara cardunculus* | 0.6 [1] | - | [86] |

[1] Only α-tocopherol.

## 2.4. Terpenes

The essential oil of edible flowers contains several volatile and aromatic compounds, which also belong to secondary metabolites of plants. They have been used for centuries in cosmetics and medicine, and due to their bioactive components are well-known for their antimicrobial, antioxidant and antipest activities [87]. The main components of flowers' essential oils belong to the group of terpenes; however, the final composition of each essential oil depends on species (Table 11). In general, the main compounds detected in edible flowers' essential oil are linalool, α-pinene, 1,8-cineole, eugenol, camphor and camphene.

**Table 11.** Major terpenes detected in some edible flowers' essential oils.

| Terpene | Flower |
|---|---|
| Linalool | *Jasminum sambac* L. (59%) [a], *Cananga odorata* (29%) [b], *Lavandula hybrid* (37%) [c], *Crocus sativus* (26%) [d] |
| α-Pinene | *Hypericum lydium* Boiss (71%) [e], *Myrtus communis* var. italica L. (18%) [f], *Chrysanthemum coronarium* (15%) [g], *Prangos ferulacea* (21%) [h] |
| 1,8-Cineole | *Myrtus communis* var. italica L. (13%) [f], *Santolina rosmarinifolia* (13%) [i], *Ocotea quixos* (8%) [j], *Crocus sativus* (44%) [d] |
| Eugenol | *Myrtus communis* var. italica L. (10%) [f], *Eugenia caryophyllata* (80%) [k] |
| Camphor | *Chrysanthemum flos* (11%) [l], *Chrysanthemum coronarium* (29%) [g], *Santolina rosmarinifolia* (8%) [i], *Rosmarinus officinalis* (36%) [m] |
| Camphene | *Prangos ferulacea* (12%) [h], *Cistus ladanifer* (6%) [n] |

a, [88]; b, [89]; c, [90]; d, [91]; e, [92]; f, [93]; g, [94]; h, [95]; i, [96]; j, [97]; k, [98]; l, [99]; m, [100]; n, [101].

# 3. Antioxidant Activity of Edible Flowers

Chemical reactions that involve electron transfer between electron-rich molecules to an oxidizing agent, which undergoes reduction, is called oxidation [102]. The oxidizing agents, or simply oxidants, are usually forms of free radicals that have unpaired electrons such as hydroxyl, alkoxyl and reactive oxygen species [3]. These oxidants are very reactive and attack other molecules. The mechanism by which these oxidants (free radicals) usually work involves three main steps: (a) initiation (the number of free radicals increases); (b) propagation (the total number of radicals remains constant and the reaction spreads); and (c) termination (the number of free radicals decreases) [102]. Antioxidants are compounds that prevent the oxidation of systems, and edible flowers contain numerous such compounds. There are two main classes of antioxidants: those that actively inhibit oxidation reactions (primary antioxidants) and those that inhibit oxidation indirectly by mechanisms such as oxygen scavenging, binding pro-oxidants, etc. [103]. Phenolic compounds present in edible flowers may act both as primary antioxidants and secondary antioxidants. Two mechanisms are available for the action of primary antioxidants: the hydrogen-atom transfer (an antioxidant compound quenches free-radical species by donating hydrogen atoms) and the single-electron transfer (an antioxidant transfers a single electron to aid in the reduction of potential target compounds) [102]. Finally, phenolic compounds have the ability to bind with potentially pro-oxidative metal ions operating as secondary antioxidants [104].

Antioxidant activity has been correlated with the maintenance of good health in humans, and therefore is very important to develop analytical protocols to evaluate it to several food products, including edible plants. The first important step to evaluate the antioxidant activity, in plant-based materials, is the extraction of the antioxidant compounds. There are several extraction methods available and each one has its benefits and negatives, and therefore its selection is very crucial for the final estimation of antioxidant activity [105]. Furthermore, for the quantification of antioxidant activity of edible flowers' extracts, there are several methods available that may be categorized based on the chemistry of the reactions involved. The methods that pertain to the mechanisms of hydrogen-atom transfer include oxygen radical absorbance capacity (ORAC) assay, while those that pertain to the mechanisms of single-electron transfer include Ferric-reducing antioxidant power (FRAP) assay and Cupric-reducing antioxidant capacity (CUPRAC) assay. However, there are also methods that pertain to both mechanisms, such as Trolox equivalent antioxidant capacity (TEAC) assay, 2,2-azinobis (3-ethyl-benzothiazoline-6-sulfonic acid) (ABTS) assay or DPPH• (2,2-diphenyl-1-picrylhydrazyl radical cation) assay [102]. In the case of edible flowers, all of these methods have been applied for the estimation of antioxidant activity (Tables 12–14).

There are numerous studies in food products that have found a correlation between the TPC and antioxidant activity; however, there are also some studies available that were not able to confirm such correlation. As already highlighted, the mechanisms of antioxidant activity are very complicated and they are affected by a wide range of variables [102]. In addition, since different assays for evaluation of antioxidant activity are available and based on different mechanisms, it is common to detect a correlation between, for example, TPC and DPPH assay, and not for FRAP assay. In the studies where a correlation was observed, this was attributed to the antioxidant capacity of phenolic compounds; while in the studies where the correlation was absent, this was attributed to other compounds, not quantified by TPC analysis, which had antioxidant activity. In a study with 65 edible flowers from China, the correlations between TPC and antioxidant capacities were 0.6344 for DPPH, 0.7587 for ABTS and 0.8588 for FRAP. The correlations between TFC and antioxidant capacities were 0.3265, 0.2435 and 0.2205, respectively [20]. In a similar study with 51 edible flowers, positive linear correlations between total antioxidant capacities and TPC ($R^2$ = 0.911 and 0.954 for FRAP and TEAC values, respectively) were reported. Similar results were reported for water-soluble and fat-soluble fractions [13]. Lower correlations were reported in a study with 23 edible flowers [18]. More specifically, in the case of TPC, the correlations were 0.9589 for ABTS, 0.6333 for DPPH and 0.5991 for FRAP; and in the case of TFC they were 0.2598, 0.0794 and 0.6188, respectively. All these studies confirm that there is not a specific pattern for the correlation of TPC and TFC with the antioxidant capacity and especially by using different antioxidant assays. In general, there is a positive correlation between TPC and antioxidant activity, something that it is not the case for TFC.

**Table 12.** Antioxidant activity (FRAP and ABTS in DW) of several edible flowers.

| Flower | FRAP | ABTS | Flower | FRAP | ABTS | Flower | FRAP | ABTS |
|---|---|---|---|---|---|---|---|---|
| *Agave salmiana* | 25 [d] | | *Dianthus caryophyllus* | 98 [a] | 100 | *Myosotis sylvatica* | 839 [a] | 261 |
| *Aglaia odorata* | 202 [a] | 167 | *Dianthus* L. | 101 [b] | | *Myrtillocactus geometrizans* | 820 [d] | |
| *Albizzia julibrissin* | 159 [a] | 109 | *Epipremnum aureum* | 68 [a] | 89 | *Nelumbo nucifera* | 308 [a] | 248 |
| *Allium schoneoprasum* L. | 55 [b] | | *Eriobotrya japonica* | 163 [a] | 90 | *Nymphaea stellata* | 736 [a] | 442 |
| *Aloe vera* | 26 [d] | | *Erythrina americana* | 28 [d] | | *Oroxylum indicum* | 210 [a] | 142 |
| *Amygdalus persica* | 311 [a] | 192 | *Florists chrysanthemum* (yellow) | 224 [a] | 180 | *Osmanthus fragrans* | 1196 [a] | 430 |
| *Armeniaca mume* | 499 [a] | 220 | *Florists chrysanthemum* (white) | 154 [a] | 106 | *Osmanthus fragrans* (Thunb.) *Lour*. | 914 [c] | 689 |
| *Bauhinia variegata* | 223 [a] | 273 | *Gomphrena globosa* | 95 [a] | 22 | *Paeonia lactiflora* Pall. | 837 [c] | 2078 |
| *Begonia tuberhybrida* Voss. | 317[b] | | *Gomphrena globosa* Linn. | 8 [c] | 46 | *Paeonia suffruticosa* | 1893 [a] | 859 |
| *Bombax ceiba* | 200 [a] | 121 | *Hedychium coronarium* | 75 [a] | 28 | *Panax pseudoginseng* | 44 [a] | 17 |
| *Calendula officinalis* | 182 [a] | 74 | *Helichrysum bracteatum* | 565 [a] | 336 | *Perennial chamomile* | 328 [c] | 215 |
| *Calendula officinalis* L. | 84 [b] | | *Hemerocallis citrina* | 333 [a] | 41 | *Plumeria rubra Acutifolia* | 127 [a] | 118 |
| *Calendula officinalis* L. | 58 [c] | 71 | *Hemerocallis hybrida* hort | 67 [b] | | *Plumeria rubra* Linn. Sp. | 330 [a] | 169 |
| *Camellia azalea* | 843 [a] | 305 | *Hibiscus sabdariffa* L. | 166 [c] | 260 | *Prunella vulgaris* | 122 [a] | 31 |
| *Camellia japonica* | 197 [a] | 166 | *Hibiscus sabdariffa* | 155 [a] | 67 | *Punica granatum* | 1275 [a] | 460 |
| *Campsis grandiflora* | 271 [a] | 206 | *Hylocereus undatus* | 42 [a] | 91 | *Radix Gentianae* | 118 [c] | 153 |
| *Canna edulis* | 254 [a] | 47 | *Jasminum sambac* | 67 [a] | 84 | *Redartfulplum tea* | 19 [c] | 87 |
| *Centaurea cyanus* L. | 64 [b] | | *Jasminum sambac* (L.) Ait | 48 [c] | 97 | *Rhododendron simsii* planch | 2226 [a] | 765 |
| *Chamomilia* | 287 [c] | 285 | *Lavandula angustifolia* | 202 [a] | 141 | *Rosa centifolia* | 1543 [a] | 495 |
| *Chimonanthus praecox* | 354 [a] | 182 | *Lavandula angustifolia* Mill. | 278 [c] | 261 | *Rosa chinensis* | 3620 [a] | 309 |
| *Chimonanthus praecox* | 111 [c] | 188 | *Lavandula angustifolia* Mill. | 185 [b] | | *Rosa gallica* | 1292 [a] | 530 |
| *Chrysanthemum indicum* | 248 [a] | 209 | *Lilium brownie* | 246 [a] | 234 | *Rosa rugosa* (rose) | 2657 [a] | 1037 |
| *Chrysanthemum indicum* | 466 [a] | 211 | *Lilium brownii* var. *viridulum* | 68 [c] | 160 | *Rosa rugosa* (white-rose) | 363 [a] | 239 |
| *Chrysanthemum lavandulifolium* | 356 [a] | 116 | *Lilium bulbiferum* | 93 [a] | 33 | *Rosa rugosa* Thunb (pink) | 122 [c] | 358 |
| *Chrysanthemum morifolium ramat* | 215 [a] | 135 | *Lonicera japonica* | 701 [a] | 349 | *Rosa rugosa* Thunb (purple) | 331 [c] | 818 |
| *Chrysanthemum morifolium* | 183 [c] | 103 | *Magnolia denudate* | 79 [a] | 30 | *Rosa rugosa* | 56 [b] | |
| *Citrus aurantium* | 155 [a] | 126 | *Magnolia grandiflora* | 112 [a] | 35 | *Rosmarinus officinalis* L. | 226 [c] | 274 |
| *Coreopsis tinctoria* | 1235 [a] | 392 | *Malus pumila* | 184 [a] | 231 | *Sambucus nigra* L. | 175 [b] | |

**Table 12.** *Cont.*

| Flower | FRAP | ABTS | Flower | FRAP | ABTS | Flower | FRAP | ABTS |
|---|---|---|---|---|---|---|---|---|
| *Crocus sativus* L. | 133 [a] | 28 | *Malus spectabilis* | 60 [a] | 26 | *Siraitia grosvenorii* | 134 [a] | 141 |
| *Cucumis sativus* Linn. | 43 [a] | 13 | *Matricaria recutita* | 224 [a] | 129 | *Siraitia grosvenorii* | 49 [c] | 151 |
| *Cucurbita pepo* L. | 54 [b] | | *Matricaria recutita* | 326 [c] | 316 | *Sophora japonica* L. | 1364 [a] | 289 |
| *Cymbidium sinense* | 150 [a] | 48 | *Matthiola incana* | 133 [a] | 74 | *Tagates* L. | 1328 [b] | |
| *Dendranthema morifolium* | 189 [c] | 210 | *Michelia alba* | 155 [a] | 112 | *Tropaeolum majus* | 838 [a] | 208 |
| *Dianthus caryophyllus* | 48 [c] | 122 | *Myosotis sylvatica* | 172 [c] | 215 | *Tropaeolum majus* | 117 [b] | |
| | | | | | | *Viola tricolor* L. | 465 [b] | |

a, [20] (FRAP µmol $Fe^{2+}$/g; ABTS µmol TE (Trolox equivalents)/g). b, [16] (FRAP µmol $Fe^{2+}$/g). c, [18] (FRAP µmol TE/g; ABTS µmol TE/g). d, [14] (FRAP µmol TE/g; ABTS µmol TE/g).

**Table 13.** Antioxidant activity (FRAP and ABTS in FW) of several edible flowers.

| Flower | FRAP | ABTS | Flower | FRAP | ABTS | Flower | FRAP | ABTS |
|---|---|---|---|---|---|---|---|---|
| *Ageratum conyzoides* | 27 [a] | 8 | *Flos chrysanthemi* | 18 [a] | 8 | *Oxalis corymbosa* | 15 [a] | 29 |
| *Allamanda cathartica* | 24 [a] | 9 | *Geranium sylvaticum* | 267 [b] | 55 | *Paeonia officinalis* | 304 [b] | 55 |
| *Allium ursinum* | 4 [b] | 1 | *Gerbera jamesonii* Bolus | 27 [a] | 12 | *Pelargonium hortorum* | 213 [a] | 132 |
| *Bauhinia purpurea* | 38 [a] | 23 | *Gladiolus hybrids* | 13 [a] | 6 | *Phaseolus vulgaris* | 6 [a] | 8 |
| *Bellis perennis* | 82 [b] | 13 | *Helianthus annuus* | 11 [a] | 7 | *Platycodon grandiflorus* | 12 [a] | 6 |
| *Bidens pilosa* | 64 [a] | 31 | *Hibiscus rosa-sinensis* | 89 [a] | 40 | *Primula veris* | 230 [b] | 39 |
| *Bombax malabaricum* | 32 [a] | 15 | *Impatiens walleriana* | 76 [a] | 36 | *Primula vulgaris* | 127 [b] | 22 |
| *Borago officinalis* | 30 [b] | 4 | *Ipomoea cairica* | 12 [a] | 4 | *Rhapniolepis indica* | 59 [a] | 33 |
| *Bougainvillea spectabilis* | 57 [a] | 21 | *Iris japonica* | 0.2 [a] | 0.2 | *Rhododendron simsii* Planch | 65 [a] | 16 |
| *Brassica campestris* | 17 [a] | 7 | *Jasminum nudiflorum* | 15 [a] | 5 | *Rhoeo discolor* | 16 [a] | 6 |
| *Brassica compestris* | 24 [a] | 11 | *Jatropha integerrima* | 220 [a] | 115 | *Robinia pseudoacacia* | 16 [b] | 2 |
| *Brunfelsia acuminata* | 16 [a] | 8 | *Lantana camara* | 22 [a] | 10 | *Rosa canina* | 258 [b] | 56 |
| *Calendula officinalis* | 23 [b] | 9 | *Lavandula angustifolia* | 90 [b] | 14 | *Rosa hybrida* | 630 [a] | 175 |
| *Calliandra haematocephala* | 149 [a] | 70 | *Leucanthemum vulgare* | 44 [b] | 11 | *Rosa pendulina* | 254 [b] | 56 |
| *Camellia japonica* | 40 [a] | 26 | *Ligustrum sinense* | 35 [a] | 16 | *Salvia pratensis* | 39 [b] | 9 |
| *Centaurea cyanus* | 68 [b] | 18 | *Lilium brownii* | 6 [a] | 6 | *Salvia splendens* | 19 [a] | 9 |
| *Chaenomeles sinensis* | 98 [a] | 70 | *Limonium sinuatum* | 500 [a] | 157 | *Sambucus nigra* | 79 [b] | 18 |
| *Chrysanthemum coronarium* | 28 [a] | 8 | *Lorpetalum chindense* var.*rubrum* | 107 [a] | 54 | *Strelitzia reginae* Aiton | 49 [a] | 49 |
| *Cichorium intybus* | 138 [b] | 27 | *Magnolia soulangeana* | 25 [a] | 9 | *Tagetes patula* | 144 [b] | 23 |

**Table 13.** *Cont.*

| Flower | FRAP | ABTS | Flower | FRAP | ABTS | Flower | FRAP | ABTS |
|---|---|---|---|---|---|---|---|---|
| *Dianthus caryophyllus* | 14 [a] | 8 | *Malvaviscus arboreus* | 18 [a] | 10 | *Taraxacum officinale* | 13 [b] | 3 |
| *Dianthus carthusianorum* | 222 [b] | 34 | *Matthiola incana* | 8 [a] | 8 | *Trifolium alpinum* | 92 [b] | 20 |
| *Dianthus chinensis* | 40 [a] | 17 | *Mentha aquatica* | 256 [b] | 43 | *Tropaeolum majus* | 45 [b] | 13 |
| *Dianthus pavonius* | 176 [b] | 24 | *Oncidium varicosum* | 22 [a] | 12 | *Viola odorata* | 66 [b] | 16 |
| *Ericaceae rhododendron* | 54 [a] | 28 | *Orostachys fimbriatu* | 108 [a] | 62 | *Wedelia trilobata* | 31 [a] | 13 |
| *Erythrina variegata* | 12 [a] | 5 | *Osmanthus fragrans* | 164 [a] | 72 | *Youngia japonica* | 2 [a] | 2 |
| *Erythronium dens-canis* | 54 [b] | 14 | | | | *Zantedeschia aethiopica* Spreng | 22 [a] | 9 |

a, [13] (FRAP µmol $Fe^{2+}$/g; ABTS µmol TE (Trolox equivalents)/g). b, [17] (FRAP µmol $Fe^{2+}$/g; ABTS µmol TE/g).

**Table 14.** Antioxidant activity (DPPH, µmol TE/g in DW) of several edible flowers.

| Flower | DPPH | Flower | DPPH | Flower | DPPH |
|---|---|---|---|---|---|
| *Aglaia odorata* | 100 [a] | *Dianthus* L. | 28 [b] | *Nelumbo nucifera* | 273 [a] |
| *Albizzia julibrissin* | 63 [a] | *Epipremnum aureum* | 24 [a] | *Nymphaea stellata* | 382 [a] |
| *Allium schoneoprasum* L. | 5 [b] | *Eriobotrya japonica* | 129 [a] | *Oroxylum indicum* | 291 [a] |
| *Amygdalus persica* | 171 [a] | *Florists chrysanthemum* (yellow) | 166 [a] | *Osmanthus fragrans* | 365 [a] |
| *Armeniaca mume* | 174 [a] | *Florists chrysanthemum* (white) | 126 [a] | *Osmanthus fragrans* (Thunb.) Lour. | 476 [c] |
| *Bauhinia variegata* | 108 [a] | *Gomphrena globosa* | 17 [a] | *Paeonia lactiflora* Pall. | 599 [c] |
| *Begonia tuberhybrida* Voss. | 99 [b] | *Gomphrena globosa* Linn. | 30 [c] | *Paeonia suffruticosa* | 411 [a] |
| *Bombax ceiba* | 66 [a] | *Hedychium coronarium* | 20 [a] | *Panax pseudoginseng* | 15 [a] |
| *Calendula officinalis* | 38 [a] | *Helichrysum bracteatum* | 346 [a] | *Perennial chamomile* | 167 [c] |
| *Calendula officinalis* L. | 16 [b] | *Hemerocallis citrina* | 11 [a] | *Plumeria rubra Acutifolia* | 29 [a] |
| *Calendula officinalis* L. | 70 [c] | *Hemerocallis hybrida* hort | 32 [b] | *Plumeria rubra* Linn. Sp. | 153 [a] |
| *Camellia azalea* | 216 [a] | *Hibiscus sabdariffa* L. | 113 [c] | *Prunella vulgaris* | 21 [a] |
| *Camellia japonica* | 74 [a] | *Hibiscus sabdariffa* | 38 [a] | *Punica granatum* | 374 [a] |
| *Campsis grandiflora* | 96 [a] | *Hylocereus undatus* | 16 [a] | *Radix Gentianae* | 89 [c] |
| *Canna edulis* | 76 [a] | *Jasminum sambac* | 69 [a] | *Redartfulplum tea* | 21 [c] |
| *Centaurea cyanus* L. | 33 [b] | *Jasminum sambac* (L.) Ait | 64 [c] | *Rhododendron simsii* planch | 368 [a] |
| *Chamomilia* | 141 [c] | *Lavandula angustifolia* | 132 [a] | *Rosa centifolia* | 423 [a] |
| *Chimonanthus praecox* | 90 [a] | *Lavandula angustifolia* Mill. | 185 [c] | *Rosa chinensis* | 414 [a] |
| *Chimonanthus praecox* | 126 [c] | *Lavandula angustifolia* Mill. | 94 [b] | *Rosa gallica* | 243 [a] |
| *Chrysanthemum indicum* | 163 [a] | *Lilium brownie* | 56 [a] | *Rosa rugosa* (rose) | 522 [a] |
| *Chrysanthemum indicum* | 199 [a] | *Lilium brownii* var. *viridulum* | 82 [c] | *Rosa rugosa* (white-rose) | 270 [a] |
| *Chrysanthemum lavandulifolium* | 155 [a] | *Lilium bulbiferum* | 27 [a] | *Rosa rugosa* Thunb (pink) | 176 [c] |
| *Chrysanthemum morifolium ramat* | 162 [a] | *Lonicera japonica* | 204 [a] | *Rosa rugosa* Thunb (purple) | 562 [c] |
| *Chrysanthemum morifolium* | 128 [c] | *Magnolia denudate* | 20 [a] | *Rosa rugosa* | 469 [b] |
| *Citrus aurantium* | 27 [a] | *Magnolia grandiflora* | 20 [a] | *Rosmarinus officinalis* L. | 174 [c] |
| *Coreopsis tinctoria* | 344 [a] | *Malus pumila* | 124 [a] | *Sambucus nigra* L. | 85 [b] |
| *Crocus sativus* L. | 15 [a] | *Malus spectabilis* | 18 [a] | *Siraitia grosvenorii* | 21 [a] |
| *Cucumis sativus* Linn. | 8 [a] | *Matricaria recutita* | 84 [a] | *Siraitia grosvenorii* | 65 [c] |
| *Cucurbita pepo* L. | 11 [b] | *Matricaria recutita* | 183 [c] | *Sophora japonica* L. | 263 [a] |
| *Cymbidium sinense* | 13 [a] | *Matthiola incana* | 82 [a] | *Tagates* L. | 520 [b] |
| *Dendranthema morifolium* | 131 [c] | *Michelia alba* | 58 [a] | *Tropaeolum majus* | 206 [a] |
| *Dianthus caryophyllus* | 53 [c] | *Myosotis sylvatica* | 206 [c] | *Tropaeolum majus* | 42 [b] |
| *Dianthus caryophyllus* | 24 [a] | *Myosotis sylvatica* | 461 [a] | *Viola tricolor* L. | 294 [b] |

a, [20]; b, [16]; c, [18].

## 4. Toxic and Antinutritional Compounds in Edible Flowers

Although edible flowers have been used throughout centuries for culinary purposes, there is still a need for research studies to evaluate the presence of antinutritional compounds or even compounds with potential toxic properties. Such compounds, which have been reported in foods, include saponins, tannins, phytic acid, protease and amylase inhibitors, antivitamin factors, alkaloids, etc. [106]. Compared to other food products, fewer studies are available for potential antinutritional and toxic compounds in edible flowers. In the case of antinutritional compounds, studies revealed that flowers of *Yucca filifera* contain undesirable saponins with hemolytic activity [107], flowers of *Erythrina americana* and *Erythrina caribaea* contain trypsin inhibitor enzymes and those of *Agave salmiana* show hemagglutinating activity [61]. However, the traditional common practices applied in culinary uses of edible flowers, such as cooking/boiling and their main use as garnishment, usually reduce their content or even eliminate them and minimize the risk of high intakes, respectively [8]. A characteristic example is the flowers of the Erythrina species that contain a high content of alkaloids, but before intake traditionally people cook/boil them and remove the water in which the flowers are cooked, thus reducing the alkaloid concentration [108].

Another important factor that affects the potential toxicity of edible flowers is their source and origin. More specifically, their cultivation should be very careful in order to avoid contamination by the excessive use of agrochemicals or potential polluted soil, etc. Furthermore, there are several plants that are similar in different countries using different common names, or on the other hand, the use of the same common name for plants from several species. All these suggest that it is very important to perform a complete chemical characterization of every new flower before proposing it for edibility [8]. As already mentioned, there are few studies available, compared to the numerous edible flowers, regarding their potential toxicity. The majority of them use Ames mutagenicity assay in combination with specific analyses in animal models. Most of them concluded that there is no evidence for the toxicity of edible flowers and their extracts when used in an appropriate dosage. Some recent studies evaluated the toxic potential of extracts from *Nasturtium officinale* [109], marigold flower [110], *Bombax ceiba* [111], *Hibiscus rosa-sinensis* [112] and *Butea monosperma* [113], revealing their safety.

However, in a study with extracts of *Hibiscus sabdariffa* flowers, although they presented biological activities, they also had toxic effects when consumed for long periods and may increase side effects of certain drugs when coadministered with them [114]. Extracts from *Hibiscus sabdariffa* L. also proved toxic in an animal model study [115]. All the above revealed that there is a need for more studies regarding the safety of each possible edible plant. Furthermore, some aspects regarding the correlation of edible flowers and potential food allergies should be clarified [116].

## 5. Conclusions

In the present review article, more than 200 edible flowers are presented alongside with their TPC, TFC and antioxidant activity. Moreover, the most important classes of phytochemicals compounds are reported. Edible flowers may play a very important role to fulfill the growing demand of consumers for natural functional foods. Indeed, edible flowers may find applications in the food industry (food ingredients, beverages, food coloring, floral hydrolates, syrups and jams) or in the biomedical industry as raw material for the extraction of valuable compounds with nutraceutical potentials and health benefits. However, edible flowers are very popular on a small scale. In order to industrialize and increase their production, there is a need to deal with their low lifetimes, their availability in a specific time of year and the need for the application of appropriate drying methods. Edible flowers, over centuries, have been proven as carriers of significant amounts of phytochemicals, belonging to the groups of phenolic acids, flavonoids, carotenoids, tocols and others, which can be incorporated in traditional foods to increase their functionality. Although there are numerous studies regarding the phenolic content and the antioxidant activity of edible flowers, their high numbers all over the world demand for more studies. The present study may be very useful in order to select specific edible flowers with increased phytochemical content and functionality, since not all of them contain significant amounts, to further evaluate their incorporation in food products and also their stability during processing and storage. Furthermore, the present review also revealed the low number of research studies regarding the safety of such edible flowers and extracts, and in particular their potential toxicity. The antinutritional compounds contained in edible flowers are also an issue and more work is needed. Therefore, it is proposed to carry out more in-depth research studies for each edible flower, covering all the above mentioned issues, in order to appropriately and safely use them as ingredients in functional foods.

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