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Review

The Unexplored Potential of Edible Flowers Lipids

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Abstract: Edible flowers have been historically linked to traditional world cuisine and culture. They are often used as ingredients in food and beverages for medicinal or pharmaceutical purposes. However, little attention has been paid to the quality of their lipids, and therefore to their potential for oil extraction and use in the food and food supplements industries. This review summarizes the current knowledge on the lipid composition of several edible flowers, including fat content, fatty acids, vitamin E, and carotenoids profiles. Edible flower lipids were found to be rich in linoleic (C18:2) and α-linolenic (C18:3) acids, which are essential fatty acids. Furthermore, most flowers are a good source of α-tocopherol and xanthophylls, such as lutein and zeaxanthin. This review provides valuable information on the lipid profile of some edible flowers in order to better characterize them and to increase their popularization among the food industry and consumers, boosting agriculture demand for these products.

Keywords: edible flowers; lipid composition; fatty acids; tocopherols; carotenoids

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1. Introduction

Lipids are major and essential constituents of all plant cells, providing structural integrity and energy for various metabolic processes [1]. In plants, the compartmentation of neutral lipids is mostly associated with seed tissues, where triacylglycerols are stored [2]. As such, most of the research on the lipid composition of plants has mainly focused on the oil from their seeds [3–6]. However, some non-seed tissues, such as leaves, flowers, and fruits, also synthesize and store lipids, although until now, their formation or function in these tissues is poorly understood [2]. Indeed, lipids are among the least studied metabolites in flowers, but recently they began to be further explored. The lipid composition was reported to be significantly different among flowers' organs and tissues [7]. Furthermore, the majority of studies on edible flowers lipids have focused on their essential oils including basil (*Ocimum basilicum* L.) [8], chrysanthemum (*Chrysanthemum indicum* L.) [9], marigold (*Tagetes minuta* L.) [10], yarrow (*Achillea millefolium* L.) [11], calendula (*Calendula officinalis* L.) [12], and rose (*Rosa* × *damascena* Herrm.) [13]. However, the literature assigns more importance to pollen compared to other flowers' parts (petals, sepals, and buds), because of their distinctive fatty acid profiles, characteristically dominant in one or more fatty acids [14]. However, pollen may detract flower's flavor and cause allergies in some people, and so it is usually removed when edible flowers are marketed.

In order to improve knowledge about the lipid composition of edible flowers, the purpose of this paper was to provide an overview of published data on the lipid content, fatty acids profile, tocols, and carotenoids in edible flowers, to increase their acceptability as potential food ingredients and therefore their production for food purposes. The authors of the present review want to state that inflorescences, such as cauliflower, broccoli, and artichoke, were not included in this discussion.

2. Edible Flowers

The edible flowers market is gaining interest from consumers and chefs of restaurants because they add color, fragrance, and flavor to food, and due being a potential source of nutrients and bioactive compounds [15]. The use of flowers as a food ingredient has been traced back to ancient civilizations. For example, edible flowers were especially popular in Victorian era in England. Other cultures incorporated edible flowers as ingredients in a wide variety of recipes: ancient Romans used violets and roses in dishes and lavender in sauces, native Americans ate blossoms from pumpkin and squash, medieval French put calendula in salads, and Europeans prepared drinks and salads with dandelion flowers [16,17]. Nowadays, edible flowers are most often consumed fresh, but they can also be consumed dried, in ice cubes, canned in sugar, and preserved in distillates [16]. In general, edible flowers can be eaten whole, but depending on the flower species, in some cases, only some parts should be consumed. For example, only the petals of *Tulipa*, *Chrysanthemum*, and *Rosa* spp., or the flower buds of daisies (*Bellis perennis* L.) or garden nasturtium (*Tropaeolum majus* L.) are consumed. Furthermore, in some flowers, it is necessary to remove some parts due to their bitterness, such as the white base in petals of roses and chrysanthemums.

Many flowers are edible but proper identification is essential because some are poisonous. In Figure 1 some edible flowers are represented. Popular edible flowers include hibiscus (*Hibiscus rosa-sinensis* L.), calendula (*Calendula officinalis*), nasturtium (*Tropaeolum majus*), pansy (*Viola* × *wittrockiana* Gams), rose (*Rosa* spp.), borago (*Borago officinalis* L.), begonia (*Begonia* × *tuberhybrida* Voss), busy lizzie (*Impatiens walleriana* Hook.f.), and viola (*Viola cornuta* L., *hybrida* Wiesb., *tricolor* L., *odorata* L.) [18]. Some herb flowers are also edible: alliums (leeks, chives, garlic), thyme (*Thymus vulgaris* L.), summer savory (*Satureja hortensis* L.), marjoram (*Origanum majorana* L.), mint (*Mentha* spp.), and common sage (*Salvia officinalis* L.), as well as flowers of some fruit trees, such as elderberry blossoms (*Sambucus* spp.) and citrus blossoms (orange, lemon, lime, grapefruit, and kumquat). Moreover, some flowers are recognized by consumers as vegetables, such as artichoke (*Cynara scolymus* L.), broccoli, and cauliflower (*Brassica oleracea* L.). Even though these are inflorescences, they are not discussed in this review.

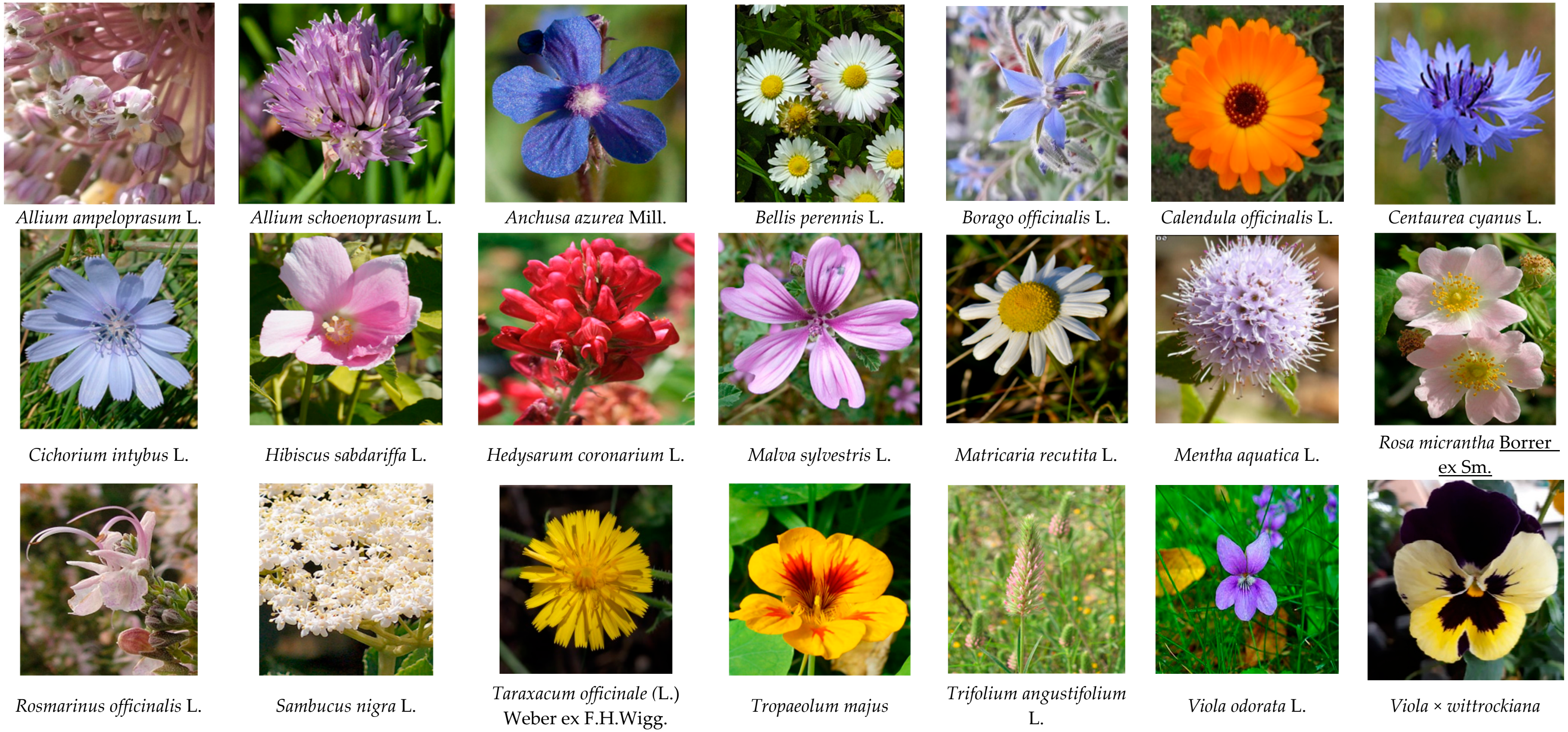

Figure 1. Examples of edible flowers. Sources: Flora-On: Flora de Portugal Interactiva. (2014). Sociedade Portuguesa de Botânica [19].

3. Lipid Content and Composition

Lipid contents reported in the literature for edible flowers are described in Table 1. Hibiscus flowers showed the highest fat content at 19 and 26 g/100 g dry weight (dw). In general, the fat content in other edible flowers ranges from 0.1 to 8.5 g/100 g dw for *Centaurea cyanus* and *Antirrhinum majus* L., respectively. However, since the main component is water, varying between 70% and 95%, the fat content in fresh edible flowers is low [20]. Furthermore, the fat content in edible flowers is not very distinct from other aerial parts of the plant; on a 100 g dw basis, moringa flowers had 2.91 g of fat, leaves 4.96 g, and immature pods 1.28 g [21]. Common mallow flowers had 2.84 g of fat, leaves 2.76 g, and leafy flowered stems 3.09 g [22]. When comparing the fat contents of edible flowers with other vegetables, such as asparagus (3.99 g/100 g dw) [23], lettuce (0.25 g/100 g dw), cabbage (0.2 g/100 g dw), and spinach (0.38 g/100 g dw) [24], the values are similar.

Table 1. Fat content (g/100 g dry weight) reported in the literature for some edible flowers.

Flower		Fat (g/100 g Dry Weight)	References
Scientific Name	Common Name		
Agave salmiana Otto ex Salm-Dyck	Agave	2.8	[25]
Allium schoenoprasum	Chives	3.4	[26]
Antirrhinum majus	Snapdragon	4.2–8.5	[25,27]
Arbutus xalapensis Kunth	Texas madrone	3.9	[25]
Azadirachta indica L.	Neem	5.2	[28]
Calendula officinalis	Calendula/common marigold/pot marigold	3.6–5.6	[29–31]
Centaurea cyanus	Centaurea	0.1	[30]
Cucurbita pepo L.	Pumpkin	5.0	[25]
Cynara scolymus	Artichoke	2.8	[29]
Dahlia mignon	Dahlia	2.2	[30]
Erythrina americana Mill.	Coral tree	2.3	[25]
Erythrina caribaea Krukoff & Barneby	Erythrina	1.5	[25]
Euphorbia radians Benth.	Sun spurge	4.9	[25]
Hibiscus esculentus L.	Hibiscus	19.0	[32]
Hibiscus sabdariffa		26.0	[32]
Madhuca indica J.F.Gmel.	Mahua	6.1	[15]
Malva sylvestris	Common mallow	2.8	[22]
Moringa oleifera Lam.	Moringa	2.9	[21]
Rosa canina L.	Rose	2.0	[30]
Rosa micrantha		1.3	[33]
Spilanthes oleracea L.	Sechuan button	2.2	[34]
Tagetes erecta L.	Mexican marigold	1.9	[34]
Tropaeolum majus	Garden nasturtium	3.1–3.6	[29,34]
Viola × wittrockiana	Pansies	5.0–6.0	[27,29]
Yucca filifera Chabaud	Yucca	2.1	[25]

The major lipid classes—fatty acids and lipid-soluble components (vitamin E and carotenoids) are detailed in the next sections.

3.1. Fatty Acids

The fatty acids profile of some edible flowers, including total saturated fatty acids (SFA), monounsaturated fatty acids (MUFA), and polyunsaturated fatty acids (PUFA) contents, are summarized in Tables 2 and 3. Thirty-six fatty acids were identified and quantified in edible flowers. The major fatty acids found in flowers were palmitic acid (C16:0), linoleic (C18:2), and α-linolenic (C18:3) (Figure 2) with a high proportion of essential fatty acids. However, their ranges varied widely among species: palmitic acid ranged from 0.08% to 53.9% for *Hibiscus sabdariffa* and *Chrysanthemum morifolium* Ramat., respectively; linoleic acid varied between 0.05% and 57.02% for *Hibiscus sabdariffa* and *Punica granatum* L., respectively; and, α-linolenic acid between 0.02% and 36.9% for *Hibiscus esculentus* and *Calendula officinalis* (petals), respectively.

Palmitic acid is one of the most common SFA found in plants. Although associated with increased risk of developing cardiovascular diseases [35], oxidative DNA damage, DNA strand breakage, necrosis, and apoptosis in human cells in vitro [36,37], when consumed with other fatty acids, like PUFAs, which were also detected in edible flowers, SFA are unlikely to have any significant impact on human health [37,38]. Furthermore, a recent review reported that more rigorous investigations are needed to understand the advantages and disadvantages induced by palmitic acid consumption, because there are some controversial results [39]. Edible flowers also contain low amounts of other saturated fatty acids, such as stearic (C18:0) (0.01–16.8% for *Hibiscus sabdariffa* and *Rosa canina*, respectively), lauric (C12:0) (0.09–3.66% for *Moringa oleifera* and *Calendula officinalis* flowers, respectively), and myristic (C14:0) acids (0.1–24.9% for *Chrysanthemum morifolium* and *Calendula officinalis* flowers, respectively).

Among the PUFAs, two of the most important fatty acids, linoleic acid (omega (ω)-6 group) and α-linolenic acid (omega(ω)-3 group), are essential fatty acids. So, humans must obtain them through diet because the body lacks the desaturase enzymes required for their production. These PUFAs are present in high proportions in some flowers (>50%), such as *Calendula officinalis* (petals), *Taraxacum* sect. Ruderalia, *Punica granatum, Rosa micrantha,* and *Trifolium angustifolium* (Table 2). Both fatty acids have important roles in human growth and development, as well as in the prevention and treatment of coronary artery diseases, hypertension, diabetes, arthritis, other inflammatory and autoimmune disorders, and cancer [40–44]. So, the presence of ω-3 and ω-6 fatty acids in edible flowers could be a way to promote their consumption and inclusion in the human diet. Regarding MUFAs, they are mainly represented by oleic acid (C18:1), ranging from 0.01% (*Hibiscus sabdariffa*) to 28.5% (*Gundelia tournefortii* L.), followed by eicosenoic (C20:1) and erucic (C22:1) acids in low quantities.

In Table 3, PUFA and SFA predominate over MUFA due to the significant contribution of α-linolenic and linoleic, and palmitic acids, respectively. However, in all cases, unsaturated fatty acids predominate over saturated ones (generally higher than 53%), with one exception observed in calendula flowers (23.3%). Furthermore, high PUFA/SFA ratios reduce the risk of cardiovascular diseases [45]. In general, all edible flowers studied until now showed high ratios of PUFA/SFA (higher than 0.45) [46] and low ω-6/ω-3 ratios (lower than 4.0) [33], which are recommended for the human diet, except calendula (PUFA/SFA ratio equal to 0.27) and dahlia (ω-6/ω-3 ratio equal to 4.25). Additionally, a ω-6/ω-3 ratio equal or lower than 4 is beneficial for reducing serum "bad cholesterol", and inhibiting a major receptor for oxidized low-density lipoprotein (ox-LDL) uptake [47], with potential to protect against obesity, insulin resistance, and inflammation [48]. However, Tsoupras et al. [49] presented data that supports inflammation induced by several factors, with platelet-activating factor (PAF), as being strongly implicated in cardiovascular diseases, rather than serum cholesterol alone. Therefore, food antioxidants might be lipid counterparts on the onset of cardiovascular diseases. So, edible flowers are a healthy lipid source (rich in oleic, linoleic, and linolenic fatty acids), offering potential health benefits.

Table 2. Fatty acids (%) profile of some edible flowers mentioned in the literature.

Fatty Acids	*Allium schoenoprasum*	*Anchusa azurea*	*Azadirachta indica*	*Calendula officinalis*		*Capparis spinosa* L.	*Cassia fistula* L.	*Centaurea cyanus*	*Chrysanthemum morifolium*	*Cichorium intybus*	*Taraxacum* sect. Ruderalia	Dahlia mignon	*Gundelia tournefortii*
	Flowers	**Flowers**	**Flowers**	**Petals**	**Flowers**	**Flowers**	**Flowers**	**Petals**	**Flowers**	**Flowers**	**Flowers**	**Petals**	**Bud**
Caproic (C6:0)				0.3	0.5			0.2				0.9	nd
Caprylic (C8:0)			0.3	0.3	0.7			0.07				0.9	nd
Capric (C10:0)			0.1	0.2	0.3			0.1				1	nd
Undecylic (C11:0)			0.3	0.1				nd				nd	nd
Lauric (C12:0)			1	1.6	3.7		nd	nd	0.1–1.1			0.7	nd
Myristic (C14:0)		11.6	1.9	9.9	24.9	1.9	2.1	0.9	0.1–14.8	0		3.1	nd
Myristoleic (C14:1ω5)				nd	0.1			0.2		7		0.6	nd
Pentadecylic (C15:0)	7.9–16.9	0.6	0.8	0.2	0.5	1.6		0.4		1.8		0.7	nd
Palmitic (C16:0)		14.3	31.8	23.4	35.6	25.7	34.5	23.4	0.6–53.9	18.5	17	23.4	23.4
Palmitoleic (C16:1ω7)				0.2	0.2			0.3				0.9	nd
Margaric (C17:0)		nd	0.3	0.2	0.5	tr		0.8		0.4		0.9	nd
Stearic (C18:0)		5.5	2.9	3.9	5.9	3.3	15.2	9.7	1	1.7		7.6	2.5
Oleic (C18:1ω9)		5.8	9.7	1.6	2.5	0.4	nd	4.4		1		5.8	28.5
Linoleic (C18:2ω6)	7.6–13.4	6	18.6	20.3	9.3	0.7	41.2	6.7		1.9	33	36.5	57.8
α-Linolenic (C18:3ω3)		7.3	12.6	36.9	11.1	0.5		18.8		0.6	23.1	8.6	0.1
Arachidic (C20:0)		tr	1.3	0.63	0.8	2.6	2.8	5.3		0.8		1.6	0.3
Eicosenoic (C20:1ω9)			0.4	nd	0.1		nd	nd				nd	nd
Eicosadienoic (C20:2ω6)				nd				nd				0.4	nd
Eicosatrienoic (C20:3ω3)				0.26				0.5				0.6	nd
Dihomo-γ-linolenic (C20:3ω6)													
Eicosapentaenoic (C20:5ω3)				nd				26.9				nd	nd
Behenic (C22:0)		1.7	2.1	0.56	0.3	5.9	0.9	2		1.5		nd	nd
Erucic (C22:1ω9)				nd			nd	6				nd	nd
Docosadienoic (C22:2ω6)			5.7										
Tricosylic (C23:0)		1.8		0.1		nd		0.2		0.3		0.2	nd

Table 2. *Cont.*

Fatty Acids	*Allium schoenoprasum*	*Anchusa azurea*	*Azadirachta indica*	*Calendula officinalis*		*Capparis spinosa* L.	*Cassia fistula* L.	*Centaurea cyanus*	*Chrysanthemum morifolium*	*Cichorium intybus*	*Taraxacum* sect. Ruderalia	Dahlia mignon	*Gundelia tournefortii*
	Flowers	**Flowers**	**Flowers**	**Petals**	**Flowers**	**Flowers**	**Flowers**	**Petals**	**Flowers**	**Flowers**	**Flowers**	**Petals**	**Bud**
Lignoceric (C24:0)		nd	1.7	0.9	0.9	tr	nd	1.1		nd		2.3	nd
References	[26]	[50]	[28]	[29]	[31]	[50]	[51]	[30]	[52]	[50]	[53]	[30]	[54]
Fatty Acids	***Hedysarum coronarium***	***Hibiscus esculentus***	***Hibiscus sabdariffa***	***Malva sylvestris***	***Moringa oleifera***	***Punica granatum***	***Robinia pseudoacacia***	***Rosa canina***	***Rosa micrantha***	***Rosmarinus officinalis***	***Sambucus nigra***	***Trifolium angustifolium***	
	Flowers	**Flowers**	**Flowers**	**Flowers**	**Flowers**	**Flowers**	**Flowers**	**Petals**	**Petals**	**Flowers**	**Flowers**	**Flowers**	
Caproic (C6:0)				0.6	nd			0.2	0.1			0.2	
Caprylic (C8:0)				0.03	0.09			0.2	0.4			0.8	
Capric (C10:0)				0.02	nd			0.3	0.3			0.2	
Undecylic (C11:0)					nd			nd	nd			nd	
Lauric (C12:0)				0.12	0.09	1.2–6.6		1.22	0.9			2.3	
Tridecylic (C13:0)					nd			0.03	nd			0.02	
Myristic (C14:0)		tr	tr	0.9	0.59	0.6–3.7		2.6	1.5			4.8	
Myristoleic (C14:1)	6.4			0.2–0.8	1.96		2.4	0.3	nd	3.7	1.7	0.2	
Pentadecylic (C15:0)	1			0.07–1.5	nd		nd	0.3	0.2	0.4	1.2	0.3	
Palmitic (C16:0)	7.7	3.4	0.08	17.2–22.4	23.43	27.7–43.6	9.1	23.4	11.3	7.1	17.7	15.4	
Palmitoleic (C16:1)		0.03	nd	0.62	nd	nd–0.95		0.22	nd			0.3	
Margaric (C17:0)	nd			nd–0.3	nd		0.7	0.53	0.7	0.3	nd	0.4	
Stearic (C18:0)	4.4	0.3	0.01	2.4–3.6	4.52	4.8–10.1	2.3	16.8	0.6	2.2	nd	3.2	
Oleic (C18:1ω9)	0.4	1.8	0.01	1.9–6.1	21.55	6.3–20.5	0.7	1.95	1.8	1.1	1.5	6.1	
Linoleic (C18:2ω6)	1.3	2.5	0.05	0.8–23.5	18.96	47.4–57.0	2.7	31.9	21.2	1.5	0.8	20.2	
α-Linolenic (C18:3ω3)	0.7	0.02	0.03	3.1–33.5	23.01	14.8–25.4	0.6	19.5	32.3	1.9	1.3	34.7	
Arachidic (C20:0)	1.2	0.02	tr	1.2–1.6	0.98	2.3–8.4	0.8	3.6	3.7	0.5	0.2	2.6	
Eicosenoic (C20:1)				0.07	nd	0.9–4.9		nd	0.6			0.2	
Eicosadienoic (C20:2ω6)				0.1	0.75	0.8–1.8		nd	nd		1	0.1	
Eicosatrienoic (C20:3ω3)					nd	nd–0.5		0.33	nd				

Table 2. *Cont.*

Fatty Acids	*Hedysarum coronarium*	*Hibiscus esculentus*	*Hibiscus sabdariffa*	*Malva sylvestris*	*Moringa oleifera*	*Punica granatum*	*Robinia pseudoacacia*	*Rosa canina*	*Rosa micrantha*	*Rosmarinus officinalis*	*Sambucus nigra*	*Trifolium angustifolium*
	Flowers	**Flowers**	**Flowers**	**Flowers**	**Flowers**	**Flowers**	**Flowers**	**Petals**	**Petals**	**Flowers**	**Flowers**	**Flowers**
Dihomo-γ-linolenic (C20:3ω6)						0.6–0.9						
Eicosapentaenoic (C20:5ω3)					nd			nd	nd			
Behenic (C22:0)	2.1			1–1.5	2.06	0.3–5.5	0.5	1.8	4.4	nd	nd	2.4
Erucic (C22:1)					nd	0.7–1.8		nd				
Docosadienoic (C22:2ω6)						0.9–1.6						
Tricosylic (C23:0)	nd			10	nd		nd	0.08	9.3	0.3	nd	0.2
Lignoceric (C24:0)	0.2			1	nd	0.3–1.5	0.3	1	3.4	nd	nd	3.2
References	[50]	[32]	[32]	[22,50]	[21]	[55]	[50]	[30]	[33]	[50]	[50]	[56]

nd—not detected; tr—trace amounts.

Table 3. Saturated, monounsaturated, polyunsaturated and unsaturated fatty acids in edible flowers *.

Flowers		SFA (%)	MUFA (%)	PUFA (%)	UFA (%)	PUFA/SFA	ω-6/ω-3	References
Scientific Name	**Common Name**							
Azadirachta indica	Neem	45.1	10.2	44.7	54.9	1.0	1.5	[28]
Bauhinia variegata L.	Cow's foot	42.3	6.2	51.4	57.6	1.2	1.2	[57]
Calendula officinalis	Calendula (common marigold)	40.7–76.7	1.8–2.9	20.5–57.5	23.3–59.3	0.3–1.4	0.6–0.8	[30,31]
Centaurea cyanus	Centaurea	36.2	10.9	52.9	63.8	1.5	0.4	[30]
Dahlia mignon	Dahlia	46.6	7.2	46.2	53.4	1.0	4.2	[30]
Moringa oleifera	Moringa	31.8	26.3	42.2	68.4	1.3	0.8	[21]
Punica granatum cv. Chelfi	Punica	15.0	59.2	25.8	85.0	1.7	2.6	[55]
Punica granatum cv. Gabsi	Punica	33.5	14.4	52.0	66.5	1.6	2.8	[55]
Punica granatum cv. Tounsi	Punica	33.8	8.8	57.4	66.2	1.7	3.2	[55]
Punica granatum cv. Nabli	Punica	31.6	8.1	14.4	59.2	1.4	2.3	[55]
Rosa canina	Rose	45.8	2.5	51.7	54.2	1.1	1.6	[30]
Rosa micrantha	Rose	11.2	13.4	75.4	88.8	6.7	1.4	[33]
Taraxacum officinale	Dandelion	33.5	3.0	63.5	66.5	1.9	1.1	[53]

* SFA—Saturated fatty acids; MUFA—Monounsaturated fatty acids, PUFA—Polyunsaturated fatty acids, UFA—Unsaturated fatty acids.

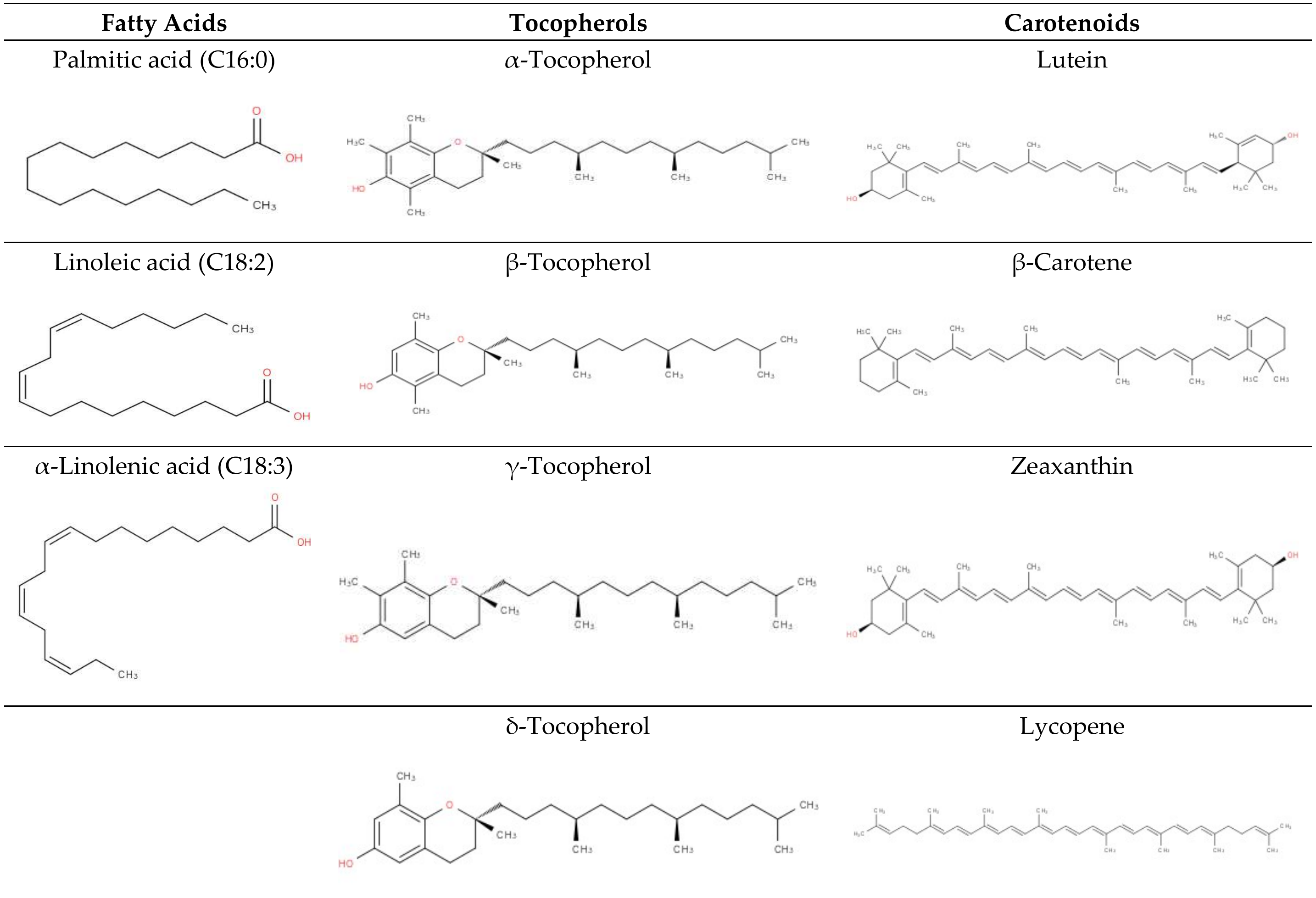

Figure 2. Chemical structures of the main lipophilic compounds detected in edible flowers. Source: Hastings, et al. [58].

3.2. Tocopherols

Vitamin E is a class of lipid-soluble antioxidants synthesized by plants and photosynthetic organisms [59]. There are four isoforms (α, β, γ, and δ) of tocopherols and tocotrienols, which differ in the number and positions of the methyl groups in the chromanol ring. In flowers, tocols are mostly located in petal leucoplasts [59]. Tocopherols are also essential components of the human diet because they perform numerous critical functions, including quenching and scavenging of various reactive oxygen species (ROS) and free radicals, and protecting PUFA from lipid peroxidation [60].

Tocopherols identified and quantified in edible flowers are listed in Table 4. In the majority of the flowers analysed, only the four isoforms of tocopherols (α, β, γ, and δ) were detected (Figure 2), with α-tocopherol being the major compound. *Calendula officinalis* was the flower that had the highest content of α-tocopherol (56.78 mg/100 g dw), followed by *Rosa micrantha* (26.72 mg/100 g dw) and *Taraxacum* sect. Ruderalia (21.60 mg/100 g dw). These flowers presented higher contents of α-tocopherol when compared with some vegetables, such as wild asparagus (0.75–4.51 mg/100 g dw) or leafy vegetables (2.59–10.12 mg/100 g dw) [61]. The Academy of Sciences reports a Recommended Dietary Allowance (RDA) value for α-tocopherol of 15 mg/day [62], whereas the daily recommended dose for tocopherols consumption in adults is 300 mg/day [63]. Despite the low amounts of tocopherols in edible flowers, their daily consumption may contribute to supplying this vitamin to the organism. In parallel, γ-tocopherol was also detected in almost all flowers studied, ranging from 0.16 to 7.68 mg/100 g dw in *Gundelia tournefortii* and *Rosa micrantha*, respectively.

3.3. Carotenoids

Carotenoids are lipophilic pigments widely distributed in nature, and they have different roles in the plant life cycle including photo-protective functions, and provision of substrates for plant growth, regulator of abscisic acid and other hormones [64–67], as well as, in human nutrition and health, providing provitamin A and having anti-cancer activities [68]. Carotenoids can be classified into two classes: carotenes (α-carotene, β-carotene, and lycopene) and xanthophylls (β-cryptoxanthin, lutein, and zeaxanthin) [69]. In flowers, carotenoids are found in all anatomical parts: sepals, pollen, anthers, stamens, and petals [70]. Flowers offer distinct carotenoids profiles that depend on species and variety [71], as shown in Tables 5 and 6. The edible flowers studied have shown a very different range in values between species.

Table 5 also shows that different flowers of the same species may have different amounts of total carotenoids. This may be due to their different colors, cultivars, soil characteristics, conditions of production, and parts of the flower (petals or whole flowers), or other factors including analytical ones. Among published studies in edible flowers, the majority of carotenoids are xanthophylls (Table 6), such as lutein and zeaxanthin (Figure 2). Lutein was the main carotenoid in chrysanthemum (11.78–307.22 μg/g dw), snapdragon (14.1 μg/g dw), garden nasturtium (350–450 μg/g fw), Mexican marigold (1062 μg/g fw), crem (243.23 μg/g dw), and pansies (51.1 μg/g dw). Epoxy xanthophylls, such as flavoxanthin (calendula), violaxanthin (yellow bloom), auroxanthin (golden aster), antheraxanthin (rose), and neoxanthin (flame tree), are also common and can be found in high contents in some flowers (Table 6). Edible flowers also contain carotenes, such as lycopene and β-carotene (Figure 2). In some cases, edible flowers showed higher values of β-carotene than green leafy and root vegetables. For example, garden petunias *cv*. Summer Sun (358.1 mg/100 g fw), Mexican marigold (8.55 mg/100 g fw), and squash flowers (1.01–13.35 mg/100 g fw) showed higher values than spinach (4 mg/100 g fw), carrot (2.2 mg/100 g fw), coriander (6.1 mg/100 g fw), and mint (4.3 mg/100 g fw) [72].

As expected, the carotenoid amounts were different according to the distinct parts of the plants. For example, leaves of caper (mean 5.02 and 8.09 mg/100 g fw, β-carotene and lutein respectively) had higher concentrations of β-carotene and lutein than flower buds (mean 1.17 and 2.24 mg/100 g fw, β-carotene and lutein respectively) [73]; petals of calendula (7.71 mg/g dw) had higher values of total carotenoids than pollen (1.61 mg/g dw), stems (0.18 mg/g dw), and leaves (0.85 mg/g dw) [74].

Furthermore, different carotenoids are also detected in different parts of the flower: the stems of calendula contained carotenoids typical of photosynthetic tissue (e.g., lutein and β-carotene), whereas petals and stems showed more furanoid-oxides (e.g., flavoxanthin, auroxanthin, luteoxanthin, and 9*Z*-antheraxanthin) [74]. So, consumers of edible flowers can obtain different carotenoids according to the part of flower they eat.

Some studies found correlations between the color of the flowers and their carotenoids content [75,76], and that carotenoids in flowers are responsible for the yellow, orange, and red color classes of pigments [71]. Pintea et al. [75] found that calendula flowers with distinct colors (different varieties) contain the same pigments but in different amounts. For example, the variety that is dark orange (Double Esterel Orange) presented the highest total content of carotenoids (276 mg/100 g fw). Similar results were detected by Park et al. [77], who reported that between different cultivars and colors of chrysanthemums, the yellow-orange flowers were those that showed the highest content of carotenoids, namely Il Weol (345.56 μg/g dw) and popcorn ball (189.57 μg/g dw). So, carotenoids are important compounds in edible flowers, because the color of the flower is an essential attribute that influences the commercial acceptance of consumers [78]. Some colors of edible flowers may induce a reluctant attitude by consumers during the purchase, whereas others are more appealing. Since color may influence taste, reddish flowers may suggest to the consumer that they have a "sweet cherry or strawberry flavor", whereas yellowish flowers may be associated with a sour or citrus flavour [79]. Furthermore, at the time of purchase of edible flowers, color influences the consumers because they may like one color or combination of colors more than others. According to Kelley et al. [79], consumers prefer dark colors, such as orange (associated to carotenoids) and crimson, because they are more appealing.

Table 4. Tocopherols determined in edible flowers mentioned in the literature.

Flowers		Tocopherols (mg/100 g dw)				Ref.
Scientific Name	**Common Name**	**α-Tocopherol**	**β-Tocopherol**	**γ-Tocopherol**	**δ-Tocopherol**	
Musa × sapientum L.	Banana flower	5.1				[80]
Calendula officinalis	Calendula (Common marigold)	19.4–56.8	1.1–1.5	2.4–2.9	nd	[30,31]
Capparis spinosa	Caper (different regions)	1.8–2.7		0.4–1.1		[81]
Centaurea cyanus	Centaurea	0.6	nd	0.3	nd	[30]
Matricaria recutita	Chamomile	3.5	0.2	2.6–4.0	1.2	[56]
Trifolium angustifolium	Clover	12.7	0.6	5.4	0.4	[56]
Malva sylvestris	Common mallow	14.0	0.6	2.5	0.2	[22]
Tropaeolum pentaphyllum Lam.	Crem	2.8		1.0		[82]
Dahlia mignon	Dahlia	4.4	1.8	0.7	0.4	[30]
Bauhinia variegata	Cow's foot	1.7				[57]
Taraxacum sect. Ruderalia	Dandelion	21.6	11.2	5.6	6.3	[53]
Gomphrena globosa L.	Globe amaranth	0.4		3.0	5.2	[83]
Rosa canina	Rose	8.2	0.2	0.8	0.1	[30]
Rosa micrantha	Rose	26.7	0.7	7.7	0.2	[33]
Gundelia tournefortii	Tumbleweed	7.9	0.2	0.2		[54]

nd: not detected.

Table 5. Total carotenoids contents in edible flowers reported in the literature.

Edible Flowers		Part Flower	Color	Total Carotenoids	Reference
Scientific Name	**Common Name**		**Results Expressed in μg/g Fresh Weight**		
Calendula officinalis	Calendula/Common marigold	Flowers	Dark orange to yellow	57–2760	[75,84–86]
		Petals	Yellow and orange	1073–1696	[87]
Chrysanthemum morifolium	Chrysanthemum	Petals	Yellow and orange	122–343	[87]
Cucurbita pepo	Squash flower	Flowers	ns	768	[88]
Cucurbita maxima Duchesne	Squash flower	Flowers	Yellow	12–188	[76]
Dianthus caryophyllus L.	Carnation	Petals	Green and red	2–12	[71]
Helianthus annuus L.	Sunflower	Petals	Yellow and orange	144–1600	[87]
Helianthus tuberosus L.	Jerusalem artichoke	Flower	ns	15.6	[85]
Hibiscus rosa-sinensis	Hibiscus	Flowers (different cultivars)	ns	2×10^3–40×10^3	[89]
Matricaria recutita	Chamomile	Flowers (different varieties)	ns	135–162	[90]
Petunia × *hybrida* Vilm.	Garden petunias	Flowers	Solid colour or bicolour (Red, rose, pink, blue, burgundy, white, yellow)	0.32–96.8	[91]
Tagetes erecta	Mexican marigold African Marigold	Petals	Yellow and orange	48–2130	[87]
		Flowers	Deep orange	6.3–1304	[85,92]
Tagetes patula L.	French marigold	Petals	Yellow and orange	270–2020	[86]
Rosa spp.	Rose	Flowers	Pink; Yellow; Red; Orange; White	0.1–61.7	[93]
			Results expressed in μg/g dry weight		
Antirrhinum majus	Snapdragon	Flowers	ns	29 [1]	[27]
Calendula officinalis	Calendula/Common marigold	Petals	ns	7.71×10^3	[74]
		Flowers	ns	1405	[94]
Dendranthema grandiflorum (Ramat.) Kitam.	Chrysanthemum	Flowers (different cultivars)	Purple, White, Green, Red, Yellow	19–346	[77]
Tropaeolum pentaphyllum	Crem	Flowers	ns	396	[82]
Viola × *wittrockiana*	Pansies	Flowers	ns	146 [1]	[27]
Viola tricolor	Viola	Petals	ns	23 [2]	[95]

ns—not specified; [1] Lutein equivalent; [2] Composition of chromoplast globules (% of total dry weight).

Table 6. Individual carotenoids values in edible flowers.

Edible Flower		Part Flower	Color	Carotenoids		Reference
Scientific Name	Common Name			Results Expressed in μg/g fw		
Calendula officinalis	Calendula/ Common marigold	Petals (different var.)	Orange Yellow	Luteoxanthin	186.6–195.0 [1]	[87]
				Lutein-5,6-epoxide	27.1–40.0 [1]	
				Flavoxanthin	483.4–532.5 [1]	
				Auroxanthin	120.4–133.7 [1]	
				(9′Z)-Lutein-5,6-epoxide	84.8–106.2 [1]	
				Lutein	33.9–62.5 [1]	
				Antheraxanthin	17.0–31.2 [1]	
				(9Z)-Lutein	10.2–18.7 [1]	
				(5′Z,9′Z)-Rubixanthin	67.8 [1]	
				α-Carotene	13.6 [1]	
				β-Carotene	12.5–57.7 [1]	
				(5′Z)-Rubixanthin	50.9 [1]	
				δ-Carotene	23.7 [1]	
				(5Z,9Z,5′Z,9′Z)-Lycopene	69.5 [1]	
				γ-Carotene	33.9 [1]	
				(5′Z)-γ-Carotene	74.6 [1]	
				(5Z,9Z,5′Z)-Lycopene	59.4 [1]	
				(5Z,9Z)-Lycopene	68.5 [1]	
				Lycopene	147.6 [1]	
Capparis spinosa	Caper	Flower buds	—	β-carotene	4–23.3	[73]
				Lutein	5.2–40.8	
Chrysopsis scabrella Torr. & A.Gray	Golden aster	Flowers	—	Auroxanthin	29.1	[69]
				Bixin	3.5	
Cucurbita maxima	Squash flower	Petals	Yellow	β-Carotene	10.1–133.5	[76]
Delonix regia (Hook.) Raf.	Flame tree	Flower	—	Astaxanthin	2.9	[69]
				Violaxanthin	38.7	
				Neoxanthin	38.7	
				Zeaxanthin	36.7	
Delonix regia var. *flavida* Stehle	Yellow bloom	Flowers	—	Violaxanthin	12	[69]
				Canthaxanthin	0.13	
Gerbera jamesonii Bolus ex Adlam	Gerbera	Flowers	—	Antheraxanthin	11.9	[69]
				Crocetin	3.7	
Petunia hybrida	Garden petunias	Flowers	Solid color/ bicolor (Red, rose, pink, blue, burgundy, white yellow)	β-Carotene	0.14–35.8	[91]
				Lutein	0.00–13.9	
				Zeaxanthin	0.00–3.3	

Table 6. *Cont.*

Edible Flower		Part Flower	Color	Carotenoids		Reference
Scientific Name	Common Name			Results Expressed in µg/g fw		
Rosa	Rose	Petals	—	Antheraxanthin Crocetin	10.2 2.7	[69]
Solidaster lutens M.L.Green	Solid aster	Petals	—	Auroxanthin Bixin	22.1 5.7	[69]
Tagetes erecta	Mexican marigold	Flowers	Deep orange	β-cryptoxanthin Lutein Neoxanthin Violaxanthin Zeaxanthin β-Carotene	31.6 1062 nd 43.7 53.7 85.5	[92]
Tropaeolum majus	Garden nasturtium	Flowers	Yellow Brownish orange	Neoxanthin Violaxanthin Lutein β-Carotene	nd tr 350–450 tr	[96]
				Results expressed in µg/g dw		
Antirrhinum majus	Snapdragon	Flowers	—	Violaxanthin Antheraxanthin Lutein Zeaxanthin β-carotene	nd nd 14.1 7.4 7.7	[27]
Dendranthema grandiflorum	Chrysanthemum	Flowers (different cultivars)	Purple White Green Red Yellow	Lutein Zeaxanthin β-Cryptoxanthin 13-*cis*-β-Carotene α-carotene Trans-β-carotene 9-*cis*-β-carotene	11.8–307 0.14–2.9 0.09–2.1 0.13–5.6 0.04–3.5 1.4–55.8 0.3–5.12	[77]
Matricaria recutita	Chamomile	Flowering aerial parts	White	β-carotene	1277	[56]
Viola declinata Waldst. & Kit.	Viola	Aerial parts	—	Neoxanthin Violaxanthin Antheraxanthin Lutein Zeaxanthin α-cryptoxanthin β-carotene 5,6-epoxide β-carotene 9Z-β-carotene	tr 2.81 2.83 8.96 4.79 tr 0.48 5.46 0.76	[97]
Trifolium angustifolium	Clover	Flowering aerial parts	—	β-carotene	342–388	[56]
Tropaeolum pentaphyllum	Crem	Flowers	—	Lutein Zeaxanthin β-cryptoxanthin α-carotene β-carotene	243 14.2 2.6 3.6 132	[82]

Table 6. *Cont.*

			Results expressed in µg/g dw			
Viola × wittrockiana	Pansies	Flowers	—	Violaxanthin	8.9	[27]
				Antheraxanthin	8.5	
				Lutein	51.1	
				Zeaxanthin	38.2	
				β-carotene	41.5	
			Results expressed in % of peak area of carotenoids in the HPLC chromatogram			
Calendula officinalis	Calendula/ Common marigold	Petals	—	Neoxanthin	0.52	[74]
				Z-Neoxanthin	1.2	
				Violaxanthin	0.3	
				Luteoxanthin	11.8	
				Auroxanthin	9.5	
				9Z-Violaxanthin	2.6	
				Flavoxanthin	21.1	
				Mutatoxanthin	3	
				9Z-Antheraxanthin	5.1	
				Lutein	5.7	
				9/9VZ-Lutein	2.6	
				13/13VZ-Lutein	1.8	
				α-Cryptoxanthin	5.5	
				β-Cryptoxanthin	2.11	
				Lycopene	7.4	
				α-Carotene	5.7	
				β-Carotene	6.5	
			Orange	(8′*R*)-Luteoxanthin	11	[98]
				Lutein-5,6-epoxide	1.6	
				Flavoxanthin	28.5	
				(8*R*,8′*R*)-Auroxanthin	7.1	
				(9′*Z*)-Lutein-5,6-epoxide	5	
				Lutein	2	
				Antheraxanthin	1	
				(9*Z*)-Lutein	0.6	
				(5′*Z*,9′*Z*)-Rubixanthin	4	
				α-Carotene	0.8	
				β-Carotene	3.4	
				(5′*Z*)-Rubixanthin	3	
				δ-Carotene	1.4	
				(5*Z*,9*Z*,5′*Z*,9′*Z*)-Lycopene	4.1	
				γ-Carotene	2	
				(5′*Z*)-Carotene	4.4	
				(5*Z*,9*Z*,5′*Z*)-Lycopene	3.5	
				(5*Z*,9*Z*)-Lycopene	4.1	
				(all-*E*)-Lycopene	8.7	

Table 6. *Cont.*

				Results expressed in % of peak area of carotenoids in the HPLC chromatogram		
		Flowers (four varieties)	Yellow-orange Lemon yellow Orange Dark orange	Neoxanthin	0.9–2.8	[75]
				Luteoxanthin + Auro	8.9–19.0	
				Antheraxanthin	2.1–6.8	
				Flavoxanthin	14.1–42.0	
				Mutatoxanthin	0.4–2.2	
				Lactucaxanthin	4.5–11.3	
				Lutein	8.3–12.3	
				Zeaxanthin	0.11–0.23	
				Rubixanthin	4.6–14.4	
				Lycopene	0.6–14.0	
				γ-carotene	5.1–12.2	
				α-carotene	0.1–1.9	
				β-carotene	2.4–17.5	
				Identification without quantification		
Chrysanthemum morifolium	Florist's daisy	Petals (different cultivars)	Yellow/White	Violaxanthin all-*E*-lutein β-carotene 5,6-dihydro-5,6-dihydroxylutein 9*Z*-L, (9*Z*)-lutein 9′*Z*-L, (9′*Z*)-lutein 9*Z*-Le, (9*Z*)-lutein 5,6-epoxide 9′*Z*-Le, (9′*Z*)-lutein 5,6-epoxide Neoxanthin Zeaxanthin Antheraxanthin.	—	[99]
Cucurbita pepo	Squash flower	Flowers	Yellow-orange	Zeaxanthin Flavoxanthin Cryptoxanthin	—	[100]
Dianthus caryophyllus	Carnation	Petals	Green/Red (during development)	Lutein and violaxanthin Zeaxanthin	Decreased Increased	[71]
Taraxacum officinale	Dandelion	Petals	Yellow	Isomers of lutein epoxide	—	[101]
Viola × wittrockiana	Viola	Petals	—	β-Carotene Lycopene Xanthophyll	—	[102]

dw: dry weight, fw: fresh weight; tr: trace amounts. [1] Lutein equivalent.

4. Oil Extraction

Until now, the studies performed on oil extraction of edible flowers have been performed for identification and characterization purposes only. To the best of our knowledge, there is no information on oil extraction from edible flowers for commercial purposes, only for essential oils (topic not discussed in the present review). Concerning the completed experimental studies, only solvent-based extractions are reported, and most of the studies involved hot-Soxhlet extraction or cold maceration. Edible flowers used in extraction can be prepared either from fresh or dried flowers. In case of dried samples, flowers are initially subjected to drying (e.g., air and freeze-drying), followed by grinding, milling, or homogenization to reduce sample particle size and enhance the extraction efficiency. Various solvents are commonly used in the Soxhlet extraction, such as petroleum ether [22,30,52,57] and hexane [51], whereas in maceration, a mixture of solvents is mainly used, such as chloroform-methanol [21,28,55]. However, in the future, new extraction technologies may be tested in edible flowers to improve extraction time, oil yield, and reduce the amount of solvent or even use green solvents. Based on its compositional data, edible flowers can be a potential source of fat and oil that are currently unexploited that could to complement the existing sources. Furthermore, different edible flowers can offer a diversity of products that can be used for food flavoring and drink products.

5. Conclusions

In general, fresh edible flowers show low nutrient content, including fat, because water is their main component. Nevertheless, their oils have an interesting composition from a health point of view, supporting an increased use for food purposes or as food supplements. The fatty acid profile of most flowers is rich in essential fatty acids and their vitamin E is mainly represented by α-tocopherol—the vitamin E compound with the highest biological activity. Most carotenoids found in flowers are xanthophylls, such as lutein, although carotenes have also been reported (lycopene and β-carotene), all with interesting heath attributes. Regarding different species and varieties of edible flowers, some variability in their lipid profiles and compositions has been observed.

In summary, and based on the available literature, it is evident that a wide gap still persists in the scientific knowledge regarding many edible flowers used for culinary and therapeutic purposes. The lipid composition of edible flowers merits further investigation to search for prospective food industry applications. This increased demand for edible flowers, as is or for oil extraction, will require a strong response from agriculture to increase productivity and quality.

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