

Crocus Sativus Linn: An Informative Review

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Abstract

Saffron, *Crocus Sativus* L. is a perennial bulbous herb. The plant has been priced since antiquity for its yellow-orange coloured tripartite stigmas that constitute the Saffron. Also known as saffron crocus, the odour of saffron is described as like the "sea" air. *Crocus* (Family: Iridaceae) is an important genus consisting of 80 species. The reported life zone of *Crocus* in the world extends through 30-45° N latitude and 0° to 90° E longitude (usual temperature 4 to 23° Celsius), with an annual precipitation of 0.1 to 1.1 meter and a soil pH of 5.8 to 7.8. The crop grows best in well-drained soils of medium fertility. Principally saffron grown in Spain, India, Turkey, Greece, Austria, Belgium, France, Germany, Holland, Hungary, Italy, Japan, Norway, Russia, Switzerland, Turkey, Persia and the People's Republic of China. *Crocus Sativus* L. is famous for its diversified pharmacological activities. Almost all the parts of this plant (stigma, stamen, petals, sepals, style, and corm) were evaluated by the researches. The present review will be focused on the detailed literature survey on *Crocus Sativus* L. The species was extensively studied with the view of its pharmacological importance.

Keywords: *Crocus Sativus*; Saffron; Crocetin; Crocins; Safranal; Pharmacology and Analyses

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Saffron, *Crocus Sativus* L. is a perennial bulbous herb. The plant has been priced since antiquity for its yellow-orange coloured tripartite stigmas that constitute the Saffron. Also known as saffron crocus, the odour of saffron is described as like the "sea" air. *Crocus* (Family: Iridaceae) is an important genus consisting of 80 species [1]. Some species of *Crocus* have been cultivated worldwide for use in folk medicines and for colouring purposes. *C. sativus* L. is principally grown in Spain, India, Turkey, Greece, Austria, Belgium, France, Germany, Holland, Hungary, Italy, Japan, Norway, Russia, Switzerland, Turkey, Persia and the People's Republic of China [2-4].

Crocus Sativus L. (Fam. Iridaceae) is cultivated in India around Srinagar latitude 34°50' N, longitude 74°50' E and Kishtwar, Distt. Doda, Jammu region, latitude 33°19' N, longitude 75°48' E, The reported life zone of *Crocus* in the world extends through 30-45° N latitude and 0° to 90° E longitude (usual temperature 4 to 23° Celsius), with an annual precipitation of 0.1 to 1.1 meter and a soil pH of 5.8 to 7.8. The

crop grows best in friable, loose, low-density, well-watered, and well-drained clay calcareous soils of medium fertility. Early sowing time and greater corm dimension resulted in a greater number of flowers and increased stigma yield [5, 6]. Also corms size and planting depth had the greatest effect in increasing the quantitative production of saffron and selection of high quality germ plasm [7, 8]. However size of the mother corm, the cultivation method used (greenhouse versus field), fertilizer and water availability significantly affects the crop [9-13]. Micropropagation becomes a valuable tool to assist breeders to release new species and cultivars [14]. Dry stigma weight had significant and positive correlation with leaf number, flower number, picrocrocin and safranal [15]. Three Year-old plants have increased amounts of saffron components in comparison to 6-year-old ones [16]. Colder environment resulted in a higher flower production, but lower quality of stigmas [17]. Corms stored at low temperatures reduce contamination levels and increases multiplication rates [18]. When saline water was used to irrigate saffron, the irrigation interval needed to be more frequent (i.e., at 2-d intervals) to avoid severe water stress [19]. The corms are planted from early spring to autumn and remain undisturbed for three to ten years before they need to be replanted. Blossoming lasts only for few weeks and full bloomed flowers must be collected daily in order to get the stigmas of high quality [20, 21]. Several reviews on the world's most expensive spice saffron, its constituents and on pharmacological properties have already been published [22-32].

Saffron traditionally has been considered as an anodyne, antispasmodic, antianginal, aphrodisiac, diaphoretic, emmenagogue, galactagogue, expectorant, and sedative. Saffron has been used as a folk remedy against scarlet fever, smallpox, colds, insomnia, asthma, tumors, cancer, and diseases of the kidney, the liver, the spleen, and the brain [4, 33-35].

Saffron with higher dose (400 mg) decreased standing systolic blood pressure and mean arterial pressures significantly and also decreases slightly some hematological parameters such as red blood cells, hemoglobin, hematocrit and platelets. Saffron increases sodium, blood urea nitrogen and creatinine [36],

nursing mothers should avoid high doses [37]. Saffron can be used in treatment of gentamicin-induced nephrotoxicity and lung cancer [38, 39], reduces buccal pouch carcinogenesis [40], antidepressant [41], induction of cellular defense systems [42], does not effect coagulant and anticoagulant system with dose of 200 and 400 mg [43], increases the AV nodal refractoriness [44], improves oocyte maturation and embryo development [45], act as antisolar agent [46], does not affect semen parameters [47], however positively effect sperm parameters in rats exposed with cadmium [48], efficacious in treatment for fluoxetine-related dysfunctions [49, 50], minimizes the toxic effects of $AlCl_3$ on the liver and neurons [51, 52], significantly decreased lipid peroxidation and increased superoxide dismutase activity [53], and have antibacterial activity [54]. Saffron is also used by bird Fanciers, as they believe it assists the moulting of birds [55]. As a facial cream, it is very specific for decolouration of the skin [56]. It is used as flavouring and colouring agent in pharmaceutical, confectionery, icecreams, sweets, chewing-zarda, pan-masalas and for flavouring aperitif beverages and also used to colour foods such as butter, cheese, rice, sauces and soups [57-59].

Saffron extract is useful for neuro disorders accompanying memory impairment [60-62], could prevents selenium-induced cataractogenesis and metabolic syndrome [63, 64], treatment of mild to moderate depression [65-68], reduces stress-induced anorexia [69], relaxant [70], preventive effect on tracheal responses and serum levels of inflammatory mediators [71], have ameliorative [72], cardioprotective [73, 74], diuretic [75], satiating effect [76], treatment of mild-to-moderate alzheimer's disease [77- 79], effective in preventing the cognitive deficits caused by intracerebroventricular injection of streptozotocin [80], improves liver function and have chemopreventive effect against liver cancer [81, 82], selective Th_2 immunomodulation [83], leads to increased ratio of IFN-gamma to IL-4 [84], treatment of multiple sclerosis [85], protect's from genotoxins [86], an effective anticancer and chemopreventive agent [87-91], a potential chemotherapeutic agent in breast cancer [92], prevents in renal ischemia-reperfusion induced oxidative injury [93], effective in focal

ischemia [94], have anti-oxidant activity [95, 96], increases nitric oxide [97], positively effects on sperm morphology [98], efficacious in the treatment of premenstrual syndrome [99], positive effect on erectile dysfunction [100], can modify the reproduction activities [101], improves fertility [102] and protects from genetic damages caused by antitumor agents [103]. Potent inhibitory effect of aqueous-ethanol extract on the calcium channel of guinea-pig heart and inhibits histamine (H-1) receptors [104, 105], protect photoreceptors from retinal stress [106], effective on alleviating lung inflammatory cells and could be useful in asthma [107, 108] etc. [109-113]. Ethanolic extract can be used as chemotherapeutic agent in lung cancer [114], alleviation of oxidative stress of hepatic tissue [115], improved retention of visual short-term memory [116] and displays a considerable anti-inflammatory potency and could potentially be used as an anti-arthritis agent [117]. Hydromethanolic extract of saffron have hypoglycemic and hypolipidemic effects [118].

It is quite interesting that diterpenoid derivatives crocetin and crocins absorbed into blood plasma as crocetin and its glucuronide conjugates [119, 120]. Saffron and crocetin have binding capacity at the PCP binding site of the NMDA receptor and at the sigma(1) receptor [121], inhibits pancreatic cancer cell proliferation and tumor progression [122, 123] and have memory enhancing effects [124]. Crocin-1 and crocetin were found to significantly increase the blood flow in the retina and choroid and to facilitate retinal functional recovery by electroretinogram and has protective effects against retinal damage [125]. Saffron and its crocins are potential anti-cancer and also a hypolepidemic and antioxidant agent [126, 127], protects brain against excessive oxidative stress [128], protective on ischemic hearts [129, 130], useful in alleviation of cognitive deficits [131, 132], possesses significant anti-proliferation effects on human prostate and colorectal cancer cells [133-135], aphrodisiac activity [136], immunomodulatory [137, 138], growth inhibition of Dalton's lymphoma [139], useful in diabetic neuropathy treatment [140], effects glucose uptake and insulin sensitivity [141] and a number of other activities possessed [142-154].

Crocetin increases alveolar oxygen transport and enhances pulmonary oxygenation, inhibits skin tumor promotion and protects against oxidative damages [155, 156], have cardiovascular protective effects [157], improves acetylcholine-induced vascular relaxation in hypertension [158], acts as potent antitumor agent [159, 160], inhibits VEGF-Induced angiogenesis [161], antithrombotic [162], inhibits MDA-MB-231 cell invasiveness via downregulation of MMP expression [163], can modulate inflammatory processes [164], involved in the antagonistic effect of CSE on NMDA [165]. Crocetin penetrates the blood brain barrier to reach the CNS [166].

Crocetin and crocetin have been reported to exhibit the inhibitory effect against increase of bilirubin in blood and the deterioration activities of cholesterol and triglyceride levels in serum [167], inhibits apoptosis in PC-12 cells by affecting the function of tumor necrosis factor- α [168], increases the non-rapid eye movement sleep [169] etc [170]. However, crocetin is most effective in neuronal injury [171], enhancing recognition and spatial memory [172], induces anxiolytic-like effects [173], treatment of anxiety and depression [174], antihypertensive and normalizing effect on BP [175], treatment of neurodegenerative diseases such as Alzheimer's [176], antilithiatic effects on ethylene glycol-induced lithiasis [177], attenuated schizophrenia-like behavioural deficits induced by the non-competitive N-methyl-D-aspartate receptor antagonist ketamine [178], alleviate viper venom induced platelet apoptosis [179], anti-ophidian [180], prevents retinal IR-induced apoptosis [181], nullify the arthritis associated secondary complication and arthritis [182, 183], increases tubulin polymerization and microtubule nucleation rate [184], effective in obsessive-compulsive disorder [185], cardioprotective in isoproterenol induced cardiac and diazinon induced cardiac and vascular toxicity [186-188], prevent cardiac dysfunction [189], candidate for the prevention of colitis and inflammation-associated colon carcinogenesis [190], partly protects cells from acrylamide-induced apoptosis [191], antihyperglycemic and antioxidant [192], can be a promising chemotherapeutic agent in cancer treatment [193-195].

The main flavouring content of saffron, safranal (intraperitoneal LD50 values of safranal were 1.48 mL/kg in male mice, 1.88 mL/kg in female mice and 1.50 mL/kg in male rats. Oral LD50 values were 21.42 mL/kg in male mice, 11.42 mL/kg in female mice and 5.53 mL/kg in male rats) have shown some protective effects on different markers of oxidative damage in hippocampal tissue from ischemic rats [196, 197] and treating neurodegenerative disorders such as alzheimer's disease [198], improving effects on crushed-injured sciatic nerve functions [199], neuroblastoma cell line to be highly sensitive to safranal-mediated growth inhibition and apoptotic cell death [200], physically binds to beta actin, cytochrome b-c1 complex sub-unit 1, trifunctional enzyme sub-unit beta and ATP synthase sub-unit alpha and beta [201], have antiabsence seizure property [202], antitussive [203], potent stimulatory effect on beta(2)-adrenoceptors [204], effects histamine (H-1) receptors [205], increases MCS and GTCS latency [206], reduces the extracellular concentrations of glutamate and aspartate [207], invaluable molecule in myocardial ischemia-reperfusion [208], preventive effect on tracheal responses and serum cytokine, total NO and nitrite levels as well as increased Th1/Th2 balance [209], could be potentially useful to retard retinal degeneration in patients with retinitis pigmentosa [210], have antioxidant properties and improves chemically-induced diabetes [211], useful in antidiabetic treatment for type 2 diabetes [212], prevent lung distress by amelioration oxidative damage in streptozotocin diabetic rats [213], suppress the development of age-induced damage [214], reduces prostate cancer cell growth [215] and convulsant activity [216]. Liposome encapsulation enhances the anti-tumor activity of safranal [217].

Saffron carotenoids and safranal have direct interaction with DNA [218, 219], repress the genotoxic potency of methyl methanesulfonate-induced DNA damage [110, 220], protective effect against lower limb ischemia-reperfusion [221], antioxidant [222], have anxiolytic and hypnotic effects [223, 224]. Saffron water extract and safranal reduces both metabolic and behavioral signs of stress [225], could be useful in treatment of different kinds of neuropathic pains and as an adjuvant to conventional medicines [226], have preventive effect on lung

inflammation [227], blood pressure lowering [228-230], effects differential count of WBC [231], on serum inflammatory markers [232], and is cardioprotective [233]. Ethanolic, aqueous extracts of saffron and safranal can inhibit the acquisition and expression of morphine-induced place preference [234, 235]. Crocetin, dimethylcrocetin and safranal all binds with human serum albumin [236]. Safranal and crocin could prevent diazinon induced enzymes elevation and augmentation of some specific biomarkers [237], and reduce diazinon hematological toxicity [238]. Cytotoxicity experiments showed that safranal and crocin mediate cytotoxic response to K562 cells [239]. Heat culinary treatment adversely affects the concentrations of both [240]. Crocin inhibits the fibrillation of apo-alpha-lactalbumin and safranal act in revers [241].

Saffron odor may be effective in treating menstrual distress [242]. Saponins from the Spanish saffron are efficient adjuvants for protein-based vaccines [243]. Petals are comparable to fluoxetine in efficiency to treat the mild-to-moderate depression [244, 245], increases antibody response [246] and have hepatoprotective effect [247]. Style constituents inhibited the breast cancer cell proliferation [248]. Stamen and perianth possess significant antifungal, cytotoxic, and antioxidant activities [249]. Pollen's extract have ability to accelerating wound healing in burn injuries [250]. Petals, stamens and entire flowers is a good source of phenolics, possess free radical scavenging activity and can be used as a food as they are not cytotoxic at concentrations lower than 900 µg/ml [251-254]. Corm, tepal and leaf also possess metal chelating properties [255]. *C. sativus* corms can be considered as a new plant material for curing depression [256].

Studies on the chemical constituents of *Crocus* have been mainly confined to the pigments and the volatile oil and several reviews on these components have been published [257-258]. The chief colouring pigments of saffron are glycosidic derivatives of crocetin, a C-20 carotenoid having seven double bonds and two carboxylic acid units. Colouring pigments namely crocetin (8, 8'-diapo- ψ , ψ' -carotenedioic acid) and bitter tasting picrocrocetin are biosynthesized by the degradation of zeaxanthin [259]. All crocins are esters of crocetin; some of

these are noble to this species. The crocins are present only in stigma of *C. sativus* which fetch a price of around 600 to 1000 US\$ per kg and is one of the costliest spices. All crocins can be detected by UV in distilled water at 440 nm. The major crocins detected in stigma are crocin-1 (all-trans-crocetin-di-(β -D-gentiobioside) ester, crocin-2 (all-trans-crocetin- β -D-gentiobiosyl- β -D-glucosyl ester), crocin-3 (all-trans-crocetin-mono (β -D-gentiobiosyl) ester, crocin-4 (β -D-monoglucoside ester of monomethyl- α -crocetin), crocetin-di-(β -D-glucosyl) ester, trans-crocetin-mono-(β -D-glucosyl) ester [260- 262], 13-cis-crocetin, xanthone-carotenoid glycosidic conjugate named mangicrocin (mangiferin-6'-O-crocetyl-1''-O- β -D-glucoside ester) [263], crocetin-(β -gentiobiosyl)-(β -neopolitanosyl) ester [264] and minor crocins of saffron containing 13-cis-crocetin- β -D-gentiobiosyl- β -D-glucosyl ester and 13-cis-crocetin-di(β -D-gentiobiosyl) ester [265], (4R)-4-hydroxy-2,6,6-trimethylcyclohex-1-enecarbaldehyde 4-O-[β -D-glucopyranosyl (1 $\rightarrow$ 3)- β -D-glucopyranoside] and trans-crocetin-1-al 1-O- β -gentiobiosyl ester [266] etc [267] along with α -crocetin (crocetin), β -crocetin (monomethyl ester of crocetin), γ -crocetin (dimethyl ester of crocetin). However tentatively trans and cis isomers of crocetin (β -D-triglucoside)-(β -D-gentiobiosyl) ester, trans and cis isomers of crocetin (β -D-neapolitanose)-(β -D-glucosyl) ester, and cis crocetin (β -D-neapolitanose)-(β -D-gentiobiosyl) ester were characterized with the help of LC-ESI-MS [268]. From the stigmas of *C. neapolitanus* variety 'blue bird' two new crocetin glycosyl esters named crocetin-(β -gentiobiosyl)-(β -neapolitanosyl) ester and crocetin-di-(β -neapolitanosyl) ester was isolated [269]. Zhang et al. (2008) [270] have synthesized crocetin successfully. The C-40 carotenes, having anticancer activity, present in stigma are α -carotene, β -carotene, lycopene and zeaxanthin [271]. Recently four new crocusatins were isolated by Chia and Tian [272]. Alanine, proline and aspartic acid were the major amino acids in Spain, Italy, Greece and Iranian saffron. Alanine presented the maximum value in Iranian samples with 0.17 $\pm$ 0.02 mg/100 mg of saffron. The highest concentration of proline (0.087 $\pm$ 0.01 mg/100 mg) appeared in Greek samples and the maximum value of aspartic acid was 0.04 $\pm$ 0.01 mg/100 mg in Spanish samples. Greek

and Iranian saffron presented the highest total free amino acid content. 0.50 $\pm$ 0.08 mg/100 mg and 0.55 $\pm$ 0.07 mg/100 mg, respectively. Furthermore, the free amino acid profile enables to differentiate the Iranian samples from the European samples ($p < 0.05$) [273].

In stigma, the percentage composition of various components vary upon the geographical location and several HPLC, HPTLC, UPLC and other methods are reported for analyses and isolation of compounds from saffron [113, 274-306] and several methods and techniques developed for detection of adulterants [307-321]. Best quality saffron contain crocins in the range of 11% to 17% but some papers have reported >23% crocetin glycosides with crocin-1 up to 14%. NIR-FT-Raman spectroscopy is also useful in the investigation of cis-trans isomerization of carotenoids during processing [322]. HPLC/DAD and HPLC/MS analysis of the byproducts of saffron shows that stamens contain mainly kaempferol-3-O-sophoroside, whereas the sepals contain mainly quercetin and methyl-quercetin glycosides [323].

Rychener et al., 1984 isolated a new trisaccharide named neapolitanose (O- β -D-glucopyranosyl-(1 $\rightarrow$ 2)-O-(β -D-glucopyranosyl-(1 $\rightarrow$ 6)-D-glucose [269] from *C. neapolitanus*. Straubinger et al., 1997 [324] isolated two major flavonol glycosides: 7-O-glucopyranoside-3-O-sophoroside and 7-O-sophoroside of kaempferol from methanolic extract of saffron and Harborn et. al. 1984 [325], isolated kaempferol-3-sophoroside and kaempferol-3-rutinoside-7-glucoside from cultivated species. Minerals like magnesium, iron, copper, calcium and zinc are also present in stigma [2].

A bitter compound picrocrocetin [4-(β -D-glucopyranosyloxy)-2,6,6-trimethyl-1-cyclohexene-1-carboxaldehyde] was reported by Buchecker et al. in 1973 [326]. The seven novel aroma precursor from stigma, separated by Straubinger et al. were characterized as (4R)-4-hydroxy-2,6,6-trimethylcyclohex-1-enecarbaldehyde-O- β -D-gentiobioside(1), (4R)-4-hydroxy-2,6,6-trimethyl cyclohex-1-enecarboxylic acid of O- β -D-glucopyranoside (2), 6-hydroxy-3-(hydroxymethyl)-2,4,4-trimethylcyclohexa-2,5-dienone-6-O- β -D-glucopyranoside (3), (2Z)-3-methylpent-2-enedioic acid 1-(1-(2,4,4-trimethyl-

3,6-dioxocyclohexenyloxy)-O- β -D-glucopyranoside-6-yl ester (4), 5(S)-5-hydroxy-7,7-dimethyl-4,5,6,7-tetrahydro-3H-isobenzofuran-1-one-O- β -D-glucopyranoside (5), (1R,5S,6R)-5-(hydroxymethyl)-4,4,6-trimethyl-7-oxabicyclo(4.1.0) heptan-2-one-O- β -D-glucopyranoside (6) and (1R)-3,5,5-trimethylcyclohex-3-enol-O- β -D-glucopyranoside (7). Straubinger et al., also isolated β -D-glucosides of (4R)-4-hydroxy-3,5,5-trimethylcyclohex-2-enone, (4S)-4-hydroxy-3,5,5-trimethylcyclohex-2-enone, (4S)-4-(hydroxymethyl)-3,5,5-trimethylcyclohex-2-enone and β -D-gentiobioside of 2-methyl-6-oxo-hepta-2,4-dienoic acid from methanolic extract [327].

Saffron also contains volatile oil (nearly 0.8%). The major constituent of volatile oil was identified as 2, 6, 6-trimethyl-1, 3-cyclohexadiene-1-carboxaldehyde (safranal), but in vacuum oven dried saffron, 2, 6, 6-trimethyl-4-hydroxy-1-cyclohexen-1-carboxaldehyde (4- β -hydroxysafranal) probably an intermediate, is found in major amounts [328]. Recent study suggests that saffron volatile generation depends on the crocetin ester isomer structure [329] and the related studies need further research [330]. However it was found that CsCCD4a and -b genes had expression patterns consistent with the highest levels of beta-carotene and emission of beta-ionone derived during the stigma development [331]. In red stigmas, β -cyclocitral, the 7, 8 cleavage product of beta-carotene, was highly produced, suggesting the implication of both beta-carotene and zeaxanthin in crocetin formation. As stigmas matured, hydroxy-p-ionone and beta-ionone were produced while safranal, the most typical aroma compound of the processed spice, was only detected at low levels [332]. Safranal further undergoes enzymic reduction and non-enzymic oxidation, decarboxylation and isomerization to 2,6,6-trimethyl-1,4-cyclohexadiene-1-carboxaldehyde (safranal isomer), (4S)-4-hydroxy-3,5,5-trimethylcyclohex-2-enone, (4S)-4-hydroxymethyl-3,5,5-trimethylcyclohex-2-enone, 2,4,4-trimethyl-3-formyl-6-hydroxy-2,5-cyclohexadiene-1-one, 3,5,5-trimethyl-4-hydroxy-2-cyclohexene-1-one, 3,5,5-trimethyl-1,4-cyclohexadiene, 3,5,5-trimethyl-2-cyclohexene-1,4-dione, 3,5,5-trimethyl-2-hydroxy-2-cyclohexene-1,4-dione, 3,5,5-trimethyl-2-cyclohexen-1-one (isophorone), 3,5,5-

trimethyl-3-cyclohexene-1-one (isomer of isophrone), 2,6,6-trimethyl-2-cyclohexen-1,4-dione and also possess 2-phenylethanol, naphthalene, 2-butanoic acid lactone and palmitic acid, stearic acid, oleic acid, linoleic acid, linolenic acid [333, 334]. More new molecules 3,5,5-trimethyl-2-hydroxy-2-cyclohexen-1-one, 5,5-dimethyl-2-methylene-1-carboxaldehyde-3-cyclohexene, dihydro- β -ionone, 2-isopropyliden-3-methyl-3,5-hexadienal, 2,4-dihydroxy-2,5-dimethyl-3(2H)-furan-3-one, 2,3-dihydro-5-hydroxy-6-methyl-4H-pyran-4-one, isomenthone, 2-hydroxyisophorone, trans-3(10)-caren-2-ol, bicyclo[3,2,0]hept-2-ene-4-ethoxy-, endo, 7a-methyl-3-methylenhexahydrobenzofuran-2-one, 1-cyclohexanone, 2-methyl-2-(3-methyl-2-oxabutyl) etc were also characterized from stigma of saffron [335, 336]. The dried hay like aroma of saffron is because of a minor component 2-hydroxy-4, 4, 6-trimethyl-2, 5-cyclohexadien-1-one [337]. Difference in 3, 5, 5-trimethyl-2-cyclohexenone, 2, 6, 6-trimethylcyclohexane-1, 4-dione and acetic acid are useful for recognizing sample origin country [338]. Several techniques currently used to isolate saffron aroma compounds; best two are solvent extraction and headspace techniques [339]. Several studies on chemical composition of essential oils variation on difference in geography and storage are also reported [340-345].

Several papers on its postharvest degradation, yield improvement and assessment of quality and development of value added products have already been published [346-364]. Parabens improves crocetin esters' shelf-life in aqueous saffron extract [365].

Tepals, blue to violet coloured were identified as a promising source of food colouring material. Its hydrolyzed extracts contained flavonol aglycons myrcetin, quercetin, kaempferol and anthocyanidins (delphinidin and petunidin). Glucosyltransferase UGT707B1 is involved in the biosynthesis of flavonol-3-O-sophorosides [366]. Two new and three known anthocyanins were isolated from the blue perianth segments of *crocus antalyensis*: delphinidin-3-O-(β -D-glucopyranoside)-5-O-(6-O-malonyl- β -D-glucopyranoside), petunidin-3,7-di-O-(β -D-glucopyranoside), 3,7-di-O- β -D-glucoside of delphinidin, 3,5-di-O- β -D-glucoside of delphinidin, 3,5-di-O- β -D-glucoside

of petunidin (Norbaek and Kondo, 1999), from *C. chrysanthus* 'Skyline': petunidin-3-O-(6-O-malonyl- β -D-glucoside)-7-O-(6-O-malonyl- β -D-glucoside), malvidin-3-O-(6-O-malonyl- β -D-glucoside)-7-O-(6-O-malonyl- β -D-glucoside), from *C. sieberi* 'Tricolor' (blue flowers): 3,5- β -D-diglucosides of delphinidin, 3,5- β -D-diglucosides of petunidin from *C. chrysanthus* 'Eyecatcher': β -rutosides of delphinidin, 3- β -rutosides of petunidin [367]. Crocusatin-C to D and I to L, (3S),4-dihydroxybutyric acid, 3-formyl-6-hydroxy-2,4,4-trimethyl-2,5-cyclohexadien-1-one, 6-hydroxy-3-(hydroxymethyl)-2,4,4-trimethyl-2,5-cyclohexadien-1-one-6-O- α -D-glucoside, picrocrocin, 4-hydroxy-3,5,5-trimethylcyclohex-2-enone), methylparaben, 4-hydroxyphenethyl alcohol, 4-hydroxybenzoic acid, p-coumaric acid, protocatechuic acid methyl ester, protocatechuic acid, vanillic acid, methylvanillate, 3-hydroxy-4-methoxybenzoic acid, kaempferol 3-O- α -D-(2-O- α -D-glucosyl)glucopyranoside, astragalin, kaempferol, kaempferol 3-O- α -D-(2-O- α -D-6-O-acetylglucosyl)glucopyranoside, kaempferol 3-O- α -D-(6-O-acetyl)glucopyranoside, kaempferol 7-O- α -D-glucopyranoside, kaempferol 3,7-di-O- α -D-glucopyranoside, kaempferol 3-O- α -D-(6-O-acetyl)glucopyranoside-7-O- α -D-glucopyranoside, kaempferol 3-O- α -D-(2-O- α -D-6-O-acetylglucosyl)glucopyranoside-7-O- α -D-glucopyranoside, tribulusterine, harman, 1-(9H- α -carbolin-1-yl)-3,4,5-trihydroxypentan-1-one, nicotinamide, and adenosine were isolated from the petals of *Crocus Sativus* and assessed antityrosinase activity [368]. Volatiles of tepals have 16 compounds; the most abundant were 2-phenylethyl alcohol (15.0%), tetracosane (10.5%), and ethyl hexadecanoate (10.0%) mid heptadecane (9.6%) [369]. Qualitative and quantitative profile of petals flavonoids was established by LC-ESI-MS/MS, UPLC DAD/APCI-MS and antioxidant activity assessed [370-372].

Anthers of several species of *Crocus* were found to contain azulenes and glycosides such as: isorhamnatin-4-O- α -L-rhamnopyranosyl-(1 $\rightarrow$ 2)- β -D-glucopyranoside (crosatoside A), isorhamnatin- β -(p-hydroxyphenyl)ethanol- α -O- α -L-rhamnopyranosyl (1 $\rightarrow$ 2)- β -D-glucopyranoside (Crosatoside B), kaempferol-3-O- β -D-glucopyranosyl-(1 $\rightarrow$ 2)- β -D-glucopyrano

side. Volatiles of anthers have 26 compounds, the major compounds being 2-phenylethyl alcohol (50.4%) and 2-phenethyl acetate (15.4%) [369].

Bulbs of *C. sativus* were found to contain sugars viz. glucose, gentiobiose, neapolitanose and amino acids viz. aspartic acid, glutamic acid, cystine, serine, glycine, proline, phenylalanine, leucine, valine, methionine, saponins viz. Azafrine 1 and Azafrine 2 and several phenolic compounds [373, 374]. Corm is a natural source of fungicides [375].

Glycosides elucidated from leaves of three *Crocus* species are 6-hydroxyluteolin-7-rhamnosyl-glucoside, scutellarein-7-glucoside, scutellarein-7-methyl-ether-6-glucoside, 6-hydroxylutedin-7-glucoside and 6-hydroxyluteolin-7-methyl-ether-6-glucoside. C-Glycoside: 8-C-(O-L-rhamnosido-O-D-glucosido)- β -D-glucopyranosyl-chrisoeriol was identified in *C. reticulatus* [325]

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