Fragaria x ananassa

Scientific Name

***Fragaria x ananassa* Duchesne ex Rozier.**

Synonyms

Fragaria ananassa Duchesne, *Fragaria* x *ananassa* (Weston) Duchesne & Naudin, *Fragaria x ananassa* hort (illeg.), *Fragaria bonariensis* (Juss.) Persoon, *Fragaria calyculata* Duchesne, in Lam., *Fragaria caroliniensis* Duchesne, *Fragaria chilensis β ananassa* Seringe, *Fragaria chilensis δ tincta* Seringe, *Fragaria chilensis γ calyculata* Seringe, *Fragaria chiloensis* var. *ananassa* L.H. Bailey, *Fragaria chiloensis* (L.) Miller var. *ananassa* (Duchesne ex Rozier) Seringe, *Fragaria chiloensis* (Linnaeus) Miller var. *ananassa* Weston, *Fragaria chiloensis* (L.) Duchesne ex Weston var. *ananassa* Weston, *Fragaria chiloensis* (L.) Miller var. *ananassa* (Duchesne ex Rozier) Seringe, *Fragaria* x *cultorum* Thorsrud & Reisaeter, *Fragaria hybrida* Duchesne, *Fragaria grandiflora* Ehrhart, *Fragaria* x *grandiflora* Ehrhart nom. illeg., *Fragaria x magna* auct., *Fragaria tincta* Duchesne, *Fragaria vesca ananassa* Desf., *Fragaria vesca ε ananas* Aiton, *Fragaria vesca* Linnaeus var. *sativa* Linnaeus, *Potentilla* x *ananassa* (Duchesne ex Rozier) Mabbley.

Family

Rosaceae

Common/English Names

Garden Strawberry, Hybrid Strawberry, Large-Fruited Strawberry, Pine Strawberry, Pineapple strawberry, Strawberries, Strawberry.

Vernacular Names

Brazil: Morango, Morango-Grande (Portuguese);
Chinese: Cao Mei, Da Hua Cao Mei;
Czech: Jahoda Aromatická, Jahodník Velkoplodý, Květy Jahodníku, Zahrodna Truskalca;
Danish: Ananasjordbaer, Have-Jordbær;
Dutch: Aardbei, Ananasaardbei, Cultuuraardbei, Grootbloemaardbei;
Estonian: Aedmaasikas;
Finnish: Mansikka, Puutarhamansikka, Tarhamansikka;
French: Fraisier, Fraisier Ananas, Fraise De Culture, Fraisier À Gros Fruits, Fraisier Cultivé;
German: Ananaserdbeere, Erdbeere, Erdbeerstaude, Grosse Erdbeere, Gartenerdbeere, Kulturerdbeere;
Indonesia: Stroberi;

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Italian: Fragola, Frangola Ananasso, Fragola Coltivata, Pianta Di Fragola;
Japanese: Ichigo, Oranda-Ichigo, Sutoroberii;
Malaysia: Stroberi;
Norwegian: Hage-Jordbær;
Polish: Poziomka;
Portuguese: Morangueiro, Morangueiro Agrícola, Morangueiro Comum, Morangueiro Cultivado;
Russian: Zemljanika;
Slovakian: Jahoda Ananásová;
Spanish: Fresa, Fresa Ananás Fresal, Frutilla, Frutilla Ananás, Fresón;
Swedish: Ananassmultron, Smultron, Jordgubbe, Smultronsläktet;
Thai: Satroboery;
Turkish: Ananas Çileği, Bahçe Çileği;
Vietnamese: Cây Dâu Tây, Dâu Tây, Quả Dâu Tây.

Origin/Distribution

*Fra*garia x *ananassa* originated spontaneously in mixed plots of *Fra*garia *virginiana* P. Miller and *Fra*garia *chiloensis* (L.) P. Miller in horticultural areas in north west France and in some botanical gardens of Europe between circa 1715 and 1760. The hybridogenic origin and the octoploid level are the basis for a high variability of all important characters. The five main producers of strawberries in the world are: USA (California), Spain, Japan, Poland and Italy.

Agroecology

Strawberry is cultivated worldwide in the temperate, Mediterranean, taiga and subtropical zones and in the tropical highlands. Most cultivation is between latitudes 28°N and 60°N and S, where summer temperatures hovers between 15°C and 40°C and winter temperatures hovers between 15°C and –40°C. It grows best in full sun, in moist, well-drained, fertile soil. It tolerates partial shade but fruit production is reduced under such conditions. It grows on a wide range of soils from acidic to basic soils and abhors water-logged conditions which cause rots and diseases.

Edible Plant Parts and Uses

The large, aromatic and attractive fruits are used for fresh consumption and are variously processed into preserves, jams and jellies. Strawberry is popularly used in ice cream, milkshakes, sherbets, smoothies, custards and yoghurts. It is also used in pies, tarts and biscuits. Strawberries are also dried for use in cereal bars. Young leaves are also edible raw.

Botany

A herbaceous perennial with a very short stem bearing a rosette of leaves, runners (stolons) and roots, 10–40 cm high (Plate 1). Leaves spirally arranged on 2–10 cm long, soft, pubescent petioles, trifoliolate. Leaflets shortly petiolulate to sessile, obovate or rhombic, pale green and sparsely hairy below, and dark green and subglabrous above, base broadly cuneate on central leaflet, oblique on lateral ones, margin acutely serrated, apex rounded (Plates 1 and 2). Inflorescence cymose, 5-15-flowered, proximally with a shortly petiolate, leaflet-like bract. Flowers bisexual but function as either male or female, 1.5–2 cm across, 5-6-merous; epicalyx segments elliptic-lanceolate with entire margin, sepals segments ovate, petals sub-orbicular, white, stamens 25–37, unequal, sterile in female functional flowers. Carpels numerous, not developed in

Plate 1 Strawberry plants grown in hydroponics

Plate 2 Strawberry fruit and leaves

Plate 3 Ripening strawberries

Plate 4 Harvested red strawberries

male functional flowers. Fruit an aggregate compound fruit or pseudocarp (false fruit), obovoid or ovoid, large up to 4.5 cm by 5.5 cm, composed of numerous ovaries each with a single ovule and crowned by persistent appressed sepals ripening red (Plates 1, 2, 3 and 4). Achenes (true fruit) acutely ovoid, sunken in the swollen torus, 1.25 mm by 1–1.25 mm, smooth.

Nutritive/Medicinal Properties

Nutrient composition of raw strawberry fruit per 100 g edible portion (Saxholt et al. 2008) was reported as: moisture 89.6 g, energy 170 kJ, total protein 0.675 g, total N 0.108 g, total fat 0.6 g, saturated fatty acids 0.05 g, monounsaturated fatty acids, 0.083 g, polyunsaturated fatty acids 0.348 g, available carbohydrate 7.3 g, total sugars 4.57 g, dietary fibre 1.49 g, ash 0.425 g; vitamin A 3.33 RE, β-carotene equivalent 40 μg, Vitamin E (α-tocopherol) 0.45 mg, vitamin K 20 μg, Vitamin B1 (thiamin) 0.021 mg, vitamin B2 (riboflavin) 0.018 mg; niacin equivalents 0.783 mg – niacin 0.6 mg, tryptophan 0.183 mg; vitamin B6 0.047 mg, pantothenic acid 0.34 mg, biotin 1.1 μg, folates 117 μg, vitamin C (L-ascorbic acid) 76 mg; Na 4 mg, K 187 mg, Ca 20.4 mg, Mg 12.4 mg, P 22.7 mg, Fe 0.27 mg, Mn 0.43 mg, Zn 0.1 mg, I 0.6 μg, Cr 0.3 μg, Se 0.2 μg, Ni 3.76 μg; amino acids – isoleucine 34 mg, leucine 54 mg, lysine 49 mg, methionine 14 mg, cystine 5 mg, phenylalanine 31 mg, tyrosine 15 mg, threonine 31 mg, tryptophan 11 mg, valine 39 mg, arginine 56 mg, histidine 16 mg, alanine 42 mg, aspartic acid 133 mg, glutamic acid 125 mg, glycine 35 mg, proline 33 mg, serine 42 mg; sugars – fructose 2.39 g, glucose 2.10 g, saccharose 0.08 g; fatty acids – C16:0 (palmitic acid) 0.05 g, C18:1, n-9(oleic acid) 0.083 g, C 18:2, n-6 (linoleic acid) 0.182 g, C18:3, n-3 (α-linolenic acid) 0.166 g, total n-3 fatty acids (ω 3 fatty acids) 0.166 g and total n-6 fatty acids (ω 6 fatty acids) 0.182 g.

Folate content in 13 different Swedish strawberry cultivars varied from 335 μg/100 g of dry matter (DM) for cv. Senga Sengana to 644 μg/100 g of DM for cv. Elsanta (Strålsjö et al. 2003). The study indicated high folate retention in intact berries during storage until 3 or 9 days at 4°C (71–99%) and also in most tested commercial products (79–103%). On the basis of these data, fresh strawberries as well as processed strawberry products were recommended to be good folate sources. For instance, 250 g (fresh weight) of strawberries (approximately 125 μg of folate) would supply approximately 50% of the recommended daily folate intake in various European countries (200–300 μg/day) or 30% of the U.S. recommendation (400 μg/day).

Vitamin C contents in different strawberry varieties ranged from 56 to 99 mg/100 g fresh weight (Hägg et al. 1995). Vitamin C contents in berries varied during different years. Frozen storage destroyed about 34% of the vitamin C contents in strawberries. The average concentration of vitamin C in strawberries ranged from 32.4 mg/100 g to 84.7 mg/100 g (Hakala et al. 2003). Strawberries were found to be a good source of potassium (1.55–2.53 g/kg), magnesium (0.11–0.23 g/kg) and calcium (0.16–0.29 g/kg). The lead content was in general below its detection limit (0.004 mg/kg). The cadmium level in the Finnish berries was lower than 0.016 mg/kg. Among the four strawberry cultivars studies, there was a 2–5-fold variation for ascorbic acid, chlorogenic acid, ellagic acid, and total antioxidative capacity, measured in both water-soluble and water-insoluble extracts (Olsson et al. 2004). Unripe berries contained lower concentrations of chlorogenic acid and p-coumaric acid and also quercetin and kaempferol compared with riper berries. During cold storage for up to 3 days, relatively few changes in the concentration of the different antioxidants occurred. The dominating sugars in strawberries were fructose and glucose, but considerable amounts of sucrose were also present, and their contents varied among cultivars, giving a predicted glycemic index of about 81. Verbascose, raffinose, and stachyose were found in only minor amounts. The study showed that the concentration of a number of bioactive compounds in strawberries varied according to cultivar, ripening stage, and storage.

Twenty-five defined anthocyanin pigments were detected in strawberries, most of them containing pelargonidin as aglycone; some cyanidin derivatives were also found (da Silva et al. 2007). Glucose and rutinose constituted the usual substituting sugars, although arabinose and rhamnose were also tentatively identified. Some minor anthocyanins showed acylation with aliphatic acids. Anthocyanin-derived pigments, namely 5-carboxypyranopelargonidin-3-glucoside and four condensed pigments containing C–C linked anthocyanin (pelargonidin) and flavanol (catechin and afzelechin) residues were also detected. Total anthocyanin content of strawberries ranged between 200 and 600 mg/kg, with pelargonidin 3-glucoside constituting 77–90% of the anthocyanins followed by pelargonidin 3-rutinoside (6–11%) and cyanidin 3-glucoside (3–10%).

Phenolic compounds detected in strawberries included: p-coumaric acid derivative, ellagic acid, p-coumaroylglucose, quercetin, quercetin 3-glucoside, quercetin 3-glucuronide, kaempferol 3-glucoside, and anthocyanins cyanidin 3-glucoside, pelargonidin 3-glucoside, pelargonidin 3-rutinoside (Gil et al. 1997). Strawberries were reported to contain flavonoids (kaempferol, quercetin, myricetin) and phenolic acids (p-coumaric, caffeic, ferulic, p-hydroxybenzoic, gallic and ellagic acids) with beneficial effects on health as antioxidants and anticarcinogens (Häkkinen et al. 1999; Häkkinen and Törrönen 2000). Total content of the phenolics detected in strawberry cultivars ranged from 42.1 to 54.4 mg/100 g. Ellagic acid was the dominant acid in strawberries where it accounted for 51% of all acids found. Studies found that ellagic acid contents after 3 months of storage at −20°C varied between 31.5 (strawberry ‘Senga Sengana’) and 68.6 mg/100 g FW (fresh weight) (arctic bramble) (Häkkinen et al. 2000). Ellagic acid content in strawberry jam (23.8 mg/100 g FW.) was 80% of that in unprocessed strawberries. The content of ellagic acid in strawberries and red raspberries was reduced by 40% and 30%, respectively, during the 9 months of storage at −20°C.

Seventeen structurally well-defined phenolic compounds including phenylpropanoids, flavonols, flavan-3-ols, and anthocyanins were found in the ripe fruits of two cultivars of the commercial strawberry (*Fragaria* x *ananassa*) as well as in accessions of *F. vesca*, *F. moschata*, and *F. chiloensis* (Muñoz et al. 2011). Metabolic analysis revealed that the majority of the compounds accumulated in a genotype-dependent manner. The presence of biosynthetic enzymes such as phenylalanine ammonia-lyase, cinnamic acid 4-hydroxylase, chalcone synthase, and flavonoid 3′-hydroxylase could partially explain the different levels of polyphenolics observed in the *Fragaria* species.

Both *cis*- and *trans*-resveratrol were detected in strawberry achenes (seeds) and pulp (receptacle tissue). Resveratrol was found to be higher in achenes than in fruit pulp (Wang et al. 2007). The contents of resveratrol in strawberries were affected by genotype variations, fruit maturation, cultural practices, and environmental conditions. High growing temperature (25°C and 30°C) or enriched CO_2 in the atmosphere significantly enhanced resveratrol content of strawberries. Advancing maturation also elevated resveratrol content. The mature pulp and achenes contained higher levels of resveratrol than the immature fruit. Adding compost as a soil supplement or preharvest application of methyl jasmonate (MJ) also significantly enhanced the level of resveratrol in strawberry fruit. Among the plants grown in hill plasticulture, fruits of 'Ovation (B28)', 'Mohawwk', 'Earliglow', and 'B35' had higher amounts of resveratrol than fruits of other genotypes. 'Ovation' contained the highest amount of resveratrol among strawberries grown in matted row, whereas 'Latestar' contained the least. Ten of 14 tested genotypes (all except 'Allstar', 'Delmarvel', 'Northeaster', and 'MEUS 8') had higher amounts of resveratrol when grown in hill plasticulture compared to matted row.

Newly identified sulfur volatiles in strawberries included methyl thiopropionate, ethyl thiobutanoate, methyl thiohexanoate, methyl (methylthio)acetate, ethyl (methylthio)acetate, methyl 2-(methylthio)butyrate, methyl 3-(methylthio) propionate, ethyl 3-(methylthio)propionate, and methyl thiooctanoate (Du et al. 2011). Most sulfur volatiles increased with increasing maturity, with only concentrations of hydrogen sulfide and methanethiol remaining relatively consistent at all five maturity stages. At the white and half red stages, most sulfur volatiles consisted of various alkyl sulfides. At three-quarter red (commercial ripe), full ripe, and overripe stages, the majority of sulfur volatiles consisted of sulfur esters. Most sulfur volatiles increased dramatically between the commercial ripe, full ripe, and overripe stages, increasing as much as 100% between full ripe and overripe. Principal component analysis indicated that sulfur volatiles could be used to distinguish overripe from full ripe and commercial ripe berries.

Strawberries and Health

Strawberries are rich in phenolic compounds that may help defend the body against several diseases and conditions, including cancer, cardiovascular disease, diabetes and neurological decline. Data from numerous scientific studies suggests the antioxidants in strawberries may help reduce levels of oxidized low density lipoprotein cholesterol, a risk factor for cardiovascular disease. Strawberries are rich in flavonoids that may confer cardioprotection by inhibiting platelet aggregation and thromboxane synthesis. Anthocyanins in strawberries may protect the neuronal cells from inflammation associated with declines in cognitive function.

Strawberry fruits have been reported to contain phenolic compounds that have antioxidant, anticancer, antiatherosclerotic and anti-neurodegenerative properties (Seeram et al. 2006a, b). The nature, size, solubility, degree and position of glycosylation and conjugation of food phenolics were found to influence their absorption, distribution, metabolism and excretion in humans. Phenolics in strawberries were identified as ellagic acid (EA), EA-glycosides, ellagitannins, gallotannins, anthocyanins, flavonols, flavanols and coumaroyl glycosides. The anthocyanidins were pelargonidin and cyanidin, found predominantly as their glucosides and rutinosides. The major flavonol aglycons were quercetin and kaempferol found as their glucuronides and glucosides.

In strawberries, the most abundant of the bioactive phytochemicals were reported to be ellagic acid, and certain flavonoids: anthocyanin, catechin, quercetin and kaempferol (Hannum 2004). These compounds in strawberries also possessed potent antioxidant power. Antioxidants help lower risk of cardiovascular events by inhibition of LDL-cholesterol oxidation, promotion of plaque stability, improved vascular endothelial function, and decreased tendency for thrombosis. In addition, strawberry extracts had been shown to inhibit COX enzymes in-vitro, which would modulate the inflammatory process. Individual compounds in strawberries had demonstrated anticancer activity in several different experimental systems, blocking initiation of carcinogenesis, and suppressing progression and proliferation of tumours. Preliminary animal studies had indicated that diets rich in strawberries may also have the potential to provide benefits to the aging brain.

In the Women's Health Study, Sesso et al. (2007) examined strawberry intake for both its prospective association with cardiovascular disease risk in 38,176 women and its cross-sectional association with lipids and C-reactive protein (CRP) in a subset of 26,966 women. They found that strawberry intake was unassociated with the risk of CVD incident, lipids, or C-reactive protein in middle-aged and older women, though higher strawberry intake may slightly reduce the likelihood of having elevated C-reactive protein levels.

Antioxidant Activity

Strawberries like other berries provide unique antioxidants, anthocyanins, which give berries their red and blue hues but also act as potent antioxidants. Specific antioxidants present in strawberries include quercetin, kaempferol, chlorogenic acid, p-coumaric acid, ellagic acid and vitamin C (Olsson et al. 2004).

The phenolic compound found in strawberry fruits were cyanidin-3-glucoside (1), pelargonidin (2), pelargonidin-3-glucoside (3), pelargonidin-3-rutinoside (4), kaempferol (5), quercetin (6), kaempferol-3-(6′-coumaroyl) glucoside (7), 3,4,5-trihydroxyphenyl-acrylic acid (8), glucose ester of (E)- p-coumaric acid (9), and ellagic acid (10) (Zhang et al. 2008). Among the pure compounds, the anthocyanins 1 (7,156 μM Trolox/mg), 2 (4,922 μM Trolox/mg), and 4 (5,514 μM Trolox/mg) were the most potent antioxidants.

The amount of total phenolics varied between 617 and 4,350 mg/kg in fresh berries (blackberries, red raspberries, blueberries, sweet cherries and strawberries), as gallic acid equivalents (GAE) (Heinonen et al. 1998). In the copper-catalyzed in-vitro human low-density lipoprotein oxidation assay at 10 μM gallic acid equivalents (GAE), berry extracts inhibited hexanal formation in the order: blackberries > red raspberries > sweet cherries > blueberries > strawberries. In the copper-catalyzed in-vitro lecithin liposome oxidation assay, the extracts inhibited hexanal formation in the order: sweet cherries > blueberries > red raspberries > blackberries > strawberries. Red raspberries were more efficient than blueberries in inhibiting hydroperoxide formation in lecithin liposomes. HPLC analyses showed high anthocyanin content in blackberries, hydroxycinnamic acid in blueberries and sweet cherries, flavonol in blueberries, and flavan-3-ol in red raspberries. The antioxidant activity for LDL was associated directly with anthocyanins and indirectly with flavonols, and for liposome it correlated with the hydroxycinnamate content. Berries thus contribute a significant source of phenolic antioxidants that may have potential health effects.

On the basis of the wet weight of the fruits (edible portion), strawberry had the highest ORAC activity (15.36 μmol of Trolox equivalents per gram) followed by plum, orange, red grape, kiwi fruit, pink grapefruit, white grape, banana, apple, tomato, pear, and honeydew melon (Wang et al. 1996). On the basis of the dry weight of the fruits, strawberry (153.6 μmol TE per g DM) again had the highest ORAC activity followed by plum, orange, pink grapefruit, tomato, kiwi fruit, red grape, white grape, apple, honeydew melon, pear, and banana. The ORAC of strawberry juice extract was 12.44 μmole TE per g fruit. Fruit and vegetables rich in anthocyanins (e.g. strawberry, raspberry and red plum) demonstrated the highest antioxidant activities, followed by those rich in flavanones (e.g. orange and grapefruit) and flavonols (e.g. onion, leek, spinach and green cabbage), while the hydroxycinnamate-rich fruit (e.g. apple, tomato, pear and peach) consistently elicited the lower antioxidant activities (Proteggente et al. 2002). The TEAC (Trolox Equivalent Antioxidant Capacity), the FRAP (Ferric Reducing Ability of Plasma) and ORAC (Oxygen Radical Absorbance Capacity) values for each extract were relatively similar and well-correlated with the total phenolic and vitamin C contents. The antioxidant activities (TEAC) in terms of 100 g fresh weight uncooked portion size were in the order: strawberry >> raspberry = red plum >> red cabbage >>> grapefruit = orange > spinach > broccoli > green grape approximately/= onion > green cabbage > pea > apple > cauliflower approximately/=tomato approximately/= peach = leek > banana approximately/= lettuce. Blackberries (*Rubu*s sp.) and strawberries (*Fragaria* × *ananassa*) had the highest ORAC (oxygen radical absorbance capacity) values during the green stages, whereas red raspberries (*Rubus idaeus*) had the highest ORAC activity at the ripe stage (Wang and Lin 2000). Total anthocyanin content increased with maturity for all species of fruits. Compared with fruits, leaves were found to have higher ORAC values. In fruits, ORAC values ranged from 7.8 to 33.7 μmol of Trolox equivalents (TE)/g of fresh berries (35.0–162.1 μmol of TE/g of dry matter), whereas in leaves, ORAC values ranged from 69.7 to 182.2 μmol of TE/g of fresh leaves (205.0–728.8 μmol of TE/g of dry matter). As the leaves become older, the ORAC values and total phenolic contents decreased. The results showed a linear correlation between total phenolic content and ORAC activity for fruits and leaves. For ripe berries, a linear relationship existed between ORAC values and anthocyanin content. Of the ripe fruits tested, on the basis of wet weight of fruit, cv. Jewel black raspberry and blackberries were the richest source for antioxidants. On the basis of the dry weight of fruit, strawberries had the highest ORAC activity followed by black raspberries (cv. Jewel), blackberries, and red raspberries.

Aaby et al. (2005) found that strawberries contained 1% achenes on a fresh weight basis; however, they contributed to about 11% of total phenolics and 14% of antioxidant activities in strawberries. Ellagic acid, ellagic acid glycosides, and ellagitannins were the major contributors to the antioxidant activities of achenes. The predominant anthocyanin in the flesh was pelargonidin-3-glucoside, whereas achenes consisted of nearly equal amounts of cyanidin-3-glucoside and pelargonidin-3-glucoside. Phenolic content and antioxidant activity of strawberry achenes were reduced by industrial processing. However, the levels were still high and strawberry waste byproduct could thus be a possible source of nutraceuticals or natural antioxidants. About 40 phenolic compounds including glycosides of quercetin, kaempferol, cyanidin, pelargonidin, and ellagic acid, together with flavanols, derivatives of p-coumaric acid, and ellagitannins, were identified in strawberry fruits (Aaby et al. 2007). Quercetin-3-malonylhexoside and a deoxyhexoside of ellagic acid were reported for the first time. Antioxidative properties of individual components in strawberries were estimated by their electrochemical responses. Ascorbic acid was the single most significant contributor to electrochemical response in strawberries (24%), whereas the ellagitannins and the anthocyanins were the groups of polyphenols with the highest contributions, 19% and 13% at 400 mV, respectively.

Free phenolic contents varied between strawberry cultivars, differing by 65% between the highest (Earliglow) and the lowest (Allstar) ranked strawberry cultivars (Meyers et al. 2003). The water soluble bound and ethyl acetate soluble bound phenolic contents averaged 5% of the total phenolic content of the cultivars. The total flavonoid content of Annapolis was 2-fold higher than that of Allstar, which had the lowest content. The anthocyanin content of the highest ranked cultivar, Evangeline, was more than double that of the lowest ranked cultivar, Allstar. Overall, free phenolic content was weakly correlated with total antioxidant activity, and flavonoid and anthocyanin content did not correlate with total antioxidant activity. Studies by Ozsahin et al. (2011) confirmed that flavonoid ingredients of three different varieties of strawberry (r Camarosa, Selva and Dorit) fruit that had a scavenging effect against the radicals (DPPH* and OH*). Strawberry also inhibited lipid peroxidation, in the group given strawberries, the level of malondialdehyde (MDA)-2-thiobarbituric acid was markedly reduced.

Studies indicated that high oxygen treatments exerted the most effects on fruit quality and antioxidant capacity of strawberry fruit in the first 7 days of storage (Zheng et al. 2007). While fruit quality parameters such as titratable acidity, total soluble solids and surface colour were only slightly affected by differing levels of O2, the higher oxygen concentration treatments significantly reduced decay. Oxygen concentrations higher than 60 kPa also promoted increases in ORAC values, total phenolics and total anthocyanins as well as individual phenolic compounds during the initial 7 days of storage.

The mean total antioxidant activity (TAA) (sum of hydrophilic and lipophilic antioxidant activities) for freeze-dried strawberries based on an 'as consumed' weight was significantly higher compared to fresh, frozen strawberries and jam (Marques et al. 2010). The mean TAA based on dry weight for fresh strawberries was significantly higher than for freeze-dried, frozen and jam. Results concurred with previous studies reporting strawberries to be a valuable source of antioxidants for consumers.

Anthocyanins were detected in two strawberry jams at very low content (Da Silva Pinto et al. 2007). Kaempferol glycosides were the main flavonoids present (from 0.38 to 1.05 mg/100 g fresh weight, FW), while quercetin glycosides were present in the range 0.14–1.20 mg/100 g FW. Free and total ellagic acid content ranged from 0.4 to 2.9 mg/100 g FW, and from 17.0 to 29.5 mg/100 g FW, respectively. Total phenolics varied from 58 to 136 mg/100 g FW, and the antioxidant capacity from 0.55 to 0.76 μmol BHT (butylhydroxytoluene) equivalents/g FW. Taken together, the results indicated that jams could also represent a good source of antioxidant compounds, although compared to the fruit important losses appeared to occur.

Postharvest studies of strawberries at 20°C storage for 3 days showed that pelargonidin-3-glucoside, the major anthocyanin, increased with the increase of shelf life period, while cyanidin-3-glucoside and pelargonidin-3-rutinoside were found at lower concentrations (Goulas and Manganaris 2011). The potent radical scavenging activity, evaluated with four in-vitro assays, showed a higher antioxidant capacity after 3 and 1 day of shelf life. Further, the antioxidant effect of strawberry fruit extracts on lipid substrates and on an emulsion system showed a significant inhibition in the formation of conjugated diene hyperoxides.

The results of studies by Cao et al. (1998) showed that the total antioxidant capacity of serum determined as ORAC, TEAC and FRAP, increased significantly by 7–25% during the 4-hour period following consumption of red wine, strawberries, vitamin C or spinach. The total antioxidant capacity of urine determined as ORAC increased by 9.6%, 27.5%, and 44.9% for strawberries, spinach, and vitamin C, respectively, during the 24-hour period following these treatments. The plasma vitamin C level after the strawberry drink, and the serum urate level after the strawberry and spinach treatments, also increased significantly. However, the increased vitamin C and urate levels could not fully account for the increased total antioxidant capacity in serum following the consumption of strawberries, spinach or red wine. The researchers concluded that the consumption of strawberries, spinach or red wine, rich in antioxidant phenolic compounds, could increase the serum antioxidant capacity in humans.

A recent report published in the American Journal of Clinical Nutrition analyzed over 1,000 foods and beverages for antioxidant capacity (Halvorsen et al. 2006). On the basis of typical serving sizes, blackberries, walnuts, strawberries, artichokes, cranberries, brewed coffee, raspberries, pecans, blueberries, ground cloves, grape juice, and unsweetened baking chocolate were at the top of the ranked list in total antioxidant capacity (AOX) per serving. Strawberries ranked third in total antioxidant capacity per serving, superseded only by blackberries and walnuts which showed higher antioxidant capacity. For comparison, the researchers found that a serving of strawberries provided 3.6 mmol antioxidants/serving while blueberries were 2.7 mmol AOX/serving, sour cherries were 2.2 mmol AOX/serving and oranges, 1.3 mmol/serving.

Anticancer Activity

Ethanol extracts from two strawberry cultivars, Sweet Charlie and Carlsbad, and two blueberry cultivars, Tifblue and Premier fruits strongly inhibited CaSki and SiHa cervical cancer cell lines and MCF-7 and T47-D breast cancer cell lines (Wedge et al. 2001). Strawberry extracts rich in antioxidant enzymes glutathione peroxidase, superoxidedismutase, guaiacol peroxidase, ascorbate peroxidase, and glutathione reductase, inhibited the proliferation of human lung epithelial cancer cell line A549 and decreased tetradecanoylphorbol-13-acetate (TPA) -induced neoplastic transformation of JB6 P+ mouse epidermal cells (Wang et al. 2005). Pretreatment of JB6 P+ mouse epidermal cells with strawberry extract resulted in the inhibition of both UVB- and TPA-induced AP-1 and NF-kappaB transactivation. The results suggested that the ability of strawberries to block UVB- and TPA-induced AP-1 and NF-kappaB activation may be due to their antioxidant properties and their ability to reduce oxidative stress. The strawberries may be highly effective as a chemopreventive agent that acts by targeting the down-regulation of AP-1 and NF-kappaB activities, blocking MAPK signaling, and suppressing cancer cell proliferation and transformation.

The berry extracts (blackberry, black raspberry, blueberry, cranberry, red raspberry and strawberry) rich in phenolics such as anthocyanins, flavonols, flavanols, ellagitannins, gallotannins, proanthocyanidins, and phenolic acids, inhibited the growth of human oral (KB, CAL-27), breast (MCF-7), colon (HT-29, HCT116), and prostate (LNCaP) tumour cell lines at concentrations ranging from 25 to 200 μg/ml (Seeram et al. 2006a). With increasing concentration of berry extract, increasing inhibition of cell proliferation in all of the cell lines were observed, with different degrees of potency between cell lines. Black raspberry and strawberry extracts showed the most significant pro-apoptotic effects against the COX-2 expressing colon cancer cell line, HT-29. Meyers et al. (2003) found that the proliferation of HepG(2) human liver cancer cells was significantly inhibited in a dose-dependent manner after exposure to all strawberry cultivar (Earliglow, Annapolis, Evangeline, Allstar, Sable, Sparkle, Jewel, and Mesabi) extracts, with Earliglow exhibiting the highest antiproliferative activity and Annapolis exhibiting the lowest. No relationship was found between antiproliferative activity and antioxidant content.

Purified ellagitannins from strawberries were found to have antiproliferative activity (Pinto Mda et al. 2010). It was observed that ellagic acid had the highest percentage inhibition of cell proliferation. The strawberry extract had lower efficacy in inhibiting the cell proliferation, indicating that in the case of this fruit there was no synergism. Polyphenol-rich strawberry extract was found to have antiproliferative effect against human cervical cancer (HeLa) cells (McDougall et al. 2008). The most effective extracts (strawberry > arctic bramble > cloudberry > lingonberry) gave EC_{50} values in the range of 25–40 μg/ml of phenols. These extracts were also effective against human colon cancer (CaCo-2) cells. The strawberry, cloudberry, arctic bramble, and the raspberry extracts shared common polyphenol constituents, especially the ellagitannins, which had been shown to be effective antiproliferative agents. Crude strawberry extracts (250 μg/ml) and pure phenolic compounds cyanidin-3-glucoside, pelargonidin, pelargonidin-3-glucoside, pelargonidin-3-rutinoside, kaempferol, quercetin, kaempferol-3-(6′-coumaroyl) glucoside, 3,4,5-trihydroxyphenyl-acrylic acid, glucose ester of (E)-p-coumaric acid (9), and ellagic acid (100 μg/ml) inhibited the growth of human oral (CAL-27, KB), colon (HT29, HCT-116), and prostate (LNCaP, DU145) cancer cells with different sensitivities observed between cell lines (Zhang et al. 2008). OptiBerry, a combination of wild blueberry, wild bilberry, cranberry, elderberry, raspberry seeds, and strawberry, exhibited high antioxidant efficacy as shown by its high oxygen radical absorbance capacity (ORAC) values, novel antiangiogenic and antiatherosclerotic activities, and potential cytotoxicity towards *Helicobacter pylori*, a noxious pathogen responsible for various gastrointestinal disorders including duodenal ulcer and gastric cancer, as compared to individual berry extracts (Zafra-Stone et al. 2007). OptiBerry also significantly inhibited basal MCP-1 and inducible NF-κβ transcriptions as well as the inflammatory biomarker IL-8, and significantly reduced the ability to form hemangioma and markedly decreased

EOMA cell-induced tumour growth in an in-vivo model. Overall, berry anthocyanins triggered genetic signalling in promoting human health and disease prevention.

Studies showed that dietary freeze-dried strawberries effectively inhibited N-nitrosomethylbenzylamine (NMBA)-induced tumorigenesis in the rat esophagus (Carlton et al. 2001). At 30 weeks, 5% and 10% freeze-dried strawberries in the diet caused significant reductions in esophageal tumour multiplicity of 24% and 56%, respectively. A significant decrease in O6-methylguanine levels was observed in the esophageal DNA of animals fed strawberries, suggesting that one or more components in strawberries influenced the metabolism of NMBA to DNA-damaging species.

Fisetin, found in high level in strawberry (Arai et al. 2000) had also been reported to have anticancer activity: against human colon cancer cells (Lu et al. 2005), pancreatic cancer (Murtaza et al. 2009) and prostate cancer (Khan et al. 2008).

The cytotoxic effects of strawberry polyphenol-rich extract were investigated on normal cells and tumour cells namely a human prostate epithelial cell line (P21) and two tumour cell lines (P21 tumour cell line 1 and 2) derived from the same patient, and a normal human breast epithelial cell line (B42) and a tumour line derived from it (B42 clone 16) (Weaver et al. 2009). The strawberry extract was cytotoxic with doses of approximately 5 μg/ml causing a 50% reduction in cell survival in both the normal and the tumour lines. The extracts were also cytotoxic to peripheral blood human lymphocytes stimulated with phytohaemagglutinin but higher levels (>20 μg/ml for 50% reduction in cell survival) were required. After fractionation of the strawberry sample, the cytotoxicity was retained in the tannin-rich fraction and this fraction was considerably more toxic to all cells (normal or tumour cell lines or lymphocytes) than the anthocyanin-rich fraction. Established prostate (LNCaP and PC-3) and breast (MCF-7) tumour cell lines were more resistant to the strawberry extract with concentrations of 50 μg/ml required for 50% reduction in cell survival. From these findings, the researchers concluded that there was little evidence to assume that polyphenols from strawberry had a differential cytotoxic effect on tumour cells relative to comparable normal cells from the same tissue derived from the same patient.

Antimutagenic Activity

Fresh juices and organic solvent extracts from the fruits of strawberry, blueberry, and raspberry inhibited the production of mutations by the direct-acting mutagen methyl methanesulfonate and the metabolically activated carcinogen benzo[a]pyrene (Hope Smith et al. 2004). Juice from strawberry, blueberry, and raspberry fruit significantly inhibited mutagenesis caused by both carcinogens. Ethanol extracts from freeze-dried fruits of strawberry cultivars (Sweet Charlie and Carlsbad) and blueberry cultivars (Tifblue and Premier) were also tested. Of these, the hydrolyzable tannin-containing fraction from Sweet Charlie strawberries was most effective at inhibiting mutations.

Antiangiogenic Activity

The oxygen radical absorbance capacity (OARC) antioxidant values of strawberry powder and grape seed proanthocyanidin extract (GSPE) were higher than cranberry, elderberry or raspberry seed but significantly lower than the other samples studied. Wild bilberry and blueberry extracts possessed the highest ORAC values (Roy et al. 2002). Each of the berry samples studied significantly inhibited both H2O2 as well as TNF α induced vascular endothelial growth factor expression by the human keratinocytes. This effect was not shared by other antioxidants such as α-tocopherol or GSPE but was commonly shared by pure flavonoids. Matrigel assay using human dermal microvascular endothelial cells showed that the edible berries hindered angiogenesis.

Antithrombotic Activity

Strawberry varieties KYSt-4 (Nohime), KYSt-11 (Kurume IH-1) and KYSt-17 (Kurume 58) showed significant antiplatelet activity both in-vitro and, after oral administration, in-vivo (Naemura et al. 2005). Both KYSt-11 and KYSt-17, but not KYSt-4, significantly reduced flow-mediated vasodilation; that is, caused endothelial dysfunction. Significant correlation was found between antiplatelet and antioxidant activities or total phenolic compounds. Of the tested strawberry varieties, KYSt-4, KYSt-11 and KYSt-17 showed significant antithrombotic effect. The dual mechanism of the effect may involve a direct inhibition of both platelet function and antioxidant activities. Among various strawberry varieties tested, a particular variety (KYSt-4, Nohime) showed a significant antithrombotic effects in humans while the experimentally inactive variety (KYSt-10) as well as the relevant control (water) were ineffective (Naemura et al. 2006) Daily intake of an antithrombotic diet may offer a convenient and effective way of prevention of arterial thrombotic diseases.

Antiatherosclerotic Activity

In an 8 weeks randomized controlled trial, short-term freeze-dried strawberry supplementation was found to improve selected atherosclerotic risk factors, including dyslipidemia and circulating adhesion molecules in 27 subjects with metabolic syndrome (Basu et al. 2010). Strawberry supplementation significantly decreased total and low-density lipoprotein cholesterol and small low-density lipoprotein particles. Strawberry supplementation further decreased circulating levels of vascular cell adhesion molecule-1. Serum glucose, triglycerides, high-density lipoprotein cholesterol, blood pressure, and waist circumference were not affected.

Antidiabetic Activity

Results of in-vitro studies suggested the ellagitannins and ellagic acid from strawberries to have good potential for the management of hyperglycemia and hypertension linked to type 2 diabetes (Pinto Mda et al. 2010). Purified ellagitannins had high α-amylase and angiotensin I-converting enzyme (ACE) inhibitory activities. However, these compounds had low α-glucosidase inhibitory activity. In-vitro studies showed that of polyphenols, phenolic acids and tannins (PPTs) from strawberry inhibited glucose transport from the intestinal lumen into cells and also the GLUT2 (glucose transporter −2)-facilitated exit on the basolateral side. Further, pelargonidin-3-O-glucoside ($IC_{50} = 802\ \mu M$) contributed 26% to the total inhibition by the strawberry extract.

Among fruits and vegetable, strawberry is a rich source of the flavonol fisetin, a potent antioxidant. Strawberries contained (160 μg/g) of fisetin 5–10-fold more than apples (26.9 μg/g) and persimmon (10.6 μg/g), and 25–40 fold more than lotus roots (5.8 μg/g), onions (4.8 μg/g) and grapes (3.9 μg/g) (Arai et al. 2000). Studies showed that fisetin or a synthetic derivative may have potential therapeutic use for the treatment of diabetic complications such as kidney failure (Maher et al. 2011). Fisetin lowered the elevation of α-oxoaldehyde methylglyoxal (MG)-protein glycation that was associated with diabetes and ameliorated multiple complications of the disease.

Antiinflammatory Activity

Administration of strawberry, loquat, mulberry and bitter melon fruit juices increased IL-10 production by lipopolysaccharide-stimulated murine peritoneal macrophages in dose-dependent manners (Lin and Tang 2008). Concurrently, the levels of IL-1β, IL-6 and/or TNF-α were decreased. The results suggested that strawberry, loquat, mulberry, and bitter melon juices exhibited a prophylactic effect on LPS-induced inflammation of peritoneal macrophages via increasing anti-inflammatory cytokine and/or decreasing pro-inflammatory cytokines secretions.

In a cross-over placebo study of 24 overweight adults, concurrent consumption of strawberry beverage with the high-carbohydrate, moderate-fat meal (HCFM) significantly increased the postprandial concentrations of pelargonidin sulfate and pelargonidin-3-O-glucoside compared with the placebo beverage (Edirisinghe et al. 2011). The strawberry beverage significantly attenuated the postprandial inflammatory response as measured by high-sensitivity C-reactive protein and interleukin IL-6 induced by the HCFM. It was also associated with a reduction in postprandial insulin response. Overall, the data reflected the favourable effects of strawberry antioxidants on postprandial inflammation and insulin sensitivity. Strawberry ethanol fruit extract at 500 mg/kg showed significant amelioration of experimentally induced inflammatory bowel disease in albino rats, which may be attributed to its antioxidant and anti-inflammatory properties (Kanodia et al. 2011). The extract showed significant prevention of increase in colon weight and disease activity index along with decrease in macroscopic and microscopic lesion score as compared to control group. Significant improvement was observed in the levels of myeloperoxidase, catalase and superoxide dismutase, except glutathione. However, the effect of the extract was significantly less than 5-aminosalisylic acid.

Anti-allergic Activity

The flavonoids isolated from strawberry were found to suppress the degranulation from Ag (antigen)-stimulated rat basophilic leukemia RBL-2H3 cells to varying extent (Itoh et al. 2009). The intracellular free Ca(2+) concentration ([Ca(2+)]i) was elevated by Fc epsilonRI activation, but these flavonoid treatments reduced the elevation of [Ca(2+)]i by suppressing Ca(2+) influx. Kaempferol strongly suppressed the activation of spleen tyrosine kinase (Syk) and phospholipase Cγ (PLCγ). The findings thus suggested that suppression of Ag-stimulated degranulation by the flavonoids was mainly due to suppression of [Ca(2+)]i elevation and Syk activation. The results suggested that strawberry would be of some ameliorative benefit for the allergic symptoms. In another study, the scientists reported that among the eight isolated phenolic constituents of strawberry, linocinnamarin, 1-O-trans-cinnamoyl-β-d-glucopyranose, and cinnamic acid exhibited antigen (Ag)-stimulated degranulation in rat basophilic leukemia RBL-2H3 cells (Ninomiya et al. 2010). Treatment with both linocinnamarin and cinnamic acid markedly suppressed antigen-stimulated elevation of intracellular free Ca(2+) concentration and reactive oxygen species (ROS). Both linocinnamarin and cinnamic acid suppressed Ag-stimulated spleen tyrosine kinase (Syk) activation. These results indicated that inhibition of antigen-stimulated degranulation by linocinnamarin and cinnamic acid was primarily due to inactivation of Syk/phospholipase Cγ (PLCγ) pathways. The findings suggested that linocinnamarin and cinnamic acid isolated from strawberry could be beneficial agents for alleviating symptoms of type I allergy.

Neuroprotective Activity

The cell viability test using the 3-(4,5-dimethylthiazol-2-yl)-2,5-diphenyltetrazolium bromide (MTT) reduction assay showed that strawberry phenolics significantly reduced oxidative stress-induced neurotoxicity (Heo and Lee 2005). Strawberry showed the highest neuronal cell protective effects among the samples. The overall relative neuronal cell protective activity of three fruits by three tests followed the decreasing order strawberry > banana > orange. The protective effects appeared to be due to the higher phenolic contents including anthocyanins, and anthocyanins in strawberries.

Drug Interaction Activity

A new glycoside, 2-β-d-glucopyranosyloxy-4,6-dihydroxyisovalerophenenone (3), was isolated from strawberry fruit along with kaempferol-3-β-D-(6-O-trans-p-coumaroyl) glucopyranoside (1) and kaempferol-3-β-D-(6-O-cis-p-coumaroyl) glucopyranoside (2) (Tsukamoto et al. 2004). Compounds 1 and 2 inhibited activity of a drug-metabolizing enzyme, CYP3A4.

Traditional Medicinal Uses

Strawberry has been used in traditional medicine; both leaves and fruit have appeared in early pharmacopoeias (Grieve 1971). They have been used as laxative, diuretic and astringent.

Leaves are used in tea to treat dysentery. Roots are also astringent and used in diarrhoea. Strawberry is also a useful dentifrice for removing teeth discoloration and cosmetic for skin conditioning.

Ancient Romans used the fruit to treat melancholy, fainting, throat infections, inflammations, fevers, kidney stones, halitosis, gout, and diseases of the blood, liver and spleen.

Other Uses

Strawberry pigment extract can be used as a natural acid/base indicator due to the different colour of the conjugate acid and conjugate base of the pigment.

Comments

Strawberries can be grown from seeds but commercially are propagated from runners (stolons).

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