RASPBERRIES AND RELATED FRUIT

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Raspberries are a high-value crop due to their unique flavor, exacting climatic requirements, high costs of production, and perishability. This article describes the relationships among various raspberry species and relatives, discusses the commercial raspberry industry, describes the morphology, anatomy and chemical composition of fruit, reviews harvesting and handling techniques for fresh fruit, and presents various food uses for the raspberry.

Taxonomy and Commercial Importance

Raspberries are a diverse group of flowering plants that are closely related to blackberries. Both raspberries and blackberries belong to the genus *Rubus*. Taxonomists recognize 12 subgenera within *Rubus*, but only the raspberries *(Idaeobatus)* and blackberries *(Eubatus)* have obtained commercial significance. Species of a third group, the arctic raspberries (*Cylactis*), are harvested from the wild, and are popular in Scandinavia for making liqueurs, but these are not cultivated. The fruit of raspberries detaches from the receptacle when picked, leaving a white torus attached to the plant and a hollow fruit. This characteristic distinguishes them from blackberries in which fruit abscission occurs behind the receptacle.

The genus *Rubus* is a member of the rose family (Rosaceae), which also includes important fruit crops such as apples, pears, cherries, peaches, plums, and strawberries. Wild raspberries occur on five continents, but are most abundant in the Northern Hemisphere. The temperate and subtropical region of eastern Asia is recognized as the centre of origin where the most diversity exists. More than 200 species have been identified, but only a few are important commercially. These include the European red raspberry *(R. idaeus* subsp. *vulgatus* Arrhen.), the North American red raspberry *(R. idaeus* subsp. *strigosus* Michx.), and the black raspberry *(R. occidentalis L.)* of the eastern USA. Hybrids between the red and black raspberry are commonly called purple raspberries because of the fruit and cane color, and these were once given the specific rank of *R. neglectus* Peck. However, most taxonomists do not recognize hybrids as distinct species. Interspecific hybrids with blackberries have also been made; some of these are commercially important, such as Tayberry, Loganberry, Boysenberry and Youngberry.

Several other species within the genus *Rubus* have edible fruit, or have been used by plant breeders to improve cold hardiness and resistance to diseases and insects in raspberries. Examples are *R. glaucus* Benth., a South American tetraploid black raspberry that is probably a raspberry x blackberry hybrid, *R. leucodermis* Torr. and Gr. (the western North American black raspberry), and *R. spectabilis* Pursh. (salmonberry); the Asiatic species *R. coreanus* Miq., *R. phoenicolasius* Maxim. (Japanese wineberry), *R. parvifolius* Nutt. (trailing raspberry), *R. ellipticus* Sm. (golden evergreen), *R. illecebrosus* Focke (strawberry raspberry), *R. kuntzeanus* Hemsl. (Chinese raspberry), and *R. nivens* Thumb.; the Hawaiian species *R. macraei* Gray and *R. hawaiiensis* Gray (Akala berries); and the arctic raspberries of Europe *(R. arcticus L.)* and North America *(R. stellatus* Sm.).

Commercial Industry

Raspberries were first introduced into cultivation in Europe nearly 450 years ago. By the early nineteenth century, more than 20 cultivars of red raspberry were grown in both England and the USA. English cultivars were then exported to the USA, where crosses between them and North American seedlings gave improved cultivars. Red raspberries are the most widely grown, while black raspberries are popular only in certain regions of the eastern USA. The progeny of black and red raspberries have purple fruits and canes; these types are popular in eastern North America. Yellow-fruited *R. idaeus*, caused by a recessive mutation, is also grown on a limited scale for specialty markets. *R. occidentalis* genotypes with yellow fruit are not grown commercially.

The three major raspberry production regions are (1) Russia, (2) Europe (mostly in Poland, Hungary, Serbia, Germany, and the UK), and (3) the Pacific Coast of North America (British Columbia, Washington, and Oregon). Much of the fruit produced in these regions is harvested mechanically and processed. In other production regions, such as eastern North America, nearly all the production is for the fresh market. Many other countries, such as Chile, New Zealand, and Australia, have significant production as they supply the fresh market during winter in the northern hemisphere. World production is estimated at more than 400 000 t.

Patterns of production in North America shifted dramatically in the early 1900s. In 1920, New York State growers (East Coast) harvested more than 4000 ha. The systemic 'mosaic virus disease’ infected most of the planting stock, and the processing raspberry industry collapsed in this region. With the development of tissue culture propagation techniques, virus indexing of nursery stock, and breeding for resistance to the virus vector, the raspberry processing industry redeveloped on the West Coast. In Britain during World War II, little attention was paid to maintaining the health of raspberry stock. It was not until the 1970s that the raspberry industry reorganized with certification programs and heat treatment therapy for the elimination of viruses. Currently, there is interest in both Europe and North America in greenhouse raspberry production to supply local markets during winter and spring.

Varieties

Two types of bearing habits are found in commercial red raspberries. The first type is called a ‘summer-bearing’ habit. Canes originate from either crown buds or adventitious root buds in early spring. Canes elongate during the growing season, forming fruit buds in the axils of leaves in the autumn when temperatures decrease and day lengths shorten. The plants become dormant for winter, then the buds on the cane grow the following spring once the chilling requirement has been fulfilled. The chilling requirement varies considerably among summer-bearing varieties, ranging from a few hundred hrs to more than 1800 hrs. The lateral axillary buds on dormant canes contain both leaf and flower primordia. At the onset of warm weather, buds break and flowering occurs about 6 - 10 weeks later. Fruiting occurs in early to late summer, depending on variety, then the entire cane senesces. While these second year canes (floricanes) are flowering, first year canes (primocanes) are growing from the crown or roots. These primocanes will fruit the following year. More than 40 summer-bearing red raspberries are grown commercially, and these change with the release of new, improved varieties. Among the major varieties originating in North America are ‘Boyne’, ‘Canby’, 'Killarney', 'Meeker', 'Reveille', ‘Taylor’, ‘Titan’, ‘Tulameen’, and ‘Willamette’. The Glen and Malling series are important varieties from the UK. The Scottish Crops Research Institute is the leading institution in the world for raspberry variety development.

The second type of growth habit is called ‘fall bearing’. In some varieties, fruiting laterals will develop from the top of first year primocanes after they reach a certain height, without any chilling. If the growing season is sufficiently long, fruit can be harvested from the upper portion of these canes through autumn. The lower portion of the cane will fruit the following summer, if it is allowed to remain in the field. The major variety worldwide is ‘Heritage’; other important varieties are ‘Amity’, ‘Autumn Bliss’, 'Polana', and 'Autumn Britten.'
At least 13 varieties of black raspberries are grown in North America. The most successful are ‘Allen’, ‘Bristol’, ‘Haut’, and ‘Jewel’. ‘Royalty’ is the most popular purple raspberry. Several yellow or golden raspberry varieties are grown on a small scale for specialty markets.

Morphology and Anatomy of Fruit

Each raspberry flower contains from 60 to 160 ovaries. Each ovary contains two ovules, but one usually aborts after differentiation. About one month after pollination, the ovaries ripen simultaneously to form the fruit.
Fruits ripen in three phases. Pollination is followed by a period of rapid cell division. In the second phase, cell division slows while the embryo develops and the seed coat hardens. Finally, very rapid growth occurs due to cell enlargement. Each phase lasts from 10 to 12 days. Considerable variation in fruit size exists, with a range from 1 to 5 g. Under certain conditions, fruit can exceed 10 g.
As with most climacteric fruit, ethylene production in the raspberry begins in the receptacle when the fruit starts to color, and peaks when fully ripe. Respiration, however, decreases as ripening proceeds. Growth stresses help to fracture the

middle lamella and walls of cortical cells where the fruit attaches to the receptacle. Cell wall breakdown and disintegration are complete when the fruit is fully ripe. The detachment force is small, usually 25 g, when fruits are ripe. A 12-fold difference in detachment force can exist between underripe and overripe fruit. Mechanical harvesters exploit this differential.

The raspberry fruit is not a true berry, but rather an aggregate of many individual drupelets. Each drupelet is anatomically analogous to a cherry with a hard endocarpic seed (pyrene) surrounded by a fleshy mesocarp and an outer exocarp. The fleshy mesocarp is composed of thin-walled, turgid parenchymatous cells. Just below the exocarp is a thin layer of oval, collenchymatous cells. Large seeds are undesirable, but there is a relationship between seed size and drupelet size. Small seeds tend to be associated with small drupelets. An average seed has a mass of about 1 mg, and comprises between 4% and 5% of the total mass of a berry. A 100 g sample of raspberries may contain more than 4000 seeds.

The cohesion of individual drupelets results from the entanglement of unicellular, epidermal hairs that are most abundant on the sides and base of the drupelet. In some black raspberry varieties, fusion of the cuticle or wax also contributes to drupelet cohesion. Drupelets cannot normally be separated without tearing the exocarp. Considerable variation in fruit firmness and drupelet cohesion exists among commercial varieties. If the percentage of developed drupelets is low, then cohesion will be poor. Firmness is related to cell diameter and tissue compactness.

Chemical and Nutritional Composition

Fruit Composition

The main constituent of the raspberry fruit is water (c. 87%). Of the remaining solids, 9% are soluble and the rest insoluble. Pectins compose 0.1 - 1.0% of the soluble fraction, but this amount decreases with ripening due to hydrolysis.
The main sugars are glucose, fructose and a smaller amount of sucrose. These compose the major soluble component of the juice. A typical ripe raspberry fruit will contain 5-6% sugar. Citric acid is the second largest component of the soluble fraction; raspberries contain very little malic acid, but at least 10 other acids in trace amounts. The amount of acid in the fruit increases early in development, and then decreases as the fruit begins to ripen. The balance between the sugars and acids is important for consumer acceptance. A fruit with a low sugar: acid ratio will taste tart; one with a high ratio will taste bland. A typical pH of a ripe raspberry fruit is 3.0 - 3.5; the ratio between sugars and acids (w/w) is approximately 1.0. Fruits grown under warm, dry summers (daytime temperatures near 25 C) are sweeter, less acid, more aromatic, and more highly colored. Hot weather (temperatures greater than 30 C) will reduce the aroma of the fruit, and wet weather will reduce the sugar content.

A large number of volatile compounds are found in raspberry fruit, but most are present at less than 10 ppm and are below the threshold of detection by the human nose. Compounds include alcohols, acids, esters, carbonyls, and ketones.

and other hydrocarbons (naphthalene and related compounds). A particular ketone, 1-(*p*-hydroxyphenyl)-3-butanone, has an odor very characteristic of raspberry.

Considerable changes occur in phenolic compounds as fruits mature. Raspberry juice from ripe fruit contains 0.10 - 0.14% polyphenols, mainly as catechin and chlorogenic, ferulic and neochlorogenic acids.

Raspberry fruits contain small amounts of vitamins; only vitamin C is present at a significant level. Amino acids include alanine, serine, asparagine, glutamic acid, glutamine, (gamma)aminobutyric acid, valine, leucine, and aspartic acid. The high levels of antioxidants and ellagic acid in raspberries have been highlighted in the popular press as public interest in cancer prevention increases. Table 1 presents data on the vitamin and nutrient content of red raspberries.

Fruit Color

The color of raspberry fruit is imparted by anthocyanins. The anthocyanin molecule in raspberry consists of cyanidin and pelargonidin with glucose attached at the 3-position. Additional glucose, rhamnose or xylose sugars may be present in various combinations to give diglycosides or triglycosides. Fruits with a preponderance of pelargonidin glycosides have an orange-red color, as opposed to a deep red color with cyanidin glycosides.

A few major genes control the type and concentration of anthocyanins in the fruit. Fruits with a yellow color are produced when one or more of these genes suppress anthocyanin production. Molecules that are complexed with the anthocyanin also affect color development, and the pH of the fruit has a small effect. During storage, raspberry fruits increase in anthocyanin, darken, and become bluer, partially due to an increase in pH of the cytoplasm.

Handling and Storage of Fresh Produce

Harvest Considerations

Raspberries have one of the highest respiration rates of any fruit. This, coupled with their thin skin and sugary interior, makes them among the most perishable of all fruits. With any given variety, fruit on a bush will ripen over a period of several weeks. Harvesting the same planting frequently (once every two days) is critical. Fruit harvested before it is fully ripe will have a much longer shelf life than fully ripe or overripe fruit, but will be lower in sugar and anthocyanins. The optimum stage of maturity for the raspberry occurs when the berry first becomes completely red, but before any darker hues develop.

Fruit quality for fresh market raspberries usually declines as the season progresses. Marketing channels must be open before the first berries ripen, as these are likely to be the highest quality and have largest size for the season. Berries should not be touched before harvest, and only undamaged berries with good appearance should be placed in the pack. The magnitude of injury caused by human pickers can be so great as to mask any other causes of deterioration.

Overripe or damaged berries should be harvested and discarded because they are susceptible to moulds. *Botrytis* is the most common pathogen of raspberry fruit. Once the mould growing on overripe berries sporulates, large amounts of inoculum will be present to infect other ripening fruit. Overripe berries also attract ants, wasps, and other pests.

Containers holding approximately 150 g of raspberries are typically used. Wide, shallow containers are preferable to deep containers; each should have no more than four layers of raspberries to prevent crushing. Many different types of containers are available, but among the most popular today are plastic clamshells.

Post-harvest Considerations
The objective of post-harvest handling of raspberries is to slow the respiration and transpiration rate of fruit. Respiration and transpiration result in shrinkage and reduced sweetness. Conditions that slow the respiration process are low temperatures, high carbon dioxide levels, and low oxygen in the storage chamber. Transpiration is slowed by high humidity.

Temperature is the easiest environmental variable to modify for extended storage of raspberries. A 5C reduction in temperature reduces the respiration rate by approximately 50%: at 0C the respiration rate is 24 mg of carbon dioxide per kg of raspberry per hour; at 5C the rate is 55; at 10C the rate is 92; at 15C the rate is 135; and at 20C the rate is 200. Rapid movement of cold, humid air through the berries is essential during the first few hours after harvest to slow respiration and prevent deterioration. Large growers may have a precooling facility specifically designed for removing field heat, and an additional storage cooler. For every hour delay in cooling, shelf life can be reduced by one day. Growers take advantage of natural night cooling by harvesting fruit as early in the morning as possible. Mechanical harvesting is often done at night.

Once the berries are cool, containers are wrapped in plastic to prevent water loss from the fruit and condensation on the berries when they are removed from the cooler. The plastic is not removed until the temperature of the berries warms to near the ambient temperature.

The storage room can be maintained as low as -1C. Berries will not freeze at or above this temperature because the sugars in the fruit depress the freezing point. When temperature is lowered, the amount of moisture in the air is reduced. For raspberries, it is critical to maintain a humid atmosphere (90-95%) simultaneously with low temperature to prevent water loss from the fruit. Special cooling units designed to maintain a high humidity are required for raspberries. At 25C and 30% relative humidity, fruits lose water 35 times faster than at OC and 90% relative humidity.

A high carbon dioxide (15-20%) and/or low oxygen (5-10%) atmosphere will reduce respiration and mould growth. *Botrytis, Rhizopus, Alternaria,* *Penicillium* and *Cladosporium* can cause post-harvest fruit rots, depending on storage temperature and carbon dioxide level. Modified atmospheres are used frequently when raspberries are transported long distances. Special semi-permeable wraps are sometimes used by shippers to create a modified atmosphere (low oxygen, high carbon dioxide) within individual containers. Low-oxygen atmospheres will extend the shelf life of raspberries, but bad-tasting aldehydes and alcohols can accumulate in the raspberry fruit when oxygen is limited for an extended period. Off-flavors and browning also develop when raspberries are held under elevated carbon dioxide levels for an extended period. Raspberries are considered to be at moderate risk of physiological injury from high carbon dioxide or low oxygen atmospheres.

The loss of raspberries from harvest to the consumer's table has been estimated at more than 40%. A 14% loss occurs from farmer to wholesaler, a 6% loss occurs from wholesaler to retailer, and 22% is lost between the retailer and consumer. Most of these losses are due to poor handling of berries after harvest.

Fruit Uses

Raspberries have been eaten fresh for thousands for years. Medicinal uses of raspberries are frequently found in the literature, with references to raspberry leaf tea dating to the 16th century. In the early 1900s, black raspberry juice was extracted, concentrated, and used as an edible dye for foodstuffs, such as meat. Raspberries were also dehydrated for long-distance transport. Today, raspberry fruits are either harvested by hand and eaten fresh, or machine-harvested and processed. Approximately 27,000 tons are processed each year. The major products of processing are IQF, block frozen, puree frozen (8 – 15^{o} Brix), juice (about 9^{o} Brix), concentrate, canned, aseptic packs, and preserves. These products are then packaged and sold directly to the consumer, or reprocessed into jam, jelly, dessert topping, pie filling, ice cream, yoghurt and other desserts. Raspberry juice is usually blended with apple, pear, or grape juice because the flavor is too intense for direct consumption. Recently, the demand for fruit wines has increased, and raspberries make one of the better wines. Some wineries add raspberry juice to grape wine to obtain a less expensive raspberry-flavored wine. Raspberry beer is also made at breweries and meaderies. The popularity of raspberries continues to grow as many raspberry-containing products are now on supermarket shelves.

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Table 1. Reported values or ranges of nutrient content in 100 g of fresh raspberries

Nutrient	**Amount**
Water (g)	84-87
Food energy (kcal)	31-49
Protein (g)	0.42-1.40
Fat (g)	0.20-0.55
Carbohydrate (g)	5.8-11.6
Fiber (g)	3.0-7.4
Ash (g)	0.40-0.51

Minerals	**Amount (mg)**
Calcium	22-50
Iron	0.57-1.20
Magnesium	18-30
Phosphorus	12-50
Potassium	130-221
Sodium	0-2.5
Zinc	0.46
Copper	0.07-0.21
Manganese	1.01
Sulphur	17.3
Chlorine	22.3-22.8
Boron	71-125

Vitamins (mg)	**Amount (mg)**
Carotene	0.05-0.08
Thiamin	0.01-0.03
Riboflavin	0.03-0.10
Pantothenic acid	0.24-0.30
Nicotinamide	0.20-1.00
Vitamin B6	0.06-0.90
Vitamin C	13-38
Tocopherols	0.3-4.5