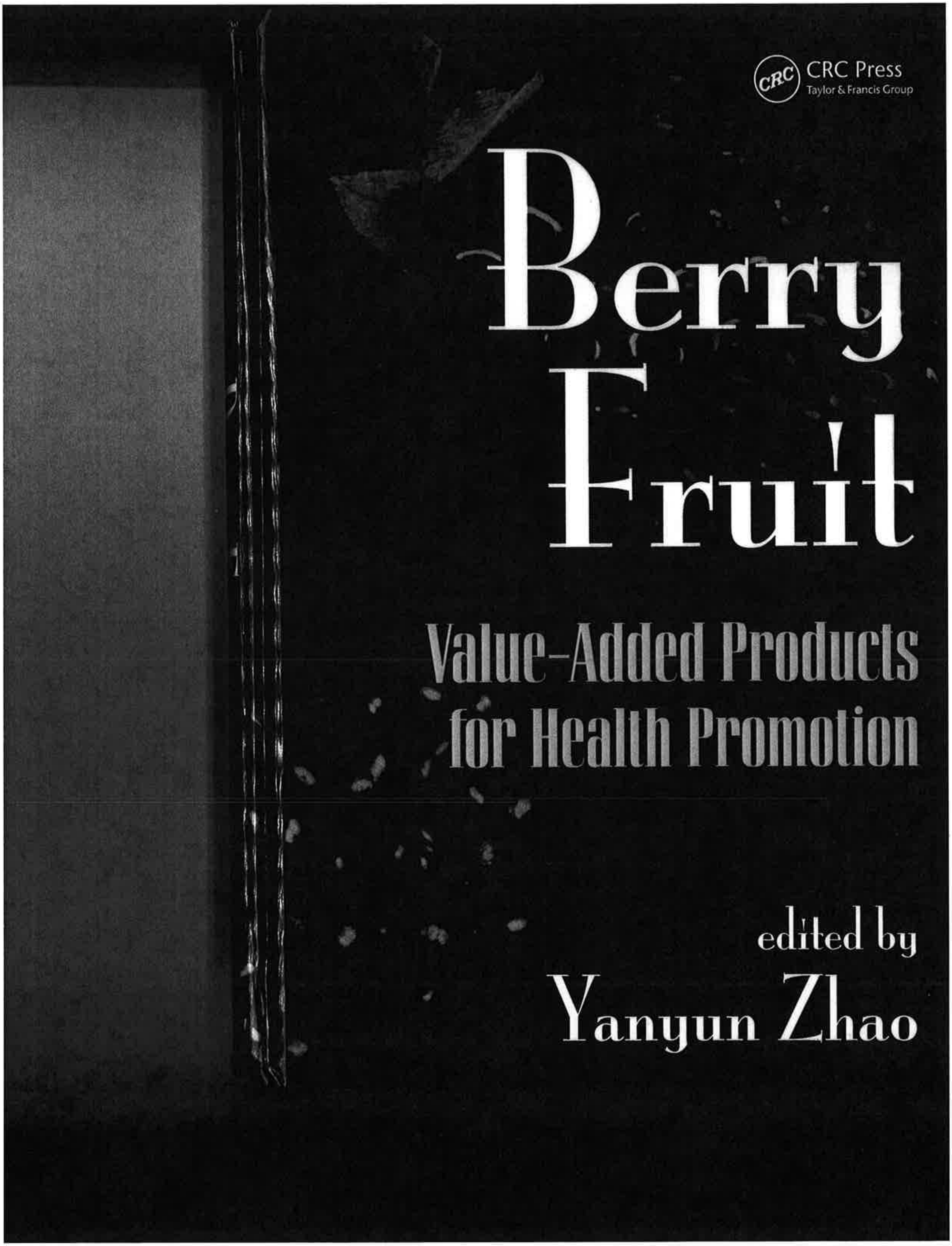

CRC Press
Taylor & Francis Group

Berry Fruit

Value-Added Products for Health Promotion

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2.2 Basic chemical compositions of berries

2.2.1 Carbohydrates

The chemical properties affecting berry flavor are a combination of volatile and nonvolatile compounds that relate to the basic taste, color, texture, and aroma of the fruit. Paramount to overall flavor is the composition and concentration of soluble sugars (sucrose, glucose, and fructose) in relation to organic acids and aroma volatiles (Table 2.1). Fruit harvest must be delayed until the fruit is ripe enough to accumulate sufficient sugars to balance fruit acidity and astringency. Therefore, the timing of the harvest and subsequent postharvest handling conditions are critical because of the relatively short shelf life from harvest to retail distribution. Varying sugar contents in relation to the overall flavor are common factors that relate to cultivar differentiation of strawberries,[4] yet sugar content alone is generally a poor index for the table quality of berry fruits.

The sugar content of ripe berries is generally an equimolar mixture of glucose and fructose, with sucrose concentrations varying based on the degree of ripeness or duration of postharvest storage. In berry plants, the carbon from photosynthesis is most often directed into sucrose for transport via the phloem into starch and other molecules, but starch is not significantly accumulated in berry fruits.[4] Although starch is the primary storage reserve in plants and is formed into starch granules via starch synthesis that polymerizes adenosine diphosphate (ADP)-glucose into higher molecular weight polymers, its storage in berry plants is primarily in the roots, stems, and leaves and it is only present in the early stages of fruit development.[5] As a mixture of two-glycan polymers (amylase and amylopectin), starch is critical for plant growth and development as a reserve energy source. During early berry development, sucrose generally dominates as the primary carbohydrate and is converted to glucose and fructose as ripening progresses, and its conversion and formation can continue during postharvest storage. Sucrose is a nonreducing disaccharide composed of α-D-glucopyranoside and β-D-fructofuranoside and is not a respiratory substrate since it cannot be phosphorylated. Sucrose hydrolysis can occur via an acid-catalyzed reaction, but hydrolysis from invertase activity in berry fruit during maturation and ripening is more likely to yield high concentrations of glucose and fructose in the ripe fruit. Since fructose is characteristically sweeter than glucose or sucrose, its concentration in berries is a desirable organoleptic trait, but total sugar content is generally a better marker for consumer acceptability. Among the factors affecting fruit quality, concentrations of soluble sugars are most commonly measured in relation to the organoleptic factors of sweetness, acidity, astringency, and overall flavor perception. For fresh fruits, the majority of consumers prefer sweeter fruit; this is not only a consequence of higher sugar concentration, but also the balance among acids, aroma active volatiles, and other constituents, such as polyphenolics, that can affect sweetness perception.

2.2.2 Organic acids

The sugar content in berries is counterbalanced by the presence of several predominant organic acids such as citric and malic acid, as well as phenolic acids that can impart bitter or astringent flavors, that are responsible for the basic taste components. The compliment of organic and phenolic acids in berries is responsible for the titratable acidity of the fruit and is commonly measured as an overall index of fruit quality, whereas measurements of pH are often poor indicators of fruit quality characteristics. High concentrations of organic acids in most fruits is also critical for fruit preservation, maintaining a low pH in processed fruit applications such as jams and jellies.[6,7] Organic acids also help to stabilize ascorbic acid and are critical in fruit color by serving to stabilize anthocyanins and extend the shelf life of fresh and processed berries.

2.2.3 Enzymes

The presence of various hydrolase and oxidase enzymes in fresh, damaged, and pureed berries can cause significant quality deterioration, including a loss of color and texture, and the formation of undesirable brown pigments. The presence of oxidizing enzymes has been reported in a variety of berries and is detrimental to color, nutritional components, and overall acceptability. The extent of browning from enzymes such as polyphenol oxidase (PPO; EC 1.14.18.1) or peroxidase (POD; EC 1.11.1.7) is often initially masked by the dark red color of the anthocyanins, but eventually secondary oxidation or condensation reactions occur that alter consumer appeal. The activity of PPO (or POD when hydrogen peroxide is present) catalyzes the oxidation of *o*-diphenolic compounds, which will eventually polymerize into brown pigments. POD was found to increase with fruit development in blueberries[8] and was found ionically bound to the cell wall. The type and amount of oxidase enzymes greatly influences overall fruit quality and may be limited by either enzyme or substrate concentrations, yet berries have an abundance of polyphenolic substrates such as phenolic acids and flavan-3-ols. Techniques to reduce the harmful effects of enzymes include proper refrigeration, reduced oxygen, pH modification, the addition of enzyme inhibitors, or the addition of reducing agents to control secondary oxidation products. In many varieties of berries, PPO and POD are the primary enzymes responsible for destruction of phytochemicals and quality characteristics[8–10] and their activity is related to fruit ripeness, physical damage, and storage temperature.

Cell wall degrading enzymes are also important components affecting overall fruit quality as they relate to ripening and postharvest shelf life. Since berries do not have a protective pericarp and possess only a thin cuticle layer, they are particularly susceptible to wounding and the action of enzymes. Because of the high content of pectic substances in most berries, the action of polygalactouronase (PG; EC 3.2.1.15) to cleave pectin chains is a major depending on the stage at harvest. Sometimes titratable acidity increases in very ripe fruit due to weight loss in storage. Blackberries can develop a red discoloration after harvest. This is theorized to result from harvesting of less mature fruit, resulting in less total pigment and a lower pH or differences in the relative concentration of various pigments.[22]

Harvest maturity is one of the main factors that determines nutritional quality.[23] Freshly harvested fruit generally has a higher vitamin content than stored products, as nutrients begin to be lost as soon as the fruit is harvested.[23] Woods et al.[21] found significant variations among blackberry cultivars in their antioxidative properties (Trolox equivalent antioxidant capacity [TEAC] values), and these were also influenced by harvest maturity. However, Perkins-Veazie and Collins[22] showed that while anthocyanin content in blackberries differed among color stages, there was no difference among cultivars, indicating other compounds are involved in blackberry antioxidant activity. Antioxidant activity declined between the red and dull black ripening stages of blackberry. Vitamin C content either declined or remained unchanged with ripening. Ascorbic acid content ranged from 15.4 to 32.0 mg/100 g among five cultivars of raspberries.[24] In black raspberries, significant changes in the antioxidant capacity occur during the periods surrounding peak ripeness, and this appears to be cultivar dependent.[25] Berry fruit is generally rich in phenolic acids.[26] The fruit phenolic content can be as high as 0.4% in some berries.[27]

High sugars and high acids are required for good berry flavor.[28] High acid with low sugar results in a tart berry, while high sugar and low acid results in a bland taste. When both are low, the fruit is tasteless. Volatile compounds are also important to aroma and flavor, especially ester compounds. Cultivar selection has a large influence on sensory quality. Good correlations were found between sensory sourness and titratable acidity, total phenolics, astringency, and sensory sweetness in strawberry cultivars.[29] Off-flavors were positively correlated with astringency and negatively correlated with strawberry flavor intensity. Blueberry flavor appears to be closely related with acid content, as high acid cultivars were also rated as high in blueberry flavor by sensory panelists and low-acid varieties had low flavor scores.[30] Preharvest and postharvest factors can also influence fruit composition and quality, such as genetic and environmental factors (light, temperature, relative humidity, water supply). Sunny days and cool nights produce better flavored berries than cloudy, humid days and warm nights. Inadequate light intensity reduces ascorbic acid, pH, color, and soluble solids. Excess nitrogen decreases firmness, soluble solids, and flavor.

7.2.2 *Pigments*

Anthocyanins are the main types of pigment responsible for the color of strawberries, blueberries, raspberries, and blackberries. Anthocyanins may be localized in the skin or in the entire fruit and are largely responsible for fruit color, although small amounts of carotenoids are also present. A high

40% of the organic acids present is quinic acid. Organic acids reach peak levels in fruits just as they reach the ripeness stage. The organic acids content tends to decrease in several types of fruit at the end of the ripening period through conversion to sugars. Thus the acid content decreases while the sugar content increases. During storage, the acid is consumed through respiration.

Berry fruits are rich in sugars; however, their levels depend on a variety of factors, such as species, soil, location, and the ripening stage. Sugar levels generally range between 0.5% and 25%. When the fruit is detached from the mother plant, sugar levels decrease due to the increase in respiration rate (cells consume sugar). In maturing fruit, the total sugar content rises for two main reasons: (1) hydrolysis of polysaccharides and (2) formation of sugars as secondary products following acid conversion.

12.2.4 *Microbial destruction kinetics*

Target microorganisms for thermal destruction in a food vary according to the type of food and the composition. Thus these target components and their respective thermal resistances determine the thermal process itself. To establish a thermal processing schedule, the thermal destruction rates of the target microorganisms must be determined under the conditions that normally prevail in the container so that an appropriate heating time can be determined at a given temperature. Furthermore, because packaged foods cannot be heated to process temperatures instantaneously, data on the temperature dependence of the microbial destruction rate are also needed to integrate the destruction effect through the temperature profile under processing conditions.

12.2.4.1 *Survivor curve and* D *value*

Normally the thermal destruction of microorganisms is traditionally assumed to follow first-order inactivation kinetics, with their destruction being a semilogarithmic function of time at a constant temperature, which ignores any lag or tailing phenomena that could be important. In other words, the logarithm of the surviving number of microorganisms in a heat treatment at a particular temperature plotted against the heating time will give a straight-line curve known as the survivor curve (Figure 12.1). The microbial destruction rate at a given temperature is defined as the decimal reduction time (*D* value), which is the heating time in minutes at a given temperature required to cause a one decimal reduction in the surviving microbial population. Graphically this represents the time range between which the survival curve passes through one logarithmic cycle (Figure 12.1). Mathematically it can be written as

$$D = \frac{t_2 - t_1}{\log\left[\frac{N_1}{N_2}\right]}, \tag{12.1}$$

where N_1 and N_2 represent the microbial population at time t_1 and t_2, respectively.