Understanding the developmental physiology, biochemistry, and molecular biology of fruits, vegetables, and flowers has resulted in several technologies that can improve shelf life and quality in agricultural and horticultural products. Postharvest Biology and Technology of Fruits, Vegetables, and Flowers provides comprehensive coverage of this key area of research.

Postharvest Biology and Technology of Fruits, Vegetables, and Flowers offers a firm grounding in basic postharvest science before branching out into the technology and practical applications currently used in crop production. An authoritative resource on the science and technology of the postharvest sector, this book surveys the body of knowledge with an emphasis on the recent advances in the field. Contributed by a global team of expert authors, Postharvest Biology and Technology of Fruits, Vegetables, and Flowers presents information on a wide range of areas, including phospholipase D inhibition technology, and the role of membranes. This book is a must-have reference for postharvest and crop science researchers, as well as professionals and advanced students in these fields.

Key Features:
- Fully covers recent advances in postharvest biology and technology
- Focuses on basic science as well as technology and practical applications
- Applies a physiology, biochemistry, and biotechnology approach to the subject
- Thorough coverage of postharvest science, including current research on phospholipase D and the role of membranes in postharvest quality

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Related Titles:
- Fruit and Vegetables: Harvesting, Handling and Storage, 2e Authored by A.K. Thompson 9781405106191
- Food Biochemistry and Food Processing Edited by Y. H. Hui, Wai-Kit Nip, Leo M.L. Nollet, Gopinadhan Paliyath and Benjamin K. Simpson 9780813803784
- Color Atlas of Postharvest Quality of Fruits and Vegetables Authored by Maria Cecilia do Nascimento Nunes 9780813817521
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Preface

Postharvest practices for the preservation of fruits, vegetables, and flowers are perhaps one of the oldest in human history. With the understanding of the molecular processes that occur during plant senescence, this discipline has developed unique features of its own. Traditionally, postharvest science is considered as an applied science focusing on the physiological aspects of enhancement of shelf life and preservation of quality of horticultural produce. However, in the past two decades, biochemical and molecular biological aspects have been extensively used for analyzing postharvest issues. The present work is a compilation of some of the advances in basic aspects of postharvest science.

Postharvest issues are common around the world. The extent of the loss of horticultural produce after harvest can vary in different countries. In those parts of the world where the methods of agricultural production and storage employ advanced technology, postharvest losses may be minimal, and most of it occurs during the transit of produce from the production site to the destination along the consumer chain. The losses can range from 10 to 20% by volume. In tropics where the production practices are basic and based on day-to-day demand, the postharvest losses can be as high as 50% or over. It is surprising and a bit disturbing to see that fruits are considered as luxury items in some parts of the world. In an era where we consider the consumption of fruits and vegetables as a means of health promotion, postharvest science gets a new meaning. Therefore, to compile the key aspects of postharvest science through international authors has been helpful in addressing some of these issues.

A common theme in most chapters is to link the biochemical and molecular aspects relevant to that topic with postharvest implications. As well, several novel advances in the area have been brought out. The chapters have been organized in such a way that the physiological aspects are linked to the postharvest aspects. The chapters on biochemistry of fruits, followed by flowers, give an overall picture of metabolic processes in horticultural produce. The role of ethylene receptors, 1-MCP technology to block ethylene receptor action changes to cell wall and membrane structure that occur during ripening, biosynthesis of quality components, technologies for shelf life enhancement and quality preservation and quality determination, and nutritional aspects, etc., have been dealt with in the following chapters. Overall, the book covers several topics that are not normally dealt within the books dealing with postharvest science at present. An example will be the chapter on membrane deterioration. The importance of membrane preservation and thus maintenance of membrane compartmentalization is a topic that has been dealt with for over 20 years. It is
difficult to find a book that deals with this topic at present. In addition, we have also described the technology of membrane preservation through the inhibition of phospholipase D, the key enzyme that initiates membrane phospholipid degradation. Phospholipase D inhibition technology using hexanal shows great promise and may serve as a widespread technology for the preservation of organically grown horticultural produce.

While preparing this book, we have given adequate consideration to present the most advanced information on all topics. In a constantly evolving field, this is always not easy; however, the contents are intended for students in the area of horticulture and postharvest science as well as scientists and other professionals. We believe that the contents will enrich the knowledge and provide a fresh angle to several issues in postharvest science. As well, the contributions by internationally reputed experts in the area provide great depth to the individual topics.

The editorial team wishes to thank all the contributors for their great effort and taking time in completing the chapters in an excellent fashion and making this effort into a success. The editorial team also wishes to thank the whole-hearted support, encouragement, and professionalism shown by the publishing team at Wiley-Blackwell during the preparation of the book and bringing it into a successful production.

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Dennis P. Murr
Avtar K. Handa
Susan Lurie
Postharvest Biology and Technology of Fruits, Vegetables, and Flowers
1.1 Importance of fruits, vegetables, and flowers in world economy

The production of fruits, vegetables, and flowers has been an important sector in the total world agricultural output. Although an accurate economic contribution from these segments around the world is difficult to obtain because of the reporting systems, it is estimated that the contribution from these segments could be over US$600 billion. The globalization of trade and free trade agreements have tremendously increased the transaction and transport of these commodities across nations and continents. The weather patterns in the Northern Hemisphere are not suited for the routine production of tropical produce, and therefore fruits such as banana, pineapple, mango, citrus fruits, and tomato are exported to countries in the Northern Hemisphere. The production of flowers in North America has severely been affected by imports from South and Central America. Thus, fruits, vegetables, and flowers are produced and transported from South and Central America and Mexico to the United States and Canada; from Europe to Asia; from India to the Middle East; from Israel and Egypt to Europe; from China to the Pacific region; and from Australia, New Zealand, and South Africa to countries around the world. Canada alone, with a population of nearly 30 million, imports these commodities valued in excess of US$3 billion. The cost of production is a factor that has positively influenced such trades. Countries where labor costs are low can effectively compete with lower-priced produce. These factors have influenced the local economies and agricultural production practices in several countries.

Several international and governmental agencies have kept track of fruits and vegetables available for consumption on a per capita basis. In the United States, the amount of fresh and processed fruits available for consumption increased from 263 lb per person per year in 1976 to 277 lb per person per year in 2003, registering a 0.2% growth (Cook, 2004). Similarly, the amount of fresh and processed vegetables available for consumption increased from 622 lb per person per year in 1976 to 712 lb per person per year in 2003, registering a 0.5% growth (Cook, 2004). Statistics Canada (Food Statistics, 2007) estimates that total fruits available for consumption increased from 117 kg per capita in 1993 to 133 kg per capita in 2004. The per capita availability of vegetables decreased from 187 kg in 1993 to 178 kg in 2004.
1.2 Importance of fruits and vegetables as food

Human evolution was potentially linked initially to the consumption of naturally available fruits and vegetables, which later might have resulted in the selection of preferred plants and varieties for agriculture. The cultivation of grapes and its processing into wine is a classic example of the use of fruits. Fruits and vegetables are also used in traditional medical systems such as Ayurveda. Fruits and vegetables are major sources of several essential nutrients that include vitamins A and C and folic acid. In addition, fruits and vegetables are rich in antioxidants such as carotenoids, polyphenols, and anthocyanins that help combat free radicals produced within the body and the excess production of which has been related to the development of cardiovascular diseases, Alzheimer’s, macular degeneration, and cancers. Fruits and vegetables are integral components of food in all societies; however, in some parts of the world, this is limited due to agricultural collapse or sociopolitical conflicts. Fruits are considered as high-value items and not readily accessible to economically challenged segments of population around the world. With the results from a number of epidemiological studies spanning several countries and continents and population groups showing the relation between increased fruit and vegetable consumption and a reduced risk of developing maladies such as cardiovascular and cerebrovascular diseases, cancer, neurodegenerative diseases such as Alzheimer’s, and macular degeneration. A very positive attitude toward fruit and vegetable consumption has emerged recently, especially in advanced countries. In Canada, fruits and vegetables form an important segment of the food guide. Daily servings of 5 or more comprising a variety of fruits, vegetables, and their processed products have been recommended both by the US and Canadian federal agencies. Flowers are also of great importance as food, examples being cauliflower and broccoli.

A new food guide was released by United States Department of Agriculture (USDA) in 2005 (USDA, 2005; Center for Nutrition Policy and Promotion) providing clear recommendations on fruit and vegetable intake. The recommendations for vegetables include the intake of 2.5 cups equivalent (250 mL per cup) per day or more, comprising dark green vegetables such as broccoli and spinach; orange vegetables such as carrots and sweet potatoes; and dry beans and lentils. A recent Canadian publication (www.healthcanada.gc.ca/foodguide, Health Canada Publication 4651, 2007) shows recommendations ranging from 4 to 6 servings (a serving is 125 mL or 1/2 cup) for children, from 7 to 8 servings for teens, and from 7 to 10 servings for adults. So far as the fruits are concerned, the recommendations are to eat a minimum of 2 cups equivalent every day comprising a variety of fruits and processed products, excluding juice. High sugar content in fruit juices may not be suitable for many health-compromised individuals. Whole fruit blends without added sugar may be an option in such cases. Detailed information is also available on the fruit and vegetable consumption habits of Americans (Lin et al., 2004). In a 2003 estimate (Guthrie et al., 2005), it was found that typical American diet falls severely short of the daily recommendations having fruit consumption equivalent to 1.4 servings per day (less than half of the recommended 4 servings or 2 cups). Vegetable consumption is relatively higher with 3.7 servings per day (below the recommended 5 servings or 2.5 cups per day). However, promotions at several levels (media, organizations, schools, fast food chains, etc.) are resulting in an increased understanding of the importance of fruit and vegetable consumption.
Table 1.1
Production of selected fruits (million metric tons) in major geographical areas of the world

<table>
<thead>
<tr>
<th>Commodity</th>
<th>Africa</th>
<th>Asia</th>
<th>China</th>
<th>India</th>
<th>Europe</th>
<th>North and Central America</th>
<th>USSR</th>
<th>World</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apple</td>
<td>2.02</td>
<td>34.36</td>
<td>25.01</td>
<td>1.47</td>
<td>13.03</td>
<td>5.15</td>
<td>4.42</td>
<td>63.48</td>
</tr>
<tr>
<td>Apricot</td>
<td>0.39</td>
<td>1.19</td>
<td>&lt;0.1</td>
<td>&lt;0.1</td>
<td>0.77</td>
<td>&lt;0.1</td>
<td>0.32</td>
<td>2.82</td>
</tr>
<tr>
<td>Banana</td>
<td>7.44</td>
<td>38.86</td>
<td>6.39</td>
<td>16.82</td>
<td>&lt;0.1</td>
<td>8.95</td>
<td>—</td>
<td>72.46</td>
</tr>
<tr>
<td>Blueberry</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>0.26</td>
<td>0.20</td>
<td>&lt;0.1</td>
<td>2.41</td>
</tr>
<tr>
<td>Cantaloupes and melons</td>
<td>1.45</td>
<td>21.48</td>
<td>15.14</td>
<td>6.45</td>
<td>3.16</td>
<td>2.48</td>
<td>&lt;0.1</td>
<td>28.32</td>
</tr>
<tr>
<td>Cherry</td>
<td>&lt;0.01</td>
<td>0.61</td>
<td>&lt;0.1</td>
<td>&lt;0.1</td>
<td>0.67</td>
<td>0.26</td>
<td>0.26</td>
<td>1.86</td>
</tr>
<tr>
<td>Citrus fruits</td>
<td>11.62</td>
<td>37.07</td>
<td>16.02</td>
<td>4.75</td>
<td>10.24</td>
<td>19.55</td>
<td>&lt;0.1</td>
<td>105.4</td>
</tr>
<tr>
<td>Dates</td>
<td>2.38</td>
<td>4.52</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>6.92</td>
</tr>
<tr>
<td>Grapes</td>
<td>3.73</td>
<td>15.66</td>
<td>5.70</td>
<td>1.20</td>
<td>29.43</td>
<td>6.96</td>
<td>2.55</td>
<td>66.53</td>
</tr>
<tr>
<td>Mango</td>
<td>2.71</td>
<td>21.18</td>
<td>3.67</td>
<td>10.80</td>
<td>—</td>
<td>2.48</td>
<td>—</td>
<td>27.96</td>
</tr>
<tr>
<td>Peach</td>
<td>0.77</td>
<td>7.78</td>
<td>6.03</td>
<td>0.15</td>
<td>4.26</td>
<td>1.62</td>
<td>0.21</td>
<td>15.67</td>
</tr>
<tr>
<td>Pear</td>
<td>0.62</td>
<td>13.38</td>
<td>11.62</td>
<td>0.2</td>
<td>3.33</td>
<td>0.82</td>
<td>0.39</td>
<td>19.51</td>
</tr>
<tr>
<td>Plum</td>
<td>2.29</td>
<td>5.46</td>
<td>4.63</td>
<td>&lt;0.1</td>
<td>2.76</td>
<td>3.76</td>
<td>0.56</td>
<td>9.84</td>
</tr>
<tr>
<td>Pineapple</td>
<td>2.61</td>
<td>8.39</td>
<td>1.46</td>
<td>1.30</td>
<td>—</td>
<td>2.22</td>
<td>—</td>
<td>15.86</td>
</tr>
<tr>
<td>Strawberry</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>1.11</td>
<td>1.15</td>
<td>0.27</td>
<td>3.52</td>
</tr>
<tr>
<td>Tomato</td>
<td>14.63</td>
<td>60.21</td>
<td>31.64</td>
<td>7.60</td>
<td>19.40</td>
<td>17.25</td>
<td>6.39</td>
<td>124.75</td>
</tr>
<tr>
<td>Watermelon</td>
<td>3.77</td>
<td>80.41</td>
<td>69.31</td>
<td>0.25</td>
<td>3.09</td>
<td>3.09</td>
<td>3.36</td>
<td>95.29</td>
</tr>
</tbody>
</table>


1.3 Fruit, vegetable, and flower production around the world

Every part of the world produces fruits and vegetables mostly according to the needs of domestic consumption and export. Table 1.1 summarizes the production statistics of certain selected fruits. Apples, bananas, citrus fruits, grapes, tomatoes, and watermelons are the largest fruit commodities produced. Asia is the largest producer of fruits, with China being the primary producer in the whole world. Although the populations of China and India are nearly the same, fruit production in India is considerably lower than that in China. This may be due to the differences in food habits between the two countries, with the Chinese population consuming a lot more fresh fruits and products. On a per capita basis, Israel produces more fruits than any other country in the world. Europe and North and Central America are also the major players in fruit production. Chile is the major producer of fruits in South America. Overall, the world produces greater than 600 million metric tons of fruits (FAO Statistics, 2005).

World vegetable production also follows similar trends as in fruits (Table 1.2), Asia being the largest producer of vegetables. Again, China is the powerhouse of vegetable production, fresh vegetables being a major component of daily diet. Europe and the Americas also contribute significantly to vegetable production. Altogether, the world vegetable production exceeds 650 million metric tons (FAO Statistics, 2005).

In contrast to fruit and vegetable production, the bulk of flower production is concentrated in specific regions of the world. The production and marketing of flowers and potted ornamentals are intricately linked across the world. A floral bouquet purchased in a local supermarket may be made with miniature carnations from Israel, chrysanthemums from Columbia, boxwood from Oregon, and statice from California. Worldwide trade in floriculture products was estimated to exceed US$7.9 billion in 2001 and was made up of cut
Table 1.2  Production of selected vegetables (million metric tons) in major geographical areas of the world

<table>
<thead>
<tr>
<th>Commodity</th>
<th>North and Central America</th>
<th>South and Central America</th>
<th>Africa</th>
<th>Asia</th>
<th>China</th>
<th>India</th>
<th>Europe</th>
<th>USSR</th>
<th>World</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asparagus</td>
<td>—</td>
<td>—</td>
<td>5.98</td>
<td>5.90</td>
<td>—</td>
<td>—</td>
<td>0.25</td>
<td>0.17</td>
<td>—</td>
</tr>
<tr>
<td>Avocados</td>
<td>0.38</td>
<td>0.45</td>
<td>&lt;0.1</td>
<td>—</td>
<td>—</td>
<td>&lt;0.1</td>
<td>—</td>
<td>1.5</td>
<td>—</td>
</tr>
<tr>
<td>Cabbage</td>
<td>1.77</td>
<td>50.16</td>
<td>34.10</td>
<td>6.00</td>
<td>6.32</td>
<td>2.99</td>
<td>1.5</td>
<td>7.59</td>
<td>69.48</td>
</tr>
<tr>
<td>Cauliflower</td>
<td>0.30</td>
<td>13.04</td>
<td>7.38</td>
<td>4.80</td>
<td>2.11</td>
<td>6.46</td>
<td>—</td>
<td>16.36</td>
<td>3.19</td>
</tr>
<tr>
<td>Carrot</td>
<td>1.13</td>
<td>10.71</td>
<td>8.39</td>
<td>0.35</td>
<td>5.16</td>
<td>2.38</td>
<td>—</td>
<td>23.90</td>
<td>3.19</td>
</tr>
<tr>
<td>Green chillies and peppers</td>
<td>2.20</td>
<td>16.31</td>
<td>12.53</td>
<td>&lt;0.1</td>
<td>2.72</td>
<td>3.05</td>
<td>—</td>
<td>24.98</td>
<td>—</td>
</tr>
<tr>
<td>Cucumbers and gherkins</td>
<td>1.05</td>
<td>33.01</td>
<td>26.56</td>
<td>0.12</td>
<td>4.62</td>
<td>2.11</td>
<td>—</td>
<td>3.12</td>
<td>41.74</td>
</tr>
<tr>
<td>Eggplant</td>
<td>1.41</td>
<td>28.22</td>
<td>17.03</td>
<td>8.2</td>
<td>0.6</td>
<td>0.1</td>
<td>—</td>
<td>30.51</td>
<td>—</td>
</tr>
<tr>
<td>Lettuce</td>
<td>0.27</td>
<td>13.21</td>
<td>11.00</td>
<td>0.79</td>
<td>3.15</td>
<td>5.37</td>
<td>—</td>
<td>22.38</td>
<td>—</td>
</tr>
<tr>
<td>Onions (dry)</td>
<td>5.12</td>
<td>35.30</td>
<td>19.04</td>
<td>5.50</td>
<td>5.57</td>
<td>4.35</td>
<td>3.56</td>
<td>57.59</td>
<td>—</td>
</tr>
<tr>
<td>Potato</td>
<td>15.39</td>
<td>125.71</td>
<td>73.77</td>
<td>25.00</td>
<td>65.16</td>
<td>26.53</td>
<td>73.72</td>
<td>321.97</td>
<td>—</td>
</tr>
<tr>
<td>Sweet potato</td>
<td>11.47</td>
<td>114.99</td>
<td>107.67</td>
<td>0.90</td>
<td>—</td>
<td>1.47</td>
<td>—</td>
<td>129.88</td>
<td>—</td>
</tr>
</tbody>
</table>


Flowers (50%), plants (41%), bulbs (9%), and cut foliage (9%). Over 70% of the production of floriculture crops is concentrated in seven countries: the Netherlands, Columbia, Italy, Belgium, Denmark, the United States, and Ecuador. The Netherlands is the flower capital of the world, with over 50% of world trade (2000 estimate, www.agf.gov.bc.ca/oramentals; British Columbia, 2003) in floriculture products that include produce grown within the Netherlands (farm gate value of US$5.4 billion), as well as floriculture products that are imported and marketed again to various destinations. Columbia was the second largest exporter with an estimated trade at 7.5%, and the rest of the flower-producing countries having export components of 2–3% each. The major flower markets (70%) include Germany, the United States, Britain, France, the Netherlands, and Japan. In the United States and Canada, the production has shifted from flowers such as carnations, chrysanthemums, and roses to speciality cut flowers such as gerbera, *Lizianthus*, snapdragons, and *Alstroemeria* that are relatively more difficult to grow and transport. Also, the cultivation of potted ornamentals is on the rise. According to USDA (2002) estimates, there were over 8,000 ha in floriculture production with a wholesale value estimated at US$4.88 billion. A similar estimate by Statistics Canada (2002) provides a value of Canadian $1.4 billion for Canadian floriculture products.

Flower production has become an important agricultural segment in some Asiatic countries. Again, on a per capita basis, Israel dominates the scene with an estimated 2,750 ha in 2005 (S. Meir, personal communication) and an estimated value of US$250 million. China had nearly 60,000 ha in flower and foliage crop production and India had nearly 35,000 ha according to 1994 estimates, which has expanded recently to include greenhouse production and marketing to the Middle East. Australia and New Zealand are the principal suppliers of floriculture products to Pacific Rim countries and Japan.

### 1.4 Postharvest loss of fruits, vegetables, and flowers

By virtue of their physiological properties, most fruits, vegetables, and flowers are highly perishable commodities. Postharvest losses can occur at any point in the production and
marketing chain, and may range anywhere from >10% in advanced countries to >50% in tropical areas and where storage facilities are limited. China, the largest fruit and vegetable producing country, experiences postharvest losses in the range of 20–25%. Since a large proportion of fruits and vegetables produced are immediately consumed, the loss from long-term storage is considerably reduced. As well, processing can also reduce postharvest losses. China is the largest producer of apple juice concentrate, and this reduces the necessity for large storage facilities. Moreover, such facilities are not suitable since the sizes of farms are rather small. Cold storage facilities may be available for 10–15% of the fruit crops in China. Cooling and transportation facilities are also being developed in China. In India, the problem of storage for pulses is reduced by letting the fresh fruits mature and dry. Several fruits from the cucumber family are ripened, after which they can be stored for months without specialized storage facilities. In countries such as India and China where the weather is tropical and subtropical, fruits and vegetables characteristic to these climates are produced. As well, the production of many of such commodities is seasonal, and this reduces the necessity of long-term storage. Thus, it is common to have peaks of availability for fruits such as apple, orange, pear, banana, mango, and guava spread throughout the year. Even then, postharvest loss of 50% or greater is common as the storage facilities at the local vendors are limited and good quality products are hard to find (e.g., apple).

1.5 Strategies to improve quality

A recent understanding among the growers on the effect of growing conditions on the quality of produce has brought a welcome change in the attitude toward the goals of production. Simply producing a commodity in large amounts need not assure the optimum postharvest quality of the produce. In general, the quality of a produce cannot be enhanced through adopting postharvest storage technologies. The quality of a produce is determined by the growing conditions, nutritional regimes, and the genetic potential of the particular variety. Thus, increased attention is being given to these attributes. Several novel postharvest technologies developed in recent years have the potential to maintain the high quality of produce during subsequent storage at optimal conditions. These include active modified atmosphere and dynamic controlled atmosphere. In addition, there is growing concern about food safety, which is also being addressed in the postharvest area. Growers in Europe and those in other countries who export to Europe are now required to implement the standards of Good Agricultural Practice. These standards are to ensure the safety and quality of fresh produce and require accountability and traceability of produce entering the European market. This means that the farmer must keep a record of the irrigation, fertilization, and pest management treatments that he applies; the packinghouse, exporter, and the shipper must record the treatments given at the packinghouse and storage conditions of the produce along the distribution chain. It also requires safety and cleanliness conditions for the workers in the farms and packinghouse. The producer and exporter must be examined by an external evaluator to ensure that Good Agricultural Practice is being implemented.

The necessity for traceability has led to the development of barcodes and radiofrequency identification stickers that can trace a commodity from “farm to fork.” Some farms and packinghouses now have barcodes on each container in the orchard that is read as it enters the packinghouse and is weighed and checked. Radiofrequency identification systems have
been given to both orchard pickers and packinghouse workers. As fruit is packed, the packer prints a label that includes a barcode, grower, count, date and time, pack house and variety details, and packer. This enables fruit to be traced back to the orchard and row from which it was harvested and to know all the steps it took along the way to the consumer.

In the area of produce quality, packinghouses have units of quality assessment, where samples of the produce entering the packinghouse as well as along the packing line are examined for quality. Recent innovations are instruments that can determine various aspects of quality nondestructively. On many packinghouse lines, currently fruit is automatically graded for color and blemishes by online cameras that photograph the fruit and send it to the proper sorting line. This is combined with sorting for weight or size by automatic weighing cups that send different sizes to different lines. Newer technologies include near-infrared spectrometers that can examine internal quality, particularly soluble solids or sugars, as well as acoustic instruments that can measure firmness. These are now being supplied in new packinghouse lines, and in addition, hand-held instruments are in development for use in orchards to determine picking date.

Biotechnological approaches are also useful for enhancing the shelf life and quality of fruits, vegetables, and flowers, but the public acceptance of this technology is limited. Several information sites describing the optimal storage procedures have also increased the importance and understanding of postharvest storage (e.g., Sydney Postharvest Laboratory, www.postharvest.com.au/; www.usda.org).

1.6 Future prospects

Demographic and socioeconomic factors are the major influencing trends that affect fruit and vegetable consumption in the United States (Guthrie et al., 2005). Rising income and education levels as well as increasing average age of the population may also influence this trend. In the United States, an increase in Hispanic population is predicted to increase the consumption of tomato and its products. By the year 2020, per capita intake of potatoes and french fries is expected to drop by 8–9%. The consumption of lettuce (+5.1%), tomatoes (+1.3%), and other vegetables (+3.6%) is expected to increase during the same period. Among fruits, the consumption of grapes (+5.1%), apples (+7.8%), citrus fruits (+7.4%), and other fruits (+7%) is anticipated to increase by the year 2020. However, an increased tendency to eat outside the home may tend to reduce the fruit intake marginally, as such a habit tends to promote the intake of lettuce and potato products marginally. In Canada, the United States, and Europe, a large increase in Asian population is anticipated to increase the consumption of fruits and vegetables native to Asia. Another important trend in fruit and vegetable production is organic farming. It is generally believed that fruits and vegetables grown organically are more nutritious and the production of organic fruits and vegetables is increasing yearly. Farmers’ markets and pick-your-own operations have increased the diversity of fruit and vegetable production and marketing. Sustainable and environment-friendly production methods are increasingly being applied in most countries. Addition of fruit components to processed food (cereals, yogurt, etc.) has become a common trend in the processing industry. Thus, several socioeconomic factors are driving the importance of fruit and vegetable consumption in a positive direction, and this in turn will influence the patterns of production, storage, and distribution of fruits and vegetables.
References


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Chapter 2

Common Fruits, Vegetables, Flowers, and Their Quality Characteristics

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2.1 Introduction

Fruits and vegetables as well as their processed products have become mainstream human dietary choices in recent days, primarily because of several epidemiological studies showing various health benefits associated with the consumption of fruits, vegetables, and their processed products. Fruits and vegetables share several common structural and nutritional properties and also characteristic differences due to differences in their biochemical composition. Fruits, in general, are attractive organs for vectors involved in seed dispersal, and thus have evolved features such as enhanced color, attractive flavor, and taste. Consequently, the developmental and biochemical processes within a fruit are programmed to achieve this goal. The term vegetables is more or less arbitrary, comprising products such as leaves, petioles, stems, roots, tubers, and fruits of cucurbits (e.g., gourds, melons, squash, and pumpkin) and Solanaceae members (e.g., tomato and eggplant). Morphologically, fruits develop from the ovary, the seed-bearing structure in plants. The developmental processes in fruits are influenced by fertilization, and the hormonal changes induced in the ovary leads to gene expression and biochemical changes resulting in the characteristic fruit that may vary in ontogeny, form, structure, and quality. Fruits originate from different parts of the ovary. Pome fruits such as apple and pear develop from the thalamus of the flower. In drupe fruits such as cherries, peaches, plums, and apricots, the ovary wall (mesocarp) develops into the fruit enclosing a single seed. Berry fruits, such as tomato and grape, possess the seeds embedded in a jellylike pectinaceous matrix, with the ovary wall developing into the flesh of the fruit. Citrus fruits belong to the class known as hesperidium, where the ovary wall develops as a protective structure surrounding the juice-filled locules that are the edible part of the fruit. In strawberry, the seeds are located outside the fruit, and it is the receptacle of the ovary (central portion) that develops into the edible part. Most vegetables are leaves, petioles, or stems containing chlorophyll, or roots, tubers, or fruits that predominantly contain storage components such as starch. Examples include potato and eggplant (Solanaceae), gourds (Cucurbitaceae), several types of yams (Dioscoreaceae and Araceae), vegetables of leaf and flower origin (cabbage, broccoli, cauliflower—Cruciferae), and unripe fruits of leguminous plants such as peas and beans (Leguminosae). The nutritional and food qualities of fruits and vegetables arise as a result of the accumulation of components derived from the intricate biochemical pathways (Kays, 1997).
2.2 Developmental characteristics of fruits and vegetables

Fruit ripening is characterized by several marked physiological and biochemical changes resulting in the coordinated development of complex characteristics. Following pollination and fertilization, the fruit develops in size leading to the ripening process, which results in the development of ideal organoleptic characters such as taste, color, and aroma that are important quality-determining features. Fruits that are used as vegetables are harvested early prior to their ripening. The physiological process of ripening occurs rapidly when the fruit is mature, and beyond a certain stage, harvested fruits undergo rapid deterioration in quality. Ideally, fruits are harvested at an optimal physiological stage or maturity characteristic to the type of fruit, after which appropriate storage procedures can be adopted for preserving the shelf life and quality of the fruits. Fruits do not ripen fully showing the appropriate quality characteristics if picked at a young stage before the attainment of physiological maturity. Citrus fruits are allowed to fully ripen before they are harvested. Avocado fruits do not ripen if left on the tree and start ripening only after harvest. Irrespective of the nature of the produce whether it is fruits, vegetables, or flowers, various technologies such as cold storage, controlled atmosphere storage, and inhibition of hormone and enzyme action are adopted to slow down the metabolic processes to provide an optimal quality produce for marketing and consumption. Advances in the biochemistry and molecular biology of the fruit ripening process have enabled the development of biotechnological strategies for the preservation of postharvest shelf life and quality of fruits, vegetables, and flowers.

Several metabolic changes are initiated after the harvest of fruits and vegetables. In the case of vegetables, harvesting induces stress responses through reduced availability of water and nutrients, wounding, and exposure to shelf life enhancing storage methods such as cooling. In most cases, these changes help the produce to enhance the shelf life. In the case of fruits, an increase in the biosynthesis of the gaseous hormone ethylene serves as the physiological signal for the initiation of the ripening process. In general, all plant tissues produce a low, basal, level of ethylene. During the ripening process, some fruits evolve large amounts of ethylene, sometimes referred to as an autocatalytic increase in ethylene production, which occurs in conjunction with an increase in respiration referred to as the respiratory climacteric. Fruits are generally classified into climacteric or nonclimacteric types on the basis of the pattern of ethylene production and responsiveness to externally added ethylene. The climacteric fruits characteristically show a marked enhancement in ethylene production and respiration, as noticeable by the evolution of carbon dioxide. By contrast, the nonclimacteric fruits emit a considerably reduced level of ethylene. (For a list of fruits showing climacteric or nonclimacteric pattern of ripening, see Kays, 1997, General Reading.) In climacteric fruits such as apple, pear, banana, tomato, and avocado, ethylene evolution can reach 30–500 ppm/(kg h) (parts per million, microliter per liter), whereas in nonclimacteric fruits such as orange, lemon, strawberry, and pineapple, ethylene levels usually range from 0.1 to 0.5 ppm/(kg h) during ripening. Climacteric fruits respond to external ethylene treatment by an early induction of the respiratory climacteric and accelerated ripening in a concentration-dependent manner. Nonclimacteric fruits, on the other hand, show increased respiration in response to increased levels of ethylene concentration without showing acceleration in the time required for ripening. Vegetables produce very low amounts of ethylene most of them with less than 0.1 μL/(kg h), with slightly higher levels as
in cassava (1.7 μL/(kg h)), breadfruit (1.2 μL/(kg h)), and cucumber (0.6 μL/(kg h)) when measured at 20–25°C.

After the initiation of ripening or harvest, several biochemical changes occur in fruits and vegetables. As some of these changes such as the development of color, flavor, and sweet taste are desirable for fruits, any sort of quality changes are ideally not desired in vegetables. Thus, strategies for the preservation of shelf life and quality in fruits and vegetables could be entirely different. It is important to know the biochemical differences between fruits and vegetables and several biochemical pathways that operate in these tissues to develop ideal conditions of storage for the preservation of shelf life and quality.

2.3 Biochemical parameters of quality

There are two major aspects that define the quality of a produce: the first being the inherent biochemical characteristics that provide the color, flavor, texture, and taste to the produce and the second being the consumer perception. The application of postharvest technologies tends to maximize these quality characteristics, though application of some technologies may not provide the optimal quality produce for the consumer. During ripening, activation of several metabolic pathways occurs, often leading to ideal changes in the biochemical composition of fruits. The stage of development in a fruit determines its biochemical composition and the quality-defining parameters. Color is perhaps the first parameter that attracts a consumer to a produce. Hence, fruits that show enhanced yellow-orange-red hue are preferred by the consumer. The composition of anthocyanins and carotenoids in a fruit will determine its color quality characteristics. Consumers also associate the depth of color with the taste, though this is influenced by practical experiences. In general, fruits that are bright red are also sweet. Some of the exceptions include sour cherries and red currants. Brightly colored fruits also tend to possess the ideal texture. Flavor is also an important component to the quality perception, and the degree of ripeness determines the level and types of flavor components such as esters and terpenoids emitted from the fruit. Aroma is derived from several types of compounds that include monoterpenes (as in lime, orange), ester volatiles (ethyl, methyl butyrate in apple, isoamyl acetate in banana), simple organic acids such as citric and malic acids (citrus fruits, apple), and small-chain aldehydes such as hexenal and hexanal (cucumber). In fruits such as mango, pineapple, strawberry, and grape, the ripening process is associated with the conversion of stored organic acids and starch into sugars, and enhanced evolution of flavor components. The presence of off-flavors resulting from the presence of certain aldehydes (e.g., acetaldehyde) may negatively impact quality perception, whereas other aldehydes such as hexanal tend to enhance the green flavor and consumer preference of vegetables. The evolution of sulfur volatiles in crucifer vegetables (e.g., broccoli and cabbage) and Allium vegetables (onion, garlic) is characteristic to their quality. In a similar way, the evolution of essential oils in Lamiaceae members (mint, oregano, rosemary, etc.) also attracts consumers. Fruits and vegetables contain a large percentage of water, which can often exceed 95% by fresh weight. Texture and the degree of softness are determined by the amount of water contained in the produce and the ability to retain that water during postharvest storage. The degradation of cell wall components and the cell membrane negatively affects the rigidity of the tissue in fruits providing the softness that consumers prefer (degradation of stored starch in banana), though excessive degradation of these components reduces the shelf life of the fruits drastically. Most vegetables
are preserved to maximize the high textural integrity, and loss of water from vegetables negatively affects their quality. The consumers are increasingly becoming aware of the disease-preventive and health-restoring roles of fruits and vegetables, because of which they are classified as functional foods. Many quality-determining components are also regarded as important functional food ingredients (nutraceuticals) that include soluble and insoluble fibers, color components such as anthocyanins and carotenoids, several polyphenolic components, and sulfur-containing components in crucifer and Allium vegetables. Fruits in general contain large amounts of fibrous materials such as cellulose and pectin. The breakdown of these large polymers into smaller water-soluble components during ripening leads to fruit softening as observed during the breakdown of pectin in tomato and cellulose in avocado. Secondary plant metabolites are major ingredients of fruits. Anthocyanins are the major color components in grapes, blueberries, apples, and plums; carotenoids, specifically lycopene and carotene, are the major color components in tomatoes, and these components provide the health benefits to consumers through their antioxidant property and ability to influence metabolic processes within the human body. Fruits are also rich in vitamin C, which is a strong antioxidant. Vegetables such as asparagus are rich in glutathione, another component in the antioxidant defense system. Lipid content is quite low in fruits; however, fruits such as avocado and olives store large amounts of triacylglycerols (oils). The amounts of proteins are usually low in most fruits. Several aspects that influence fruit and vegetable quality are discussed by Shewfelt and Bruckner (2000).

It is interesting to note that a majority of edible fruits and vegetables tend to group in certain families. For instance, some of the edible fruit-dominated families include Annonaceae, Rosaceae, Myrtaceae, Rutaceae, Oxalidaceae, and Anacardiaceae among the dicots. Bananas and plantains are the major monocot fruits (Musaceae). The major dicot vegetable families include Fabaceae, Solanaceae, Cruciferae, Cucurbitaceae, Compositae, Umbelliferae, Lamiaceae, and Dioscoreaceae. Monocot families such as the Liliaceae and Araceae are rich in vegetables. The following are some specific characteristics of fruits and vegetables.

2.4 Fruits

2.4.1 Rosaceae

The family Rosaceae dominates the scene with a variety of fruits having distinct physiological and nutritional characteristics. Rosaceous members are cultivated primarily in the subtropic and temperate regions. Unripened fruits are tart and the ripened fruits are in general sweet with varying degrees of acid content, which imparts the sour sweet taste to the fruits. The fruits are also rich in polyphenolic components such as anthocyanins, vitamin C, and soluble as well as insoluble fiber, which make them extremely important for consumption. The fruits of the Rosaceae include blackberry, raspberry (Rubus sp.), strawberry (Fragaria ananassa), plum (Prunus sp.; European plum—Prunus domestica; Japanese plum—Prunus salicina; American plum—Prunus Americana, etc.), prune (P. domestica), nectarine and peach (Prunus persica), cherry (sweet cherry—Prunus avium; sour cherry—Prunus cerasus), apple (Malus domestica), pear (Pyrus communis), quince (Cydonia oblonga), loquat (Eriobotrya japonica), etc. Apples have a very long shelf life when stored under appropriate controlled atmosphere conditions. Pears are usually stored below 0°C for a time period
without controlled atmosphere, after which they can be brought to room temperature (RT) for ripening. Most of the soft rosaceous fruits such as the berries, cherries, plums, prunes, and peaches have a short storage life and are highly perishable.

### 2.4.2 Rutaceae

Rutaceae is another family with several members that provide edible fruits. Some of these include pomelo (*Citrus maxima*), grapefruit (*Citrus paradisi*), orange (bitter orange—*Citrus aurantium*; sweet orange including Valencia orange and navel orange—*Citrus sinensis*), mandarin (*Citrus reticulata* or *Citrus nobilis*) including the tangerine, clementine, Satsuma mandarin, tangor, tangelo and the ugli fruit, lemon (*Citrus limon*), lime (*Citrus aurantifolia*), and citron (*Citrus medica*). Pomelo and citron are very large weighing over 10 lb. The citrus fruits can be stored in a cool dry place. For longer shelf life, they can be stored between 35 and 50°F (between 45 and 50°F for grapefruit) in well-ventilated bags.

### 2.4.3 Ericaceae

Blueberry (lowbush blueberry—*Vaccinium angustifolium*; highbush blueberry—*Vaccinium corymbosum*) and bilberry (*Vaccinium myrtillus*) are important members. These berries are rich in anthocyanins, have strong antioxidant property, and are considered as functional foods. The berries are also moderately acidic and not very sweet, and hence ideal for diabetic population. The berries are very fragile and do not store very well for long periods. The ripe berries are harvested, and ideally, they can be frozen to preserve the nutrients as soon as they are picked. Cranberry fruits (*Vaccinium macrocarpon* and *Vaccinium oxycoccos*), on the other hand, can be stored in perforated plastic bags for a considerable period in the cold or stored frozen. The fruits are processed into juice, sauce, fruit flavored pieces, etc. Just as blueberry and bilberry, cranberries are very rich in anthocyanins and proanthocyanidins. They are strong antioxidants as well as help prevent urinary tract infections.

### 2.4.4 Vitaceae

Grapes are one of the major fruits consumed fresh and processed into wine, jams and jellies, powder, raisins, etc. Grapes are one of the oldest cultivated plants known, dating back to over 7,000 years. There are three major species: the European grapes (*Vitis vinifera*) or their grafts that are cultivated around the world for producing wine grapes, the North American grapes (*Vitis labrusca* and *Vitis rotundifolia*), and the hybrid grapes. Grapes are primarily used for winemaking, fresh consumption, or producing raisins apart from other processing uses such as juice and jam production. Varieties such as the Concord (purple black), the Niagara (green), and the Catawba (red) are *labrusca* varieties. Several locally produced varieties exist in different parts of the world. Some of the European varieties include the Cardinal, the Muscat, and the Lival, which are blue or black grapes. Common North American varieties include the Concord, the Flame, the Ruby (red seedless), and Thompson (green seedless). The skin becomes easily separated from the pulp in the North American grapes. The grapes do not store very well and may undergo anaerobic fermentation if stored too long. They are processed immediately. Table grapes can be stored in the cold in perforated plastic bags for 1–2 months.
2.4.5 Other fruit families

Some of the other common dicot fruits include cherimoya \((Annona cherimola, Annona squamosa, Annonaceae)\), durian \((Durio zibethinus, Bombaceae)\), jackfruit \((Artocarpus heterophyllus, Moraceae)\), rambutan \((Nephelium lappaceum, Sapindaceae)\), litchi \((Litchi chinensis, Sapindaceae)\), longan \((Dimocarpus longan, Sapindaceae)\), persimmon \((Diospyros virginiana, D. kaki, Ebenaceae)\), papaya \((Carica papaya, Caricaceae)\), kiwi fruit \((Actinidia chinensis, Actinidiaceae)\), pomegranate \((Punica granatum, Punicaceae)\), guava \((Psidium guayava, Myrtaceae)\), mangosteen \((Garcinia mangostana, Guttiferae)\), mango \((Mangifera indica, Anacardiaceae)\), sapodilla (sapota) \((Manilkara sapota, Sapotaceae)\), and currants \((Ribes rubrum, Ribes sativum, Ribes vulgare, etc.; red currant; Ribes nigrum—black currant; Saxifragaceae)\). These fruits have characteristic qualities.

Annona fruits are highly flavorful and are highly perishable. Ripe fruits become damaged within days and produce off-flavors. The fruits are sometimes picked before ripening for transportation. Durian fruits are large \((\sim10–15\text{ lb})\), thorny, resembling jackfruits and are cultivated primarily in Southeast Asia and are well known for the foul smell of the fruits, composed by a variety of compounds including organosulfur compounds. Jackfruits are popular in South India and Sri Lanka. They are thorny on the outside and when ripened are highly flavorful. The fruits on some trees can weigh over 100 lb. The fruits contain latex, which can be removed by edible oils such as coconut oil. The fruit is an aggregate fruit with several fruitlets containing seeds that are rich in protein and can be consumed after cooking. Ripe fruits do not store well for more than 3–4 days uncut. Rambutan, again from Southeast Asia, is a 2–3 inches long hairy fruit and is highly perishable. The pulpy interior is edible. Litchi, originally cultivated in southern China, is a popular fruit. Removing the leathery skin in ripe fruits exposes a fleshy interior that is edible. Litchis have a reasonably long shelf life, but are best when consumed fresh. Papaya, originally native to South America, is cultivated worldwide. The flesh of ripe fruits is initially hard, but becomes soft as ripening progresses. The skin and flesh contain a latex that contains proteases, and young fruits are sometimes used as meat tenderizers. Flesh from mature fruits can also be cooked and consumed. Papayas also contain heterocyclic compounds similar to piperazine and are sometimes consumed to protect from intestinal worms. Ripe fruits of papaya have a very short shelf life. At present, kiwi fruit is widely cultivated around the world. The fruit is a berry, 3–4 inches long, and is covered by a brownish skin. The green flesh along with the seeds in ripened fruits can be eaten and tastes slightly acidic and tart. Unripe fruits can be stored for 2–3 weeks. The kiwi fruits also contain proteases and can be used as a meat tenderizer. Pomegranate, with a history of over 4,000 years, is cultivated widely and is well known for its medicinal properties. The fruits are covered with a leathery skin containing multiple chambers filled with juicy pulpy red crimson–colored seeds that are sweet with slight sour tart taste. The skin contains proanthocyanidins and polyphenols having very strong antioxidant activity. Although not consumed, the skin is commonly used in traditional medicine in India. Pomegranates have good postharvest shelf life \((2–3\text{ weeks at RT})\) and are easy to handle. Guava is becoming more popular with several new varieties. The ripe fruits have a pleasant flavor and sweet taste. The seeds are hard, and new seedless varieties are being cultivated. The ripe fruits have a very short shelf life. Some varieties have a red-colored interior like a melon and are rich in carotenoids. Mango has become an increasingly accepted fruit in the Western world. Several varieties
with excellent quality characteristics are available. Mango fruits have an extremely pleasant flavor and ripe fruits are very sweet. The shelf life of ripe fruits at RT may not exceed a week. The fruits of sapota are similar to kiwi fruits in appearance, with a leathery brown skin. When ripened, the fruits have a pleasant flavor and are extremely sweet. The fruits have a 1–2 weeks’ shelf life at RT. The currants are nutritionally rich (vitamin C, minerals, anthocyanins) fruits gaining in popularity. The fruits are sour and are processed for juice or jams. The ripe fruits will stay on the plant for 2–3 weeks. Once harvested, they decay very fast.

Some of the other major fruit crops include plantains (*Musa paradisiaca*, Musaceae), pineapple (*Ananas comosus*, Bromeliaceae), and dates (*Phoenix dactylifera*, Palmaceae). The starchy interior of plantains is consumed in several African countries as a staple food. The mature fruit ripens after harvest or on the plant and does not store well. The fruit overripens and decays within a week. The ripe fruit is soft and rich in sugar and pectin. Pineapples have become very popular as an edible fruit, and a large amount of harvested fruits are processed. The fruits are harvested when mature, and during ripening, the stored organic acids are converted to sugars. Again, pineapple may store for 2–3 weeks when kept in a cool room. Date fruits, on the other hand, can be stored for a considerable length of time and are traditionally transported to several countries from the Middle East.

### 2.5 Vegetables

#### 2.5.1 *Allium* vegetables

*Allium* vegetables belong to the family Liliaceae. These include chive (*Allium schoenoprasum* and *Allium tuberosum*), leeks (*A. porum*), garlic (*Allium sativum*), onion (*Allium cepa*), and shallot (*Allium ascalonicum*). Native to Central Asia, onions are perhaps the largest consumed of these vegetables and have been in cultivation for over 5,000 years. Onions are biennials, cultivated as annuals, and harvested at various stages of maturity to provide green leafy vegetables or when matured to provide the bulbs. During growth and maturation, food is stored in the leaf to form the fleshy, juicy edible bulb. The pigmentation in the skin in dry onion bulbs characterizes them into red, purple, yellow, brown, and white varieties with differing pungency, taste, and flavor. White and red onions are mild and sweet. Onions are harvested when the leaves wilt and outer leaf layers of the bulb become dry.

After harvest, the dry onions are dormant for a period, and depending on the storage period required, onions may be irradiated to prevent sprouting. The shelf life is longer in pungent varieties as the sulfur components may help deter the attack by pathogens. The yellow onions have a shelf life of 2–3 months in a cool dry place, whereas the red onions have a shelf life of only 2–4 weeks. Onions are not refrigerated or stored along with potatoes.

Garlic is another member of the *Allium* family with well-denoted properties of taste, flavor, and pungency. It is widely used for its medicinal properties. The bulb is a cluster of “cloves” that may vary in number. Although white garlic is common, there are varieties with pink and purple color on the skin. Garlic is best stored around 0°C at a relative humidity not greater than 60%, and can give a shelf life of 6 months or more. Chives and leeks can be stored for 2 weeks in the refrigerator.

A characteristic feature of the *Allium* family is its pungency. This property originates from the presence of sulfur-containing compounds. These precursor components such as
S-alk(en)yl cysteine sulfoxide and sulfonic acid are stored in a compartmentalized form stored in the vacuole. When the cells are ruptured, the precursor molecules react with a cytosolic enzyme allinase, releasing a number of volatile components that include thiosulfonates, thiosulfonates, disulfides, and sulfonic acids. Allicin, alliin, diallylsulfide, and ajoene are volatile components present in onion and garlic products. Lachrymatory factors (thiopropanal S-oxide, C$_2$H$_5$—CH═SO) are generated by the action of allinase on the precursor molecules such as allicin and alliin (Block et al., 1992). Despite their pungent nature, Allium vegetables contain several nutraceuticals, and consumption of these vegetables, in general, is regarded as a healthy choice.

2.5.2 Crucifer vegetables

Just as the Allium family, Cruciferae is rich in vegetables with several nutraceuticals showing wide-ranging health benefits. Some of the commonly used crucifer vegetables include turnip (Brassica rapa), radish (Raphanus sativus), rutabaga (Brassica napus var. napobrassica), cabbage (Brassica oleracea), kohlrabi (B. oleracea), cauliflower (B. oleracea var. botrytis), and broccoli (B. oleracea var. italica). Most of the crucifer vegetables appear to have originated in the Mediterranean and was consumed over 4,000 years ago by the Egyptians and Babylonians. There are several types of radishes that include the red, black, and white radish. The radish stores the essential oil in the surface cell layers of the tuber, which provides the pungency to the vegetable. The radishes are best stored unwashed in perforated plastic bags around 4°C after removal of the leaves and usually stores for a week to 10 days. Turnips have a better storage life. Rutabaga (rotabaggar in Swedish) originated as a cross between savoy cabbage and turnip in Scandinavia and was used as a staple food source during food scarcity. It is more pungent than turnip, and can be stored in a perforated plastic bag at 4°C or for months if waxed. Cabbages, cauliflower, and broccoli are potentially the most widely used crucifer vegetables today, leaves being the nutritional source in cabbage and florets being the nutritional source in cauliflower and broccoli. Cauliflower can be stored unwashed in a perforated plastic bag at 4°C for a week to 10 days. Broccoli is highly perishable, and the quality deteriorates rapidly even at low temperatures within days. Controlled atmosphere storage can extend the shelf life of broccoli over 2 months.

2.5.3 Umbelliferae vegetables

Umbelliferae (Umbellaceae) is another vegetable-rich family. In addition to the tuberous vegetables, the seeds from the plants are valuable food sources with health regulatory properties. The major vegetables of this family include parsnip (Pastinaca sativa), carrot (Daucus carota var. sativa), celeriac (Apium graveolens var. rapaceum), celery (Apium graveolens var. dulce), and fennel (Foeniculum vulgare). Carrot and parsnip roots can be stored for a considerably long period in cold. Carrots can be stored for over 6 months at near-zero temperatures. Storing along with fruits and vegetables that evolve ethylene gas causes the development of bitter taste in carrots. The leaf bases of celery and fennel are used as vegetables and have a shelf life of 1–2 weeks in the refrigerator. Celeriac, often called celery roots, can be stored refrigerated for several weeks.