1
Postharvest Handling and Preparation of Foods for Processing

Alistair S. Grandison

1.1
Introduction

Food processing is seasonal in nature, both in terms of demand for products and availability of raw materials. Most crops have well-established harvest times – for example, the sugar beet season lasts for only a few months of the year in the United Kingdom, so beet sugar production is confined to the autumn and winter, yet demand for sugar is continuous throughout the year. Even in the case of raw materials that are available throughout the year, such as milk, there are established peaks and troughs in volume of production, as well as variations in chemical composition. Availability may also be determined by less predictable factors, such as weather conditions, which may affect yields or limit harvesting. In other cases demand is seasonal, for example, ice cream or salads are in greater demand in the summer, whereas other foods are traditionally eaten in the winter months, or even at more specific times, such as Christmas or Easter.

In an ideal world, food processors would like a continuous supply of raw materials, whose composition and quality are constant and whose prices are predictable. Of course this is usually impossible to achieve. In practice, processors contract ahead with growers to synchronize their needs with raw material production.

The aim of this chapter is to consider the properties of raw materials in relation to food processing, and to summarize important aspects of handling, transport, storage, and preparation of raw materials prior to the range of processing operations described in the remainder of this book. The bulk of the chapter will deal with solid agricultural products including fruits, vegetables, cereals, and legumes, although many considerations can also be applied to animal-based materials such as meat, eggs, and milk.

Food Processing Handbook, Second Edition. Edited by James G. Brennan and Alistair S. Grandison.

1.2 Properties of Raw Food Materials and Their Susceptibility to Deterioration and Damage

The selection of raw materials is a vital consideration to the quality of processed products. The quality of raw materials can rarely be improved during processing, and while sorting and grading operations can aid by removing oversize, undersize, or poor-quality units, it is vital to procure materials whose properties most closely match the requirements of the process. Quality is a wide-ranging concept and is determined by many factors. It is a composite of those physical and chemical properties of the material which govern its acceptability to the ''user.'' The latter may be the final consumer, or more likely in this case, the food processor. Geometric properties, color, flavor, texture, nutritive value, and freedom from defects are the major properties likely to determine quality.

An initial consideration is selection of the most suitable cultivars in the case of plant foods (or breeds in the case of animal products). Other preharvest factors (such as soil conditions, climate, and agricultural practices), harvesting methods and postharvest conditions, maturity, storage, and postharvest handling also determine quality. These considerations, including seed supply and many aspects of crop production, are frequently controlled by the processor or even the retailer.

The timing and method of harvesting are determinants of product quality. Manual labor is expensive, therefore mechanized harvesting is introduced where possible. Cultivars most suitable for mechanized harvesting should mature evenly, producing units of nearly equal size that are resistant to mechanical damage. In some instances, the growth habits of plants (e.g., pea vines, fruit trees) have been developed to meet the needs of mechanical harvesting equipment. Uniform maturity is desirable as the presence of over-mature units is associated with high waste, product damage, and high microbial loads, while under-maturity is associated with poor yield, lack of flavor and color, and hard texture. For economic reasons, harvesting is almost always a ''once over'' exercise, hence it is important that all units reach maturity at the same time. The prediction of maturity is necessary to coordinate harvesting with processors' needs, as well as to extend the harvest season. It can be achieved primarily from knowledge of the growth properties of the crop combined with records and experience of local climatic conditions.

The ''heat unit system,'' first described by Seaton [1] for peas and beans, can be applied to give a more accurate estimate of harvest date from sowing date in any year. This system is based on the premise that growth temperature is the overriding determinant of crop growth. A base temperature, below which no growth occurs, is assumed, and the mean temperature of each day through the growing period is recorded. By summing the daily mean temperatures minus base temperatures on days where mean temperature exceeds base temperature, the number of ''accumulated heat units'' can be calculated. By comparing this with the known growth data for the particular cultivar, an accurate prediction of harvest date can be computed. In addition, by allowing fixed numbers of accumulated heat units between sowings, the harvest season can be spread, so that individual fields may be harvested at peak maturity. Sowing plans and harvest date are determined by negotiation between the growers and the processors, and the latter may even provide the equipment and labor for harvesting and transport to the factory.

An important consideration for processed foods is that it is the quality of the processed product, rather than the raw material, that is important. For minimally processed foods, such as those subjected to modified atmospheres, low dose irradiation, mild heat treatment, or some chemical preservatives, the characteristics of the raw material are a good guide to the quality of the product. For more severe processing, including heat preservation, drying, or freezing, the quality characteristics may change markedly during processing. Hence, those raw materials which are preferred for fresh consumption may not be most appropriate for processing. For example, succulent peaches with delicate flavor may be less suitable for canning than harder, less flavorsome cultivars, which can withstand rigorous processing conditions. Similarly, ripe, healthy, well-colored fruit may be perfect for fresh sale, but may not be suitable for freezing due to excessive drip loss while thawing. For example, Maestrelli [2] reported that different strawberry cultivars with similar excellent characteristics for fresh consumption, exhibited a wide range of drip loss (between 8 and 38%), and hence would be of widely different value for the frozen food industry.

1.2.1 Raw Material Properties

The main raw material properties of importance to the processor are geometry, color, texture, functional properties, and flavor.

1.2.1.1 Geometric Properties

Food units of regular geometry are much easier to handle and are better suited to high-speed mechanized operations. In addition, the more uniform the geometry of raw materials, the less rejection and waste will be produced during preparation operations such as peeling, trimming, and slicing. For example, potatoes of smooth shape with few and shallow eyes are much easier to peel and wash mechanically than irregular units. Smooth-skinned fruits and vegetables are much easier to clean and are less likely to harbor insects or fungi than ribbed or irregular units.

Agricultural products do not come in regular shapes and exact sizes. Size and shape are inseparable, but are very difficult to define mathematically in solid food materials. Geometry is, however, vital to packaging and controlling fill-in weights. It may, for example, be important to determine how much mass or how many units may be filled into a square box or cylindrical can. This would require a vast number of measurements to perform exactly, and thus approximations must be made. Size and shape are also important to heat processing and freezing, as they will determine the rate and extent of heat transfer within food units. Mohsenin [3] describes numerous approaches by which the size and shape of irregular food units may be defined. These include the development of statistical techniques based on a limited number of measurements and more subjective approaches involving visual comparison of units to charted standards. Uniformity of size and shape is also important to most operations and processes. Process control to give accurately and uniformly treated products is always simpler with more uniform materials. For example, it is essential that wheat kernel size is uniform for flour milling.

Specific surface (area/mass) may be an important expression of geometry, especially when considering surface phenomena, such as the economics of fruit peeling, or surface processes such as smoking and brining.

The presence of geometric defects, such as projections and depressions, complicate any attempt to quantify the geometry of raw materials, as well as presenting processors with cleaning and handling problems, and yield loss. Selection of cultivars with the minimum defect level is advisable.

There are two approaches to securing optimum geometric characteristics: first, the selection of appropriate varieties, and second, sorting and grading operations.

1.2.1.2 **Color**

Color and color uniformity are vital components of the visual quality of fresh foods, and play a major role in consumer choice. However, it may be less important in raw materials for processing. For low-temperature processes, such as chilling, freezing, or freeze drying, the color changes little during processing, and thus the color of the raw material is a good guide to suitability for processing. For more severe processing, the color may change markedly during the process. Green vegetables such as peas, spinach, or green beans change color on heating from bright green to a dull olive green. This is due to the conversion of chlorophyll to pheophytin. It is possible to protect against this by addition of sodium bicarbonate to the cooking water, which raises the pH. However, this may cause softening of texture, and the use of added colorants may be a more practical solution. Some fruits may lose their color during canning, while pears develop a pink tinge. Potatoes are subject to browning during heat processing due to the Maillard reaction. Therefore, some varieties are more suitable for fried products, where browning is desirable, than for canned products, in which browning would be a major problem.

Again there are two approaches: procuring raw materials of the appropriate variety and stage of maturity, and sorting by color to remove unwanted units.

1.2.1.3 **Texture**

The texture of raw materials is frequently changed during processing. Textural changes are caused by a wide variety of effects, including water loss, protein denaturation which may result in loss of water-holding capacity or coagulation, hydrolysis, and solubilization of proteins. In plant tissues, cell disruption leads to loss of turgor pressure and softening of the tissue, while gelatinization of starch, hydrolysis of pectin, and solubilization of hemicelluloses also cause softening of the tissues.

The raw material must be robust enough to withstand the mechanical stresses during preparation, for example, abrasion during cleaning of fruit and vegetables.

Peas and beans must be able to withstand mechanical podding. Raw materials must be chosen so that the texture of the processed product is correct, such as canned fruits and vegetables in which raw materials must be able to withstand heat processing without being too hard or coarse for consumption.

Texture is dependent on the variety as well as the maturity of the raw material, and may be assessed by sensory panels or commercial instruments. One widely recognized instrument is the tenderometer used to assess the firmness of peas. The crop would be tested daily and harvested at the optimum tenderometer reading. In common with other raw materials, peas at different maturities can be used for different purposes, so that peas for freezing would be harvested at a lower tenderometer reading than peas for canning.

1.2.1.4 Flavor

Flavor is a rather subjective property which is difficult to quantify. Flavor quality of horticultural products is influenced by genotype and a range of pre- and postharvest factors [4]. Optimizing maturity/ripeness stage in relation to flavor at the time of processing is a key issue. Again, flavors are altered during processing, and following severe processing, the main flavors may be derived from additives. Hence, the lack of strong flavors may be the most important requirement. In fact, raw material flavor is often not a major determinant as long as the material imparts only those flavors which are characteristic of the food. Other properties may predominate. Flavor is normally assessed by human tasters, although sometimes flavor can be linked to some analytical test, such as sugar/acid levels in fruits.

1.2.1.5 Functional Properties

The functionality of a raw material is the combination of properties which determine product quality and process effectiveness. These properties differ greatly for different raw materials and processes, and may be measured by chemical analysis or process testing.

For example, a number of possible parameters may be monitored in wheat. Wheat for different purposes may be selected according to protein content. Hard wheat with 11.5–14% protein is desirable for white bread, and some whole wheat breads require even higher protein levels (14–16%) [5]. On the other hand, soft or weak flours with lower protein contents are suited to chemically leavened products with a lighter or more tender structure. Hence protein levels of 8–11% are adequate for biscuits, cakes, pastry, noodles, and similar products. Varieties of wheat for processing are selected on this basis, and measurement of protein content would be a good guide to process suitability. Furthermore, physical testing of dough using a variety of rheological testing instruments may be useful in predicting the breadmaking performance of individual batches of wheat flours [6]. A further test is the Hagberg Falling Number which measures the amount of α-amylase in flour or wheat [7]. This enzyme assists in the breakdown of starch to sugars, and high levels give rise to a weak bread structure. Hence, the test is a key indicator of wheat baking quality and is routinely used for bread wheat, and often determines the price paid to the farmer.

Similar considerations apply to other raw materials. Chemical analysis of fat and protein in milk may be carried out to determine its suitability for manufacturing cheese, yoghurt, or cream.

1.2.2
Raw Material Specifications

In practice, processors define their requirements in terms of raw material specifications for any process on arrival at the factory gate. Acceptance of, or price paid for, the raw material depends on the results of specific tests. Milk deliveries would be routinely tested for hygienic quality, somatic cells, antibiotic residues, extraneous water, as well as possibly fat and protein content. A random core sample is taken from all sugar beet deliveries and payment is dependent on the sugar content. For fruits, vegetables, and cereals, processors may issue specifications and tolerances to cover the size of units, the presence of extraneous vegetable matter, foreign bodies, levels of specific defects (e.g., surface blemishes, insect damage), and so on, as well as specific functional tests. Guidelines for sampling and testing many raw materials for processing in the United Kingdom are available from Campden BRI (*www.campden.co.uk*).

Increasingly, food processors and retailers may impose demands on raw material production which go beyond the properties described above. These may include ''environmentally friendly'' crop management schemes in which only specified fertilizers and insecticides are permitted, or humanitarian concerns, especially for food produced in developing countries. Similarly animal welfare issues may be specified in the production of meat or eggs. Another important issue is the growth of demand for organic foods in the United Kingdom and western Europe, which obviously introduces further demands on production methods that are beyond the scope of this chapter.

1.2.3
Deterioration of Raw Materials

All raw materials deteriorate following harvest, by some of the following mechanisms:

- **Endogenous enzymes:** Postharvest senescence and spoilage of fruit and vegetables occurs through a number of enzymic mechanisms, including oxidation of phenolic substances in plant tissues by phenolase (leading to browning); sugar–starch conversion by amylases; postharvest demethylation of pectic substances in fruits and vegetables leading to softening tissues during ripening and firming of plant tissues during processing.
- **Chemical changes:** These include deterioration in sensory quality by lipid oxidation; non-enzymic browning; and breakdown of pigments such as chlorophyll, anthocyanins, and carotenoids.
- **Nutritional changes:** Breakdown of ascorbic acid is an important example.

- **Physical changes:** These include dehydration and moisture absorption.
- **Biological changes:** Examples are the germination of seeds and sprouting.
- **Microbiological contamination:** Both the organisms themselves and their toxic products lead to deterioration of quality, as well as posing safety problems.

1.2.4 Damage to Raw Materials

Damage may occur at any point from growing through to the final point of sale. It may arise through external or internal forces.

External forces result in mechanical injury to fruits and vegetables, cereal grains, eggs, and even bones in poultry. They occur due to rough handling as a result of careless manipulation, poor equipment design, incorrect containerization, and unsuitable mechanical handling equipment. The damage typically results from impact and abrasion between food units, or between food units and machinery surfaces and projections, excessive vibration or pressure from overlying material. Increased mechanization in food handling must be carefully designed to minimize this.

Internal forces arise from physical changes such as variation in temperature and moisture content, and may result in skin cracks in fruits and vegetables, or stress cracks in cereals.

Either form of damage leaves the material open to further biological or chemical damage including enzymic browning of bruised tissue, or infestation of punctured surfaces by molds and rots.

1.2.5 Improving Processing Characteristics through Selective Breeding and Genetic Engineering

Selective breeding for yield and quality has been carried out for centuries in both plant and animal products. Until the twentieth century, improvements were made on the basis of selecting the most desirable looking individuals, while more systematic techniques have been developed more recently, based on greater understanding of genetics. The targets have been to increase yield as well as aiding factors of crop or animal husbandry such as resistance to pests and diseases, suitability for harvesting, or development of climate-tolerant varieties (e.g., cold-tolerant maize or drought-resistant plants) [8]. Raw material quality, especially in relation to processing, has become increasingly important. There are many examples of successful improvements in processing quality of raw materials through selective plant breeding including:

- improved oil percentage and fatty acid composition in oilseed rape;
- improved milling and malting quality of cereals;
- high sugar content and juice quality in sugar beets;

- development of specific varieties of potatoes for the processing industry, based on levels of enzymes and sugars, producing appropriate flavor, texture and color in products, or storage characteristics;
- Brussels sprouts which can be successfully frozen.

Similarly, traditional breeding methods have been used to improve yields of animal products such as milk and eggs, as well as improving quality – for example, fat/lean content of meat. Again the quality of raw materials in relation to processing may be improved by selective breeding. This is particularly applicable to milk, where breeding programs have been used at different times to maximize butterfat and protein content, and would thus be related to the yield and quality of fat- or protein-based dairy products. Furthermore, particular protein genetic variants in milk have been shown to be linked with processing characteristics, such as curd strength during manufacture of cheese [9]. Hence, selective breeding could be used to tailor milk supplies to the manufacture of specific dairy products.

Traditional breeding programs will undoubtedly continue to produce improvements in raw materials for processing, but the potential is limited by the gene pool available to any species. Genetic engineering extends this potential by allowing the introduction of foreign genes into an organism, with huge potential benefits. Again many of the developments have been aimed at agricultural improvements such as increased yield, or introducing herbicide, pest, or drought resistance. Other developments have aimed to improve the nutritional quality of foods. For example, transgenic ‘‘Golden’’ rice as a rich source of vitamin A; cereal grains with increased protein quantity and quality; oilseeds engineered to contain higher levels of omega-3 fatty acids. However, there is enormous potential in genetically engineered raw materials for processing [10]. The following are some examples which have been demonstrated:

- Tomatoes which do not produce pectinase and hence remain firm while color and flavor develop, producing improved soup, paste, or ketchup.
- Potatoes with higher starch content, which take up less oil and require less energy during frying.
- Canola (rape seed) oil tailored to contain high levels of lauric acid to improve emulsification properties for use in confectionery, coatings, or low-fat dairy products; high levels of stearate as an alternative to hydrogenation in manufacture of margarine; and high levels of polyunsaturated fatty acids for health benefits.
- Wheat with increased levels of high molecular weight glutenins for improved breadmaking performance.
- Fruits and vegetables containing peptide sweeteners such as thaumatin or monellin.
- ‘‘Naturally decaffeinated’’ coffee.

There is, however, considerable opposition to the development of genetically modified foods in the United Kingdom and elsewhere, due to fears of human health risks and ecological damage, discussion of which is beyond the scope of this book. It therefore remains to be seen if, and to what extent, genetically modified raw materials will be used in food processing.

1.3
Storage and Transportation of Raw Materials

1.3.1
Storage

Storage of food is necessary at all points of the food chain from raw materials, through manufacture, distribution, retailers, and final purchasers. Today's consumers expect a much greater variety of products, including non-local materials, to be available throughout the year. Effective transportation and storage systems for raw materials are essential to meet this need.

Storage of materials whose supply or demand fluctuate in a predictable manner, especially seasonal produce, is necessary to increase availability. It is essential that processors maintain stocks of raw materials, therefore storage is necessary to buffer demand. However, storage of raw materials is expensive for two reasons: stored goods have been paid for and may therefore tie up quantities of company money, and secondly, warehousing and storage space are expensive. All raw materials will deteriorate during storage. The quantities of raw materials held in store and the times of storage vary widely for different cases, depending on the above considerations. The ''just in time'' approaches used in other industries are less common in food processing.

The primary objective is to maintain the best possible quality during storage, and hence avoid spoilage during the storage period. Spoilage arises through three mechanisms:

1) Living organisms such as vermin, insects, fungi, and bacteria – these may feed on the food and contaminate it.
2) Biochemical activity within the food leading to quality reduction, such as respiration in fruits and vegetables; staling of baked products; enzymic browning reactions; rancidity development in fatty food.
3) Physical processes, including damage due to pressure or poor handling; physical changes such as dehydration or crystallization.

The main factors that govern the quality of stored foods are temperature, moisture/humidity, and atmospheric composition. Different raw materials provide very different challenges.

Fruits and vegetables remain as living tissues until they are processed and the main aim is to reduce respiration rate without damage to the tissue. Storage times vary widely between types. Young tissues such as shoots, green peas, and immature fruits have high respiration rates and shorter storage periods, while mature fruits and roots, and storage organs such as bulbs and tubers (e.g., onions, potatoes, sugar beets) respire much more slowly, and hence have longer storage periods.

Table 1.1 Storage periods of some fruits and vegetables under typical storage conditions.

Commodity	Temperature (°C)	Humidity (%)	Storage period
Garlic	0	70	6–8 mo
Mushrooms	0	90–95	5–7 d
Green bananas	13–15	85–90	10–30 d
Immature potatoes	4–5	90–95	3–8 wk
Mature potatoes	4–5	90–95	4–9 mo
Onions	−1 to 0	70–80	6–8 mo
Oranges	2–7	90	1–4 mo
Mangoes	5.5–14	90	2–7 wk
Apples	−1 to 4	90–95	1–8 mo
French beans	7–8	95–100	1–2 wk

Data from [13].

Some examples of conditions and storage periods of fruits and vegetables are given in Table 1.1. Many fruits (including bananas, apples, tomatoes, and mangoes) display a sharp increase in respiration rate during ripening, just before the point of optimum ripening, known as the "*climacteric*." The onset of the climacteric is associated with the production of high levels of ethylene, which is believed to stimulate the ripening process. Climacteric fruit can be harvested unripe and ripened artificially at a later time. It is vital to maintain careful temperature control during storage or the fruit will rapidly over-ripen. Non-climacteric fruits (e.g., citrus fruit, pineapples, strawberries) and vegetables do not display this behavior, and generally do not ripen after harvest. Quality is therefore optimal at harvest, and the task is to preserve quality during storage.

Harvesting, handling, and storage of fruit and vegetables are discussed in more detail by Thompson [11], while Nascimento Nunes [12] visually depicts the effects of time and temperature on the appearance of fruit and vegetables throughout postharvest life.

With meat storage the overriding problem is growth of spoilage bacteria, while avoiding oxidative rancidity. Cereals must be dried before storage to avoid germination and mold growth, and subsequently must be stored under conditions which prevent infestation with rodents, birds, insects, or molds.

Hence, very different storage conditions may be employed for different raw materials. The main methods employed in raw material storage are the control of temperature, humidity, and composition of atmosphere.

1.3.1.1 **Temperature**

The rate of biochemical reactions is related to temperature, such that lower storage temperatures lead to slower degradation of foods by biochemical spoilage, as well as reduced growth of bacteria and fungi. There may also be limited bacteriocidal effects at very low temperatures. Typical Q_{10} values for spoilage reactions are approximately 2, implying that spoilage rates would double for each 10 °C rise, or conversely that shelf life would double for each 10 °C reduction. This is an oversimplification as Q_{10} may change with temperature. Most insect activity is inhibited below 4 °C, although insects and their eggs can survive long exposure to these temperatures. In fact grain and flour mites can remain active and even breed at 0 °C.

The use of refrigerated storage is limited by the sensitivity of materials to low temperatures. The freezing point is a limiting factor for many raw materials, as the tissues will become disrupted on thawing. Other foods may be subject to problems at temperatures above freezing. Fruits and vegetables may display physiological problems that limit their storage temperatures, probably as a result of metabolic imbalance leading to a build-up of undesirable chemical species in the tissues. Some types of apples are subject to internal browning below 3 °C, while bananas become brown when stored below 13 °C, and many other tropical fruits display chill sensitivity. Less obvious biochemical problems may occur even where no visible damage occurs. For example, storage temperature affects starch/sugar balance in potatoes; in particular, below 10 °C a build up of sugar occurs, which is most undesirable for fried products. Examples of storage periods and conditions are given in Table 1.1, illustrating the wide ranges seen with different fruits and vegetables. It should be noted that predicted storage lives can be confounded if the produce is physically damaged, or by the presence of pathogens.

Temperature of storage is also limited by cost. Refrigerated storage is expensive, especially in hot countries. In practice, a balance must be struck incorporating cost, shelf life, and risk of cold injury. Slower growing produce such as onions, garlic, and potatoes can be successfully stored at ambient temperature and ventilated conditions in temperate climates.

It is desirable to monitor temperature throughout raw material storage and distribution.

Precooling to remove the ''field heat'' is an effective strategy to reduce the period of high initial respiration rate in rapidly respiring produce prior to transportation and storage. For example, peas for freezing are harvested in the cool early morning and rushed to cold storage rooms within 2–3 h. Other produce, such as leafy vegetables (lettuce, celery, cabbage) or sweetcorn, may be cooled using water sprays or drench streams. Hydrocooling obviously reduces water loss.

1.3.1.2 **Humidity**

If the humidity of the storage environment exceeds the equilibrium relative humidity (ERH) of the food, the food will gain moisture during storage, and vice versa. Uptake of water during storage is associated with susceptibility to growth of microorganisms, while water loss results in economic loss, as well as more specific problems such as cracking of seed coats of cereals, or skins of fruits and vegetables. Ideally the humidity of the store would equal the ERH of the food so that moisture is neither gained nor lost, but in practice a compromise may be necessary. The water activity (a_w) of most fresh foods (e.g., fruit, vegetables, meat, fish, milk) is in the range 0.98–1.00, but they are frequently stored at a lower humidity.

Some wilting of fruits or vegetable may be acceptable in preference to mold growth, while some surface drying of meat is preferable to bacterial slime. Packaging may be used to protect against water loss of raw materials during storage and transport (see Chapter 8).

1.3.1.3 **Composition of Atmosphere**

Controlling the atmospheric composition during storage of many raw materials is beneficial. The use of packaging to allow the development or maintenance of particular atmospheric compositions during storage is discussed in greater detail in Chapter 8.

With some materials the major aim is to maintain an oxygen-free atmosphere to prevent oxidation (e.g., coffee, baked goods), while in other cases adequate ventilation may be necessary to prevent anaerobic fermentation leading to off-flavors.

In living produce, atmosphere control allows the possibility of slowing down metabolic processes, hence retarding respiration, ripening, and senescence as well as the development of disorders. The aim is to introduce N_2 and remove O_2, allowing a build up of CO_2. Controlled-atmosphere storage of many commodities is discussed by Thompson [14]. The technique allows year-round distribution of apples and pears, where controlled atmospheres in combination with refrigeration can give shelf lives up to 10 months, much greater than by chilling alone. The particular atmospheres are cultivar specific, but are in the range 1–10% CO_2, 2–13% O_2 at 3 °C for apples and 0 °C for pears. Controlled atmospheres are also used during storage and transport of chill-sensitive crops, such as for transport of bananas, where an atmosphere of 3% O_2 and 5% CO_2 is effective in preventing premature ripening and the development of crown rot disease. Ethene (ethylene) removal is also vital during storage of climacteric fruit.

With fresh meat, controlling the gaseous environment is useful in combination with chilling. The aim is to maintain the red color by storage in high O_2 concentrations, which shifts the equilibrium in favor of high concentrations of the bright red oxymyoglobin pigment. At the same time, high levels of CO_2 are required to suppress the growth of aerobic bacteria.

1.3.1.4 **Other Considerations**

Odors and taints can cause problems, especially in fatty foods such as meat and dairy products, as well as less obvious commodities such as citrus fruits, which have oil in the skins. Odors and taints may be derived from fuels or adhesives and printing materials, as well as other foods (e.g., spiced or smoked products). Packaging and other systems during storage and transport must protect against contamination.

Light can lead to oxidation of fats in some raw materials (e.g., dairy products). In addition, light gives rise to solanine production and the development of green pigmentation in potatoes. Hence, storage and transport under dark conditions is essential.

1.3.2
Transportation

Food transportation is an essential link in the food chain, and is discussed in detail by Heap [15]. Raw materials, food ingredients, fresh produce, and processed products are all transported on a local and global level, by land, sea, and air. In the modern world, where consumers expect year-round supplies and non-local products, long-distance transport of many foods has become commonplace, and air transport may be necessary for perishable materials. Transportation of food is really an extension of storage; a refrigerated lorry is basically a cold store on wheels. However, transport also subjects the material to physical and mechanical stresses, and possibly rapid changes in temperature and humidity, which are not encountered during static storage. It is necessary to consider both the stresses imposed during the transport and those encountered during loading and unloading. In many situations transport is multimodal. Air or sea transport would commonly involve at least one road trip before and one road trip after the main journey. There would also be time spent on the ground at the port or airport where the material could be exposed to wide-ranging temperatures and humidities, or bright sunlight, and unscheduled delays are always a possibility. During loading and unloading, the cargo may be broken into smaller units where more rapid heat penetration may occur.

The major challenges during transportation are to maintain the quality of the food during transport, and to apply good logistics – in other words, to move the goods to the right place at the right time and in good condition.

1.4
Raw Material Cleaning

All food raw materials are cleaned before processing. The purpose is obviously to remove contaminants, which range from innocuous to dangerous. It is important to note that removal of contaminants is essential for protection of process equipment as well as the final consumer. For example, it is essential to remove sand, stones, or metallic particles from wheat prior to milling to avoid damaging the machinery. The main contaminants are:

- unwanted parts of the plant such as leaves, twigs, husks;
- soil, sand, stones, and metallic particles from the growing area;
- insects and their eggs;
- animal excreta, hairs, and so on;
- pesticides and fertilizers;
- mineral oil;
- microorganisms and their toxins.

Increased mechanization in harvesting and subsequent handling has generally led to increased contamination with mineral, plant, and animal contaminants, while there has been a general increase in the use of sprays, leading to increased chemical contamination. Microorganisms may be introduced preharvest from irrigation water, manure fertilizer, or contamination from feral or domestic animals, or postharvest from improperly cleaned equipment, wash waters, or cross-contamination from other raw materials.

Cleaning is essentially a separation process, in which some difference in physical properties of the contaminants and the food units is exploited. There are a number of cleaning methods available, classified into dry and wet methods, but a combination would usually be used for any specific material. Selection of the appropriate cleaning regime depends on the material being cleaned, the level and type of contamination and the degree of decontamination required. In practice a balance must be struck between cleaning cost and product quality, and an ‘‘acceptable standard’’ should be specified for the particular end-use. Avoidance of product damage is an important contributing factor, especially for delicate materials such as soft fruit.

1.4.1
Dry Cleaning Methods

The main dry cleaning methods are based on screens, aspiration, or magnetic separations. Dry methods are generally less expensive than wet methods and the effluent is cheaper to dispose of, but they tend to be less effective in terms of cleaning efficiency. A major problem is recontamination of the material with dust. Precautions may be necessary to avoid the risk of dust explosions and fires.

Screens Screens are essentially size separators based on perforated beds or wire mesh by which larger contaminants are removed from smaller food items (e.g., straw from cereal grains, or pods and twigs from peas). This is termed ‘‘*scalping*’’ (Figure 1.1a). Alternatively ‘‘de-dusting’’ is the removal of smaller particles (e.g., sand or dust) from larger food units (Figure 1.1b). The main geometries are rotary drums (also known as *reels* or *trommels*) and flatbed designs. Some examples are shown in Figure 1.2. Abrasion, either by impact during the operation of the machinery, or aided by abrasive disks or brushes, can improve the efficiency of dry screens. Screening gives incomplete separations and is usually a preliminary cleaning stage.

Aspiration This exploits the differences in aerodynamic properties of the food and the contaminants. It is widely used in the cleaning of cereals, but is also incorporated into equipment for cleaning peas and beans. The principle is to feed the raw material into a carefully controlled upward air stream. Denser material will fall, while lighter material will be blown away depending on the terminal velocity. *Terminal velocity* in this case can be defined as the velocity of upward air stream in which a particle remains stationary, and depends on the density and projected area of the particles (as described by Stokes’ equation). By using different air velocities, it is possible to separate, say, wheat from lighter chaff (Figure 1.3) or denser small stones. Very accurate separations are possible, but large amounts of energy are

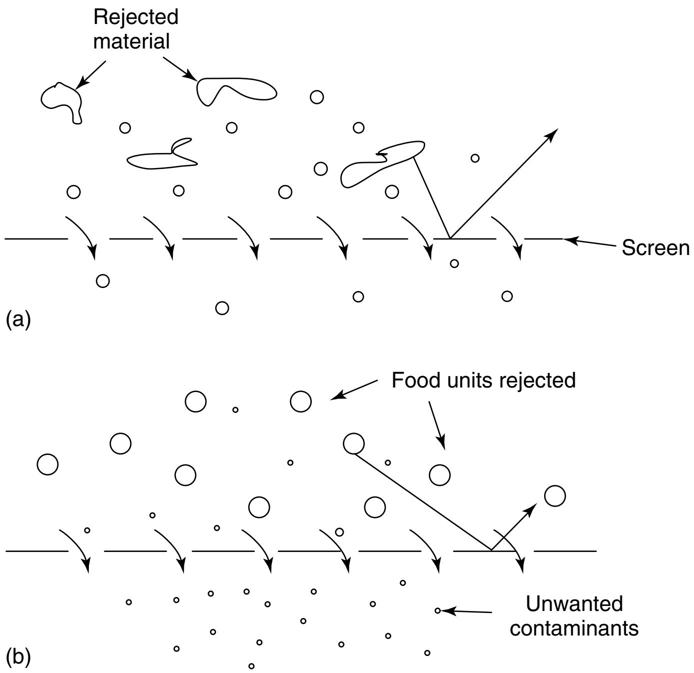

Figure 1.1 Screening of dry particulate materials: (a) scalping and (b) de-dusting.

required to generate the air streams. Obviously the system is limited by the size of raw material units, but is particularly suitable for cleaning legumes and cereals. Air streams may also be used simply to blow loose contaminants from larger items such as eggs or fruit.

Magnetic cleaning This is the removal of ferrous metal using permanent or electromagnets. Metal particles derived from the growing field or picked up during transport or preliminary operations constitute a hazard both to the consumer and to processing machinery (e.g. cereal mills). The geometry of magnetic cleaning systems can be quite variable: particulate foods may be passed over magnetized drums or magnetized conveyor belts, or powerful magnets may be located above conveyors. Electromagnets are easy to clean by turning off the power. Metal detectors are frequently employed prior to sensitive processing equipment as well as to protect consumers at the end of processing lines.

Electrostatic cleaning This can be used in a limited number of cases where the surface charge on raw materials differs from contaminating particles. The principle can be used to distinguish grains from other seeds of similar geometry but different surface charge, and has also been described for cleaning tea. The feed is conveyed on a charged belt and charged particles are attracted to an oppositely charged electrode according to their surface charge (Figure 1.4).

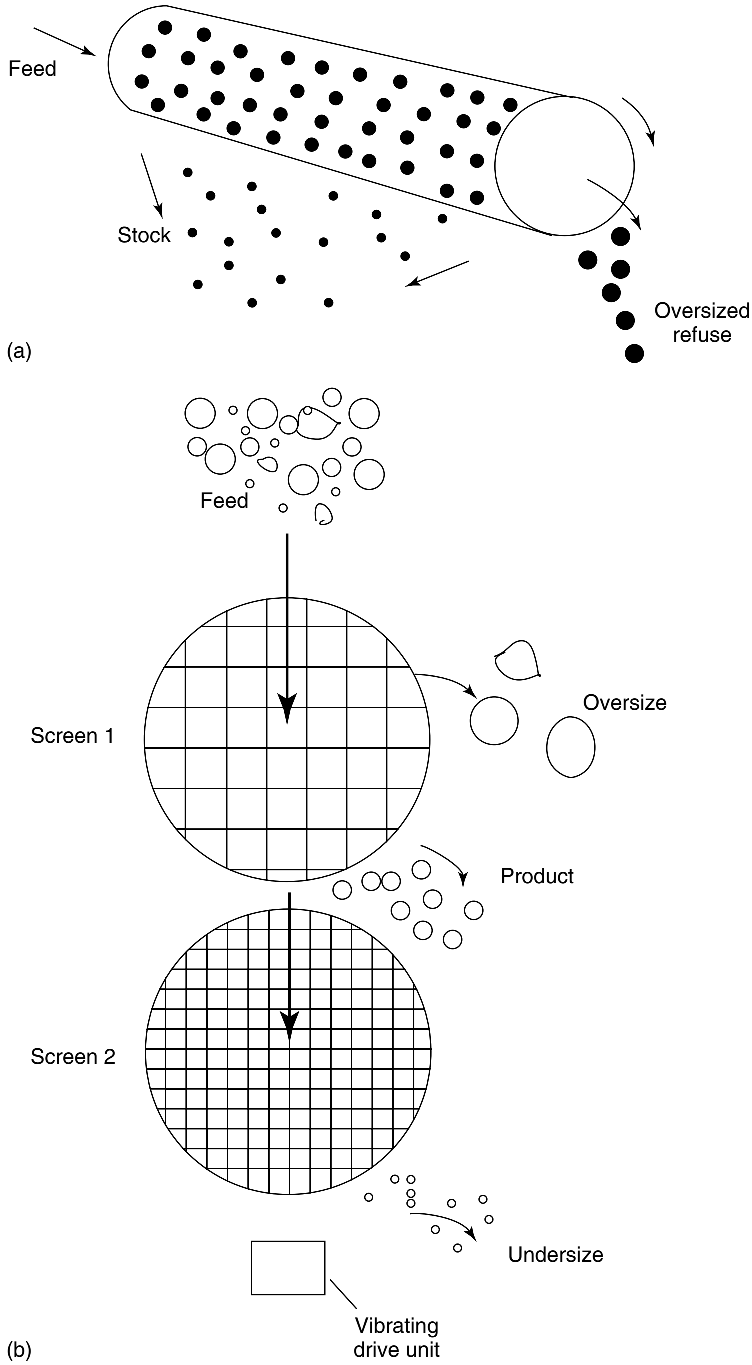

Figure 1.2 Screen geometries: (a) rotary screen and (b) principle of flatbed screen.

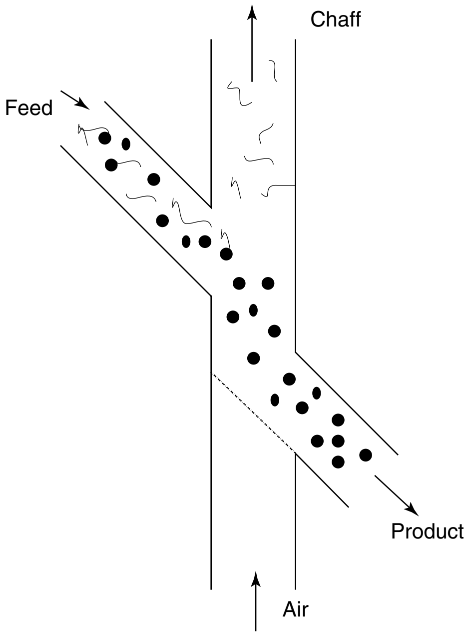

Figure 1.3 Principle of aspiration cleaning.

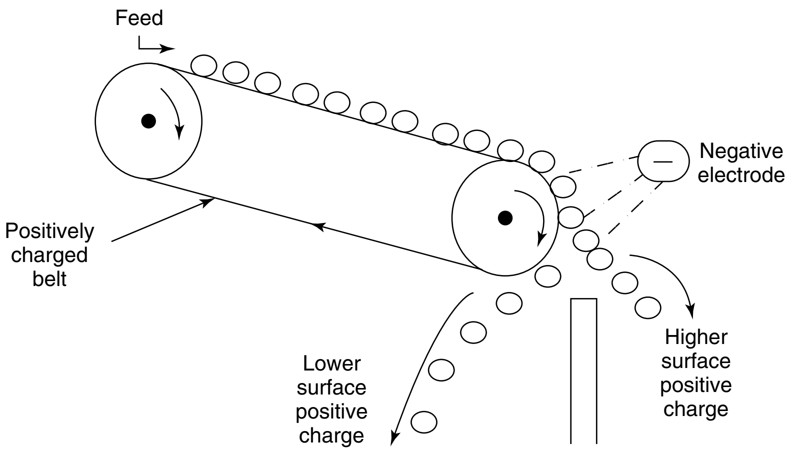

Figure 1.4 Principle of electrostatic cleaning.

1.4.2
Wet Cleaning Methods

Wet methods are necessary if large quantities of soil are to be removed, and are essential if detergents are used. They are, however, expensive as large quantities of high purity water are required, and the same quantity of dirty effluent is produced. Treatment and reuse of water can reduce costs. Employing the countercurrent principle can reduce water requirement and effluent volumes if accurately controlled. Sanitizing chemicals such as chlorine, citric acid, and ozone are commonly used in wash waters, especially in association with peeling and size reduction, where reducing enzymic browning may also be an aim [16]. Levels of 100–200 mg l^{-1} chlorine or citric acid may be used, although their effectiveness for decontamination has been questioned and they are not permitted in some countries.

Soaking is a preliminary stage in cleaning heavily contaminated materials such as root crops, permitting softening of the soil, and partial removal of stones and other contaminants. Metallic or concrete tanks or drums are employed, and these may be fitted with devices for agitating the water, including stirrers, paddles, or mechanisms for rotating the entire drum. For delicate produce such as strawberries or asparagus, or products which trap dirt internally (e.g., celery), sparging air through the system may be helpful. The use of warm water or including detergents improves cleaning efficiency, especially where mineral oil is a possible contaminant, but adds to the expense and may damage the texture.

Spray washing is very widely used for many types of food raw material. Efficiency depends on the volume and temperature of the water and time of exposure. As a general rule, small volumes of high-pressure water give the most efficient dirt removal, but this is limited by product damage, especially to more delicate produce. With larger food pieces it may be necessary to rotate the unit so that the whole surface is presented to the spray (Figure 1.5a). The two most common designs

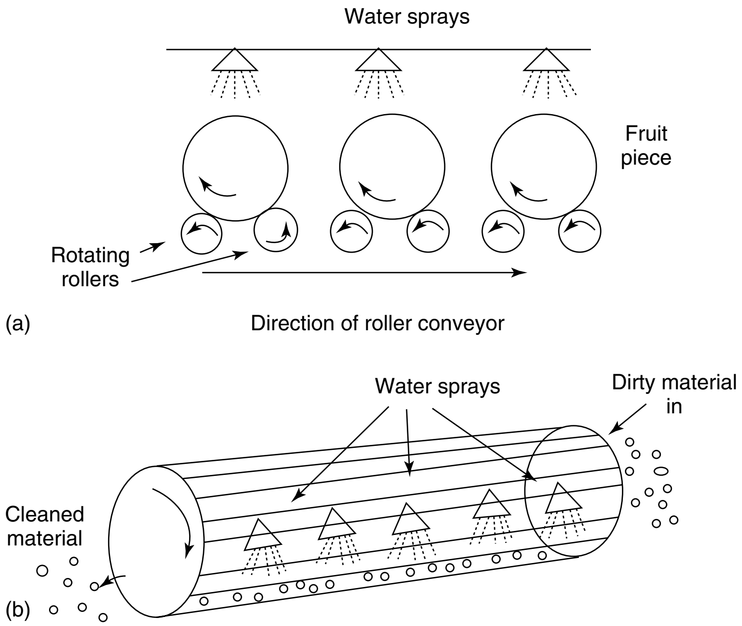

Figure 1.5 Water spray cleaning: (a) spray belt washer and (b) drum washer.

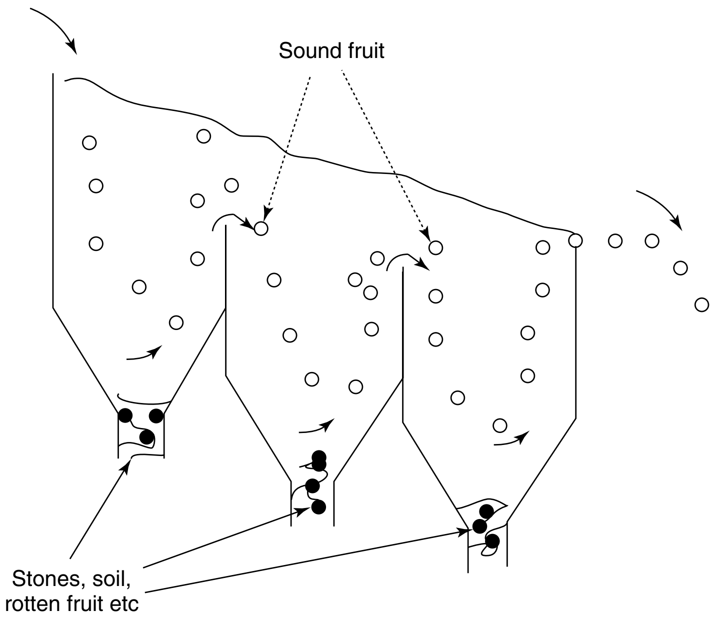

Figure 1.6 Principle of flotation washing.

are drum washers and belt washers (Figures 1.5). Abrasion may contribute to the cleaning effect, but again must be limited in delicate units. Other designs have included flexible rubber disks which gently brush the surface clean.

Flotation washing employs buoyancy differences between food units and contaminants. For instance, sound fruit generally floats, while contaminating soil, stones, or rotten fruits sink in water. Hence fluming fruit in water over a series of weirs gives very effective cleaning of fruit, peas, and beans (Figure 1.6). A disadvantage is high water use, thus recirculation of water should be incorporated.

Froth flotation is carried out to separate peas from contaminating weed seeds, and exploits surfactant effects. The peas are dipped in oil/detergent emulsion and air is blown through the bed. This forms a foam which washes away the contaminating material, and the cleaned peas can be spray washed.

Following wet cleaning it is necessary to remove the washing water. Centrifugation is very effective, but may lead to tissue damage, hence dewatering screens or reels are more common.

Prestorage hot water dipping has been used as an alternative to chemical treatments for preserving the quality of horticultural products. One recent development is the simultaneous cleaning and disinfection of fresh produce by a short hot water rinse and brushing (HWRB) treatment [17]. This involves placing the crops on rotating brushes and rinsing with hot water for 10–30 s. The effect is through a combination of direct cleaning action plus the lethal action of heat on surface pathogens. Fungicides may also be added to the hot water.

1.4.3
Peeling

Peeling of fruits and vegetables is frequently carried out in association with cleaning. Mechanical peeling methods require loosening of the skin using one of the following principles depending on the structure of the food and the level of peeling required [18]:

- **Steam** is particularly suited to root crops. The units are exposed to high-pressure steam for a fixed time and then the pressure is released causing steam to form under the surface of the skin, hence loosening it such that it can be removed with a water spray.
- **Lye** (1–2% alkali) solution can be used to soften the skin which can again be removed by water sprays. There is, however, a danger of damage to the product.
- **Brine** solutions can give a peeling effect but are probably less effective than the above methods.
- **Abrasion peeling** employs carborundum rollers or rotating the product in a carborundum-lined bowl followed by washing away the loosened skin. It is effective but here is a danger of high product loss by this method.
- **Mechanical knives** are suitable for peeling citrus fruits.
- **Flame peeling** is useful for onions in which the outer layers are burnt off and charred skin is removed by high-pressure hot water.

1.5
Sorting and Grading

Sorting and grading are terms which are frequently used interchangeably in the food processing industry, but strictly speaking they are distinct operations. Sorting is a separation based on a single measurable property of raw material units, while grading is "the assessment of the overall quality of a food using a number of attributes" [18]. *Grading of fresh produce* may also be defined as "sorting according to quality," as sorting usually upgrades the product.

Virtually all food products undergo some type of sorting operation. There are a number of benefits, including the need for sorted units in weight filling operations, and the aesthetic and marketing advantages in providing uniform-sized or uniform-colored units. In addition, it is much easier to control processes such as sterilization, dehydration, or freezing in sorted food units, and they are also better suited to mechanized operations such as size reduction, pitting, or peeling.

1.5.1
Criteria and Methods of Sorting

Sorting is carried out on the basis of individual physical properties. Details of principles and equipment are given in Saravacos and Kostaropoulos [19], Brennan *et al.* [20], and Peleg [21]. No sorting system is absolutely precise, and a balance is often struck between precision and flow rate.

Weight is usually the most precise method of sorting, as it is not dependent on the geometry of the products. Eggs, fruit, or vegetables may be separated into weight categories using spring-loaded, strain gauge, or electronic weighing devices incorporated into conveying systems. Using a series of tipping or compressed air blowing mechanisms set to trigger at progressively lesser weights, the heavier items are removed first followed by the next weight category, and so on. These systems are computer controlled and can additionally provide data on quantities and size distributions from different growers. An alternative system is to use the ''catapult'' principle where units are thrown into different collecting chutes, depending on their weight, by spring-loaded catapult arms. A disadvantage of weight sorting is the relatively long time required per unit and other methods are more appropriate with smaller items such as legumes or cereals, or if faster throughput is required.

Size sorting is less precise than weight sorting, but is considerably cheaper. As discussed in Section 1.2, the sizes and shapes of food units are difficult to define precisely. Size categories could include a number of physical parameters including diameter, length, or projected area. Diameter of spheroidal units such as tomatoes or citrus fruits is conventionally considered to be orthogonal to the fruit stem, while length is coaxial. Therefore rotating the units on a conveyor can make size sorting more precise.

Sorting into size categories requires some sort of screen, many designs of which are discussed in detail in Slade [22], Brennan *et al.* [20], and Fellows [18]. The main categories of screens are fixed-aperture and variable-aperture designs. Flatbed and rotary screens are the main geometries of fixed bed screen and a number of screens may be used in series or in parallel to sort units into several size categories simultaneously. The problem with fixed screens is usually contacting the feed material with the screen which may become blocked or overloaded. Fixed screens are often used with smaller particulate foods such as nuts or peas. Variable-aperture screens have either a continuous diverging or stepwise diverging apertures. These are much gentler and are commonly used with larger, more delicate items such as fruit. The principles of some sorting screens are illustrated in Figure 1.7.

Shape sorting is useful in cases where the food units are contaminated with particles of similar size and weight. This is particularly applicable to grain which may contain other seeds. The principle is that disks or cylinders with accurately shaped indentations will pick up seeds of the correct shape when rotated through the stock, while other shapes will remain in the feed (Figure 1.8).

Density can be a marker of suitability for certain processes. The density of peas correlates well with tenderness and sweetness, while the solids content of potatoes, which determines suitability for manufacture of crisps and dried products, relates to density. Sorting on the basis of density can be achieved using flotation in brine at different concentrations.

Photometric properties may be used as a basis for sorting. In practice this usually means color. Color is often a measure of maturity, presence of defects, or the degree of processing. Manual color sorting is carried out widely on conveyor belts

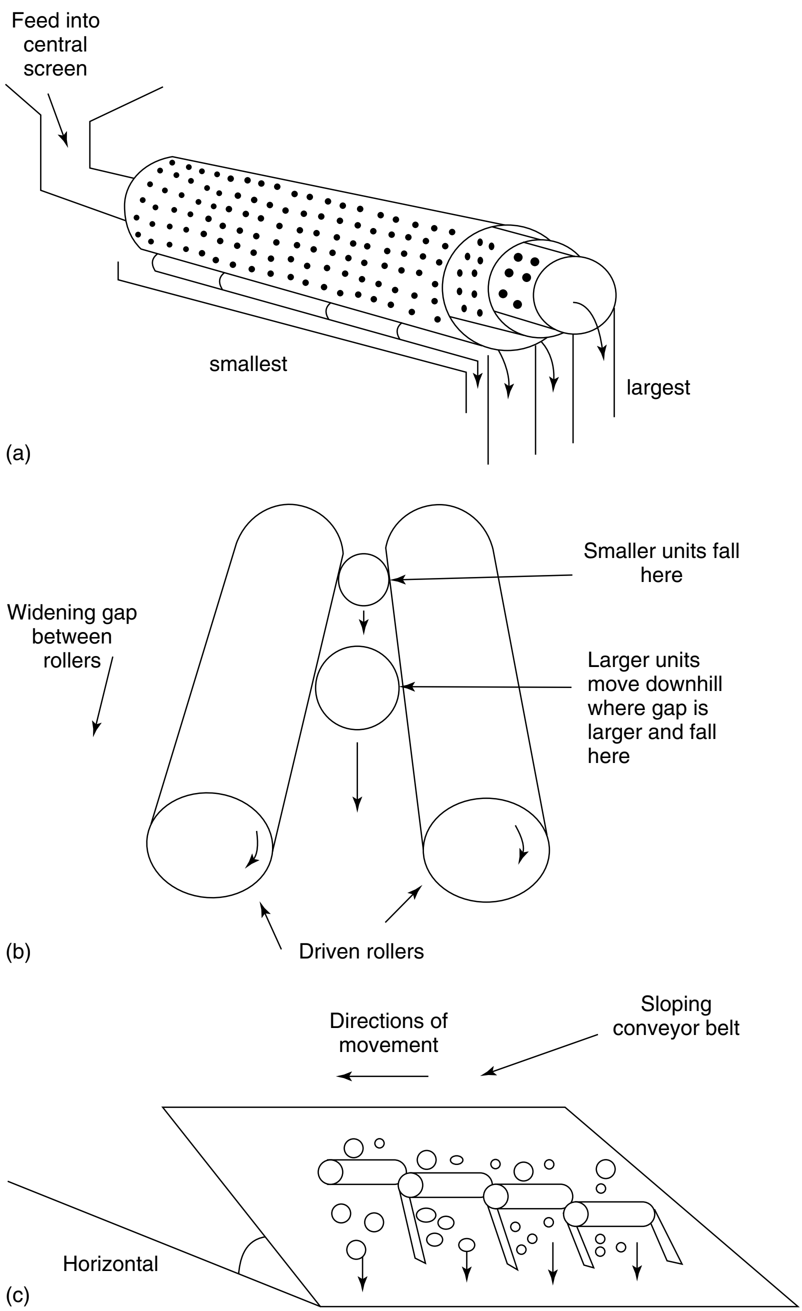

Figure 1.7 Some geometries of size-sorting equipment: (a) concentric drum screen; (b) roller size-sorter; and (c) belt and roller sorter.

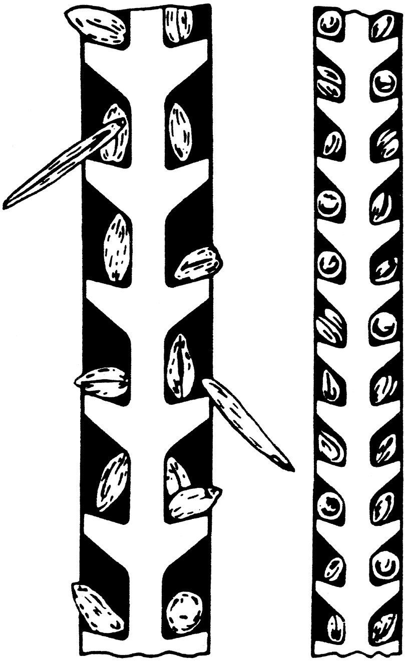

Figure 1.8 Cross section of disk separators for cleaning cereals.

or sorting tables, but is expensive. The process can be automated using highly accurate photocells which compare reflectance of food units to preset standards, and can eject defective or wrongly colored (e.g., blackened) units, usually by a blast of compressed air. This system is used for small particulate foods such as navy beans or maize kernels for canning, or nuts, rice, and small fruit (Figure 1.9). Extremely high throughputs have been reported (e.g., 16 t h^{-1}) [18]. By using more than one photocell positioned at different angles, blemishes on large units such as potatoes can be detected. Color sorting can also be used to separate materials which are to be processed separately such as red and green tomatoes. It is feasible to use transmittance as a basis for sorting, although as most foods are completely opaque very few opportunities are available. The principle has been used for sorting cherries with and without stones, and internal examination, or "candling," of eggs.

1.5.2 Grading

Grading is classification on the basis of quality (incorporating commercial value, end-use, and official standards [19]), and hence requires that some judgment on the acceptability of the food is made, based on simultaneous assessment of several properties, followed by separation into quality categories. Appropriate inspection belts or conveyors designed to present the whole surface to the operator, are frequently used. Trained manual operators are frequently used to judge the quality, and may use comparison to charted standards, or even plastic models. For

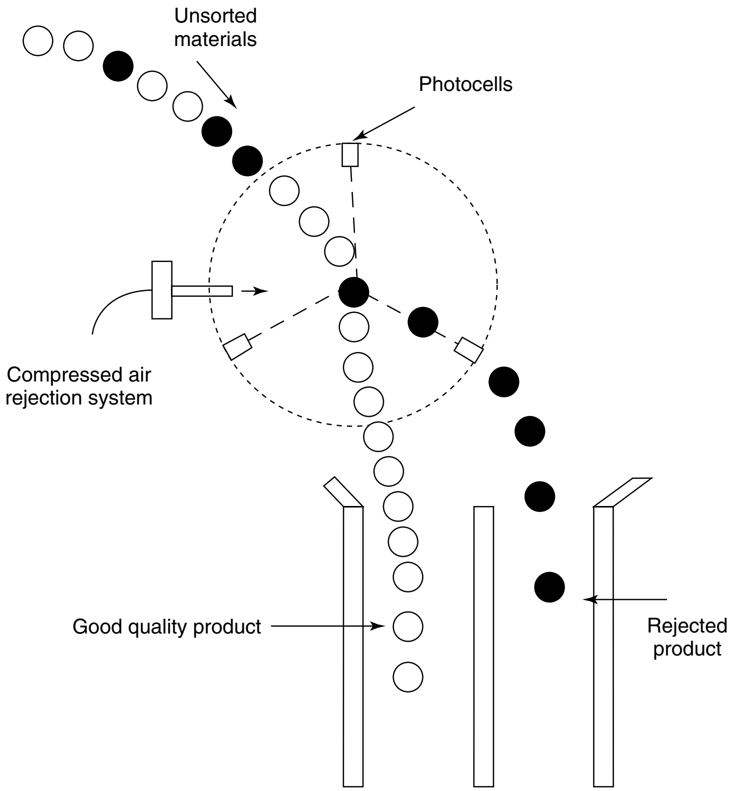

Figure 1.9 Principle of color sorter.

example, a fruit grader could simultaneously judge shape, color, evenness of color, and degree of russeting in apples. Egg ''candling'' involves inspection of eggs spun in front of a light so that many factors, including shell cracks, diseases, blood spots, or fertilization, can be detected. Apparently, experienced candlers can grade thousands of eggs per hour. Machine grading is only feasible where quality of a food is linked to a single physical property, and hence a sorting operation leads to different grades of material. Size of peas, for example, is related to tenderness and sweetness, therefore size sorting results in different quality grades.

Grading of foods is also the determination of the quality of a batch. This can be done by human graders who assess the quality of random samples of foods such as cheese or butter, or meat inspectors who examine the quality of individual carcasses for a number of criteria. Alternatively, batches of some foods may be graded on the basis of laboratory analysis.

There is increasing interest in the development of rapid, nondestructive methods of assessing the quality of foods, which could be applied to the grading and sorting of foods. Cubeddu *et al.* [23] and Nicolai *et al.* [24] have described potential application of advanced optical techniques to give information on both surface and internal properties of fruits, including textural and chemical properties. This could permit classification of fruit in terms of maturity, firmness, or the presence of defects, or even more specifically, noninvasive detection of chlorophyll, sugar, and acid levels. For example, Qin and Lu [25] were able to assess the ripeness of tomatoes and other fruit and vegetables from their absorption spectra in the visible and near infrared range, in particular, by the ratio of absorption coefficients of chlorophyll and anthocyanin. Another promising approach is the use of sonic techniques to measure the texture of fruits and vegetables [26, 27]. Similar applications of X-rays, lasers, infrared rays, and microwaves have also been studied [19].

An alternative approach to nondestructive testing is the Sinclair iQ firmness tester, which is based on the electrical response of the fruit to air bellows, which predicts the elastic response, which in turn reflects the ripeness. This equipment has been shown to relate very closely to standard penetrometer readings for a range of fruit [28] and is now available for commercial rapid online fruit grading. A recent patent [29] describes the use of nondestructive testing to assess size, Brix, maturity, and the presence of blemishes on fruit and hence to grade the fruit for the production of juice of preselected quality.

Numerous other miscellaneous mechanical techniques are available which effectively upgrade the material such as equipment for skinning and dehairing fish and meat, removing mussel shells, destemming and pitting fruit, and so on [19].

1.6 Blanching

Most vegetables and some fruits are blanched prior to further processing operations such as canning, freezing, or dehydration. Blanching is a mild heat treatment, but is not a method of preservation *per se*. It is a pretreatment usually performed between preparation and subsequent processing. Blanching consists of heating the food rapidly to a predetermined temperature, holding for a specified time, then either cooling rapidly or passing immediately to the next processing stage.

1.6.1 Mechanisms and Purposes of Blanching

Plant cells are discrete membrane-bound structures contained within semi-rigid cell walls. The outer or cytoplasmic membrane acts as a skin, maintaining turgor pressure within the cell. Loss of turgor pressure leads to softening of the tissue. Within the cell are a number of organelles including the nucleus, vacuole, chloroplasts, chromoplasts, and mitochondria. This compartmentalization is essential to the various biochemical and physical functions. Blanching causes cell death, and physical and metabolic chaos within the cells. The heating effect leads to enzyme destruction as well as damage to the cytoplasmic and other membranes, which become permeable to water and solutes. An immediate effect is the loss of turgor pressure. Water and solutes may pass into and out of the cells, a major consequence being nutrient loss from the tissue. Also cell constituents, which had previously been compartmentalized in subcellular organelles, become free to move and interact within the cell.

The major purpose of blanching is frequently to inactivate enzymes that would otherwise lead to quality reduction in the processed product. For example, with frozen foods, deterioration could take place during any delay prior to processing, during freezing, during frozen storage, or subsequent thawing. Similar considerations apply to processing, storage, and rehydration of dehydrated foods. Enzyme inactivation prior to heat sterilization is less important as the severe processing will destroy any enzyme activity, but there may be an appreciable time before the food is heated to sufficient temperature, so quality may be better maintained if enzymes are destroyed prior to heat sterilization processes such as canning.

It is important to inactivate quality-changing enzymes, that is, enzymes which will give rise to loss of color or texture, the production of off-odors and flavors or breakdown of nutrients. Many such enzymes have been studied including a range of peroxidases, catalases, and lipoxygenases. Peroxidase and to a lesser extent catalase are frequently used as indicator enzymes to determine the effectiveness of blanching. Although other enzymes may be more important in terms of their quality-changing effect, peroxidase is chosen because it is extremely easy to measure and it is the most heat resistant of the enzymes in question. More recent work indicates that complete inactivation of peroxidase may not be necessary and retention of a small percentage of the enzyme following blanching of some vegetables may be acceptable [30].

Blanching causes the removal of gases from plant tissues, especially intercellular gas. This is especially useful prior to canning where blanching helps achieve vacua in the containers, preventing expansion of air during processing, and hence reducing strain on the containers and the risk of misshapen cans. In addition, removing oxygen is useful in avoiding oxidation of the product and corrosion of the can. Removal of gases, along with the removal of surface dust, has a further effect in brightening the color of some products, especially green vegetables.

Shrinking and softening of the tissue is a further consequence of blanching. This is of benefit in terms of achieving filled weight into containers, so, for example, it may be possible to reduce the tin plate requirement in canning. It may also facilite the filling of containers. It is important to control the time/temperature conditions to avoid overprocessing leading to excessive loss of texture in some processed products. Calcium chloride addition to blanching water helps to maintain the texture of plant tissue through the formation of calcium pectate complexes. Some weight loss from the tissue is inevitable as both water and solutes are lost from the cells.

A further benefit is that blanching acts as a final cleaning and decontamination process. Selman [30] described the effectiveness of blanching in removing pesticide residues or radionuclides from the surface of vegetables, while toxic constituents naturally present (such as nitrites, nitrates, and oxalate) are reduced by leaching. Very significant reductions in microorganism content can be achieved, which is useful in frozen or dried foods, where surviving organisms can multiply on thawing or rehydration. It is also useful before heat sterilization if large numbers of microorganisms are present before processing.

1.6.2 Processing Conditions

It is essential to control the processing conditions accurately to avoid loss of texture (see Section 1.6.2), weight, color, and nutrients. All water-soluble materials, including minerals, sugars, proteins, and vitamins, can leach out of the tissue, leading to nutrient loss. In addition, some nutrient loss (especially ascorbic acid) occurs through thermal lability and, to a lesser extent, oxidation. Ascorbic acid is the most commonly measured nutrient with respect to blanching [30], as it covers all eventualities, being water soluble and hence prone to leaching from cells, thermally labile, as well as being subject to enzymic breakdown by ascorbic acid oxidase during storage. Wide ranges of vitamin C breakdown are observed depending on the raw material and the method and precise conditions of processing. The aim is to minimize leaching and thermal breakdown while completely eliminating ascorbic acid oxidase activity such that vitamin C losses in the product are restricted to a few percent. Generally steam blanching systems (see Section 1.6.3) give rise to lower losses of nutrients than immersion systems, presumably because leaching effects are less important.

Blanching is an example of unsteady state heat transfer involving convective heat transfer from the blanching medium and conduction within the food piece. Mass transfer of material into and out of the tissue is also important. The precise blanching conditions (time and temperature) must be evaluated for the raw material and will usually represent a balance between retaining the quality characteristics of the raw material and avoiding overprocessing. The following factors must be considered:

- fruit or vegetable properties, especially thermal conductivity, which will be determined by type, cultivar, degree of maturity, and so on;
- overall blanching effect required for the processed product, which could be expressed in many ways including: achieving a specified central temperature; achieving a specified level of peroxidase inactivation; retaining a specified proportion of vitamin C;
- size and shape of food pieces;
- method of heating and temperature of blanching medium.

Time/temperature combinations vary very widely for different foods and different processes and must be determined specifically for any situation. Holding times of 1–15 min at 70–100 °C are normal.

1.6.3 Blanching Equipment

Blanching equipment is described by Fellows [18]. The two main approaches in commercial practice are to convey the food through saturated steam or hot water.

Cooling may be with water or air. Water cooling may increase leaching losses but the product may also absorb water leading to a net weight gain. Air cooling leads to weight loss by evaporation but may be better in terms of nutrient retention.

Conventional steam blanching consists of conveying the material through an atmosphere of steam in a tunnel on a mesh belt. Uniformity of heating is often poor where food is unevenly distributed, and the cleaning effect on the food is limited. However, the volumes of wastewater are much lower than for water blanching. Fluidized bed designs and *individual quick blanching* (a three-stage process in which vegetable pieces are heated rapidly in thin layers by steam, held in a deep bed to allow temperature equilibration, followed by cooling in chilled air) may overcome the problems of nonuniform heating and lead to more efficient systems.

The two main conventional designs of hot water blancher are reel and pipe designs. In reel blanchers the food enters a slowly rotating mesh drum which is partly submerged in hot water. The heating time is determined by the speed of rotation. In pipe blanchers, the food is contacted with hot water recirculating through a pipe. The residence time is determined by the length of the pipe and the velocity of water.

There is much scope for improving energy efficiency and recycling water in either steam or hot water systems. Blanching may be combined with peeling and cleaning operations to reduce costs.

Microwave blanching has been demonstrated on an experimental scale but is too costly at present for commercial use.

1.7
Sulfiting of Fruits and Vegetables

Sulfur dioxide (SO_2) or inorganic sulfites (SO_3^{2-}) may be added to foods to control enzymic and nonenzymic browning, to control microbial growth, or as bleaching or reducing agents or antioxidants. The main applications are preserving or preventing discoloration of fruit and vegetables. The following sulfiting agents are permitted by European law: sulfur dioxide, sodium sulfite, sodium hydrogen sulfite, sodium metabisulfite, potassium metabisulfite, calcium sulfite, calcium hydrogen sulfite, and potassium hydrogen sulfite. However, sulfites have some disadvantages, notably dangerous side effects for asthmatics, and their use has been partly restricted by the US Food and Drug Administration.

Sulfur dioxide dissolves readily in water to form sulfurous acid (H_2SO_3), and the chemistry of sulfiting agents can be summarized as follows:

$$H_2SO_3 \Leftrightarrow H^+ + HSO_3^- \qquad pK_1 \approx 2$$

$$HSO_3^- \Leftrightarrow H^+ + SO_3^{2-} \qquad pK_1 \approx 7$$

Most foods are in the pH range 4–7, and therefore the predominant form is HSO_3^-. Sulfites react with many food components, including aldehydes, ketones, reducing sugars, proteins, and amino acids to form a range of organic sulfites [31]. It is not clear exactly which reactions contribute to the beneficial applications of sulfites in the food industry. It should be noted that some of the reactions lead to undesirable consequences, in particular, leading to vitamin breakdown. For example, Bender [32] reported losses of thiamin in meat products and fried potatoes when sulfiting agents were used during manufacture. On the other hand, the inhibitory effect of sulfiting agents on oxidative enzymes (e.g., ascorbic acid oxidase) may aid the retention of other vitamins, including ascorbic acid and carotene.

Sulfites may be used to inhibit and control microorganisms in fresh fruit and fruits used in the manufacture of jam, juice, or wine. In general, the antimicrobial action follows the order [31]: Gram-negative bacteria > Gram-positive bacteria > molds > yeasts. The mechanism(s) of action are not well understood although it is believed that undissociated H_2SO_3 is the active form, thus the treatment is more effective at low pH ($\leq$4).

A more widespread application is the inhibition of both enzymic and nonenzymic browning. Sulfites form stable hydroxysulfonates with carbonyl compounds, and hence prevent browning reactions by binding carbonyl intermediates such as quinones. In addition, sulfites bind reducing sugars, which are necessary for nonenzymic browning, and inhibit oxidative enzymes including polyphenoloxidase, which are responsible for enzymic browning. Therefore sulfite treatments can be used to preserve the color of dehydrated fruits and vegetables. For example, sun-dried apricots may be treated with gaseous SO_2 to retain their natural color [33], the product containing 2500–3000 ppm of SO_2. Sulfiting has commonly been used to prevent enzymic browning of many fruits and vegetables including peeled or sliced apple and potato, mushrooms for processing, grapes, and salad vegetables.

References

1. Seaton, H.L. (1955) Scheduling plantings and predicting harvest maturities for processing vegetables. *Food Technol.*, **9**, 202–209.
2. Maestrelli, A. (2000) Fruit and vegetables: the quality of raw material in relation to freezing, in *Managing Frozen Foods* (ed. C.J. Kennedy), Woodhead Publishing, Cambridge, pp. 27–55.
3. Mohsenin, N.N. (1989) *Physical Properties of Food and Agricultural Materials*, Gordon and Breach Science Publishers, New York.
4. Kader, A.A. (2008) Perspective: flavour quality of fruits and vegetables. *J. Sci. Food Agric.*, **88**, 1863–1868.
5. Chung, O.K. and Pomeranz, Y. (2000) Cereal processing, in *Food Proteins: Processing Applications* (eds S. Nakai and H.W. Modler), Wiley-VCH Verlag GmbH, Weinheim, pp. 243–307.
6. Nakai, S. and Wing, P.L. (2000) Breadmaking, in *Food Proteins: Processing Applications* (eds S. Nakai and H.W. Modler), Wiley-VCH Verlag GmbH, Weinheim, pp. 209–242.
7. Dobraszczyk, B.J. (2001) Wheat and flour, in *Cereals and Cereal Products: Chemistry and Technology* (eds D.A.V. Dendy and B.J. Dobraszczyk), Aspen, Gaithersburg, pp. 100–139.
8. Finch, H.J.S., Samuel, A.M., and Lane, G.P.F. (2002) *Lockhart and Wiseman's Crop Husbandry*, 8th edn, Woodhead Publishing, Cambridge.
9. Ng-Kwai-Hang, K.F. and Grosclaude, F. (2003) Genetic polymorphism of milk proteins, in *Advanced Dairy Chemistry, Proteins–Part B*, Vol. 1 (eds P.F. Fox and P.L.H. McSweeney), Kluwer Academic/Plenum, New York, pp. 739–816.

10. Nottingham, S. (1999) *Eat Your Genes*, Zed Books, London.
11. Thompson, A.K. (2003) *Fruit and Vegetables: Harvesting, Handling and Storage*, Blackwell Publishing, Oxford.
12. Nascimento Nunes, M.C. (2008) *Color Atlas of Postharvest Quality of Fruits and Vegetables*, Blackwell Publishing, Oxford.
13. Aked, J. (2002) Maintaining the post-harvest quality of fruits and vegetables, in *Fruit and Vegetable Processing: Improving Quality* (ed. W. Jongen), Woodhead Publishing, Cambridge, pp. 119–149.
14. Thompson, A.K. (1998) *Controlled Atmosphere Storage of Fruits and Vegetables*, CAB International, Wallingford.
15. Heap, R., Kierstan, M., and Ford, G. (1998) *Food Transportation*, Blackie, London.
16. Ahvenian, R. (2000) Ready-to-use Fruit and Vegetable. Fair-Flow Europe technical manual F-FE 376A/00, Fair-Flow, London.
17. Orea, J.M. and Gonzalez Urena, A. (2002) Measuring and improving the natural resistance of fruit, in *Fruit and Vegetable Processing: Improving Quality* (ed. W. Jongen), Woodhead Publishing, Cambridge, pp. 233–266.
18. Fellows, P.J. (2009) *Food Processing Technology: Principles and Practice*, 3rd edn, Woodhead Publishing, Cambridge.
19. Saravacos, G.D. and Kostaropoulos, A.E. (2002) *Handbook of Food Processing Equipment*, Kluwer Academic, London.
20. Brennan, J.G., Butters, J.R., Cowell, N.D., and Lilly, A.E.V. (1990) *Food Engineering Operations*, 3rd edn, Elsevier Applied Science, London.
21. Peleg, K. (1985) *Produce Handling, Packaging and Distribution*, AVI, Westport.
22. Slade, F.H. (1967) *Food Processing Plant*, Vol. 1, Leonard Hill, London.
23. Cubeddu, R., Pifferi, A., Taroni, P., and Torricelli, A. (2002) Measuring fruit and vegetable quality: advanced optical methods, in *Fruit and Vegetable Processing: Improving Quality* (ed. W. Jongen), Woodhead Publishing, Cambridge, pp. 150–169.
24. Nicolai, B.M., Beullens, K., Bobelyn, E., Peirs, A., Saeys, W., Theron, K.I., and Lammertyn, J. (2007) Nondestructive measurement of fruit and vegetable quality by means of NIR spectroscopy: a review. *Postharvest Biol. Technol.*, **46**, 99–118.
25. Qin, J. and Lu, R. (2008) Measurement of the optical properties of fruits and vegetables using spatially resolved hyperspectral diffuse reflectance imaging technique. *Postharvest Biol. Technol.*, **49**, 355–365.
26. Abbott, J.A., Affeldt, H.A., and Liljedahl, L.A. (2002) Firmness measurement in stored ''Delicious'' apples by sensory methods, Magness-Taylor, and sonic transmission. *J. Am. Soc. Hortic. Sci.*, **117**, 590–595.
27. Mizrach, A. (2008) Ultrasonic technology for quality evaluation of fresh fruit and vegetables in pre- and postharvest processes. *Postharvest Biol. Technol.*, **48**, 315–330.
28. Valero, C., Crisosto, C.H., and Slaughter, H. (2007) Relationship between non-destructive firmness measurements and commercially important ripening fruit stages for peaches, nectarines and plums. *Postharvest Biol. Technol.*, **44**, 248–253.
29. Evans, K., Garcia, S., Douglas-Mickey, J., Schroen, J.P., and Hitchcock, B. (2009) Method for producing juice having pre-selected properties and characteristics. US Patent 2,009,081,339 (A1).
30. Selman, J.D. (1987) The blanching process, in *Developments in Food Processing*, Vol. 4 (ed. S. Thorne), Elsevier Applied Science, London, pp. 205–249.
31. Chang, P.Y. (2000) Sulfites and food, in *Encyclopaedia of Food Science and Technology*, Vol. 4 (ed. F.J. Francis), John Wiley & Sons, Ltd, Chichester, pp. 2218–2220.
32. Bender, A.F. (1987) Nutritional changes in food processing, in *Developments in Food Processing*, Vol. 4 (ed. S. Thorne), Elsevier Applied Science, London, pp. 1–34.
33. Ghorpade, V.M., Hanna, M.A., and Kadam, S.S. (1995) *Handbook of Fruit Science and Technology: Production, Composition, Storage and Processing*, Marcel Dekker, New York, pp. 335–361.