Part II

Ambient-temperature processing

Methods used to prepare freshly harvested or slaughtered food for further processing (Chapter 3), to alter the size of foods (Chapter 4), to mix ingredients (Chapter 5) or to separate components of food (Chapter 6) are each essential unit operations in nearly all food processes. They are used to prepare specific formulations, to aid subsequent processing, or to alter the sensory characteristics of foods to meet the required quality. In each of these unit operations the sensory characteristics and nutritional properties of foods may be changed by removal of components or by the action of naturally occurring enzymes, but there is negligible damage to food quality due to heat.

Over the last ten years, consumer demand has increasingly required processed foods to have a more ‘natural’ flavour and colour, with a shelf life that is sufficient for distribution and home storage before consumption. There have been significant developments in processes that do not significantly heat the food and are thus able to retain to a greater extent their nutritional quality and sensory characteristics. Traditionally, fermented foods (Chapter 7) have many of these characteristics, and irradiation (Chapter 8) has been adopted in some countries as a minimal method of food preservation. There has also been increasing interest in developing other novel methods to achieve mild preservation, for example processing using electric fields, high hydrostatic pressure, pulsed light and ultrasound (Chapter 9). The principle underlying the use of mild processing involves the use of combinations of these low temperature unit operations with refrigerated storage and distribution (Chapter 19) and packaging (Chapters 24 and 25). Each minimal processing method destroys or inhibits microbial growth, and in some cases enzyme activity, but there are no substantial increases in product temperature. There is therefore little damage to pigments, flavour compounds or vitamins and, in contrast to heat processing (Part III), the sensory characteristics and nutritional value of foods are largely retained.
At the time of harvest or slaughter, most foods are likely to contain contaminants, to have components which are inedible or to have variable physical characteristics (for example shape, size or colour). It is therefore necessary to perform one or more of the unit operations of cleaning, sorting, grading or peeling to ensure that foods with a uniformly high quality are prepared for subsequent processing. It is not possible to produce high quality processed foods from substandard raw materials and these mechanical separation procedures, which are applied near the beginning of a process, are a highly cost-effective method of improving the quality of the raw material. Further details are given by Leniger and Beverloo (1975) and applications of these techniques to fruit processing are described by Woodroof (1975). Other separation operations are described in Chapter 6.

3

Raw material preparation

3.1 Cleaning

Cleaning is the unit operation in which contaminating materials are removed from the food and separated to leave the surface of the food in a suitable condition for further processing. A classification of the type of contaminants found on raw foods is shown in Table 3.1.

Peeling fruits and vegetables (Section 3.4), skinning meat or descaling fish may also be considered as cleaning operations. In vegetable processing, blanching (Chapter 10) also helps to clean the product.

The presence of contaminants (or foreign bodies) in processed foods is the main cause of prosecution of food companies. An analysis of the types of contaminants is given in Fig. 3.1. Methods that are used to remove foreign bodies are discussed below.

Cleaning should take place at the earliest opportunity in a food process both to prevent damage to subsequent processing equipment by stones, bone or metals, and to prevent time and money from being spent on processing contaminants which are then discarded. In addition, the early removal of small quantities of food contaminated by micro-organisms prevents the subsequent loss of the remaining bulk by microbial growth during storage or delays before processing. Cleaning is thus an effective method
of reducing food wastage, improving the economics of processing and protecting the
consumer.

Equipment for cleaning is categorised into wet procedures (for example soaking,
spraying, flotation washing and ultrasonic cleaning) and dry procedures (separation by
air, magnetism or physical methods). The selection of a cleaning procedure is determined
by the nature of the product to be cleaned and by the types of contaminant to be removed.
In general, more than one type of cleaning procedure is required to remove the variety of
contaminants found on most foods.

### 3.1.1 Wet cleaning

Wet cleaning is more effective than dry methods for removing soil from root crops or
dust and pesticide residues from soft fruits or vegetables. It is also dustless and causes
less damage to foods than dry methods. Different combinations of detergents and
sterilants at different temperatures allow flexibility in operation. However, the use of
warm cleaning water may accelerate chemical and microbiological spoilage unless
careful control is exercised over washing times and subsequent delays before processing.
Furthermore wet procedures produce large volumes of effluent, often with high

<table>
<thead>
<tr>
<th>Type of contaminant</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metals</td>
<td>Ferrous and non-ferrous metals, bolts, filings</td>
</tr>
<tr>
<td>Mineral</td>
<td>Soil, engine oil, grease, stones</td>
</tr>
<tr>
<td>Plant</td>
<td>Leaves, twigs, weed seeds, pods and skins</td>
</tr>
<tr>
<td>Animal</td>
<td>Hair, bone, excreta, blood, insects, larvae</td>
</tr>
<tr>
<td>Chemical</td>
<td>Fertiliser, pesticides, herbicides</td>
</tr>
<tr>
<td>Microbial cells</td>
<td>Soft rots, fungal growth, yeasts</td>
</tr>
<tr>
<td>Microbial products</td>
<td>Colours, flavours, toxins</td>
</tr>
</tbody>
</table>

* Not to be confused with adulterants (chemicals intentionally added to food which are forbidden by law) or
  additives (chemicals added to food to improve eating qualities or shelf life).
Adapted from Brennan et al. (1990).

![Fig. 3.1 Types of contaminants leading to prosecution in UK (1988–1994).](From Graves et al. (1998).)
concentrations of dissolved and suspended solids (measured as biological oxidation demand (BOD) or chemical oxidation demand (COD)). There is then a requirement both to purchase clean water and to either pay for high effluent disposal charges or build in-factory water treatment facilities (also Chapter 26). To reduce costs, recirculated, filtered and chlorinated water is used whenever possible. Examples of wet-cleaning equipment include spray washers, brush washers, drum or rod washers, ultrasonic cleaners and flotation tanks. They are described in detail by Brennan et al. (1990).

3.1.2 Dry cleaning
Dry cleaning procedures are used for products that are smaller, have greater mechanical strength and possess a lower moisture content (for example grains and nuts). After cleaning, the surfaces are dry, to aid preservation or further drying. Dry procedures generally involve smaller cheaper equipment than wet procedures do and produce a concentrated dry effluent which may be disposed of more cheaply. In addition, plant cleaning is simpler and chemical and microbial deterioration of the food is reduced compared to wet cleaning. However, additional capital expenditure may be necessary to prevent the creation of dust, which not only creates a health and explosion hazard but also recontaminates the product.

The main groups of equipment used for dry cleaning are:
- air classifiers
- magnetic separators
- separators based on screening of foods (Section 3.2.1).

Classifiers (for example Fig. 3.2) use a moving stream of air to separate contaminants from foods by differences in their densities. They are widely used in harvesting machines to separate heavy contaminants (for example stones) and light contaminants (for example leaves, stalks and husks) from grain or vegetables. Calculation of the air velocity required for separation is described in Chapter 1 (Equation (1.11)).

3.1.3 Removing contaminants and foreign bodies
Physical separation of contaminants from foods is possible when the food has a regular well-defined shape. For example round foods (peas, blackcurrants and rapeseed) are

![Fig. 3.2 Separation of chaff from grain by aspiration cleaning.](image)
separated from contaminants by exploiting their ability to roll down an inclined, upward moving conveyor belt. Contaminants, such as weed seeds in rape-seed or snails in blackcurrants, are carried up the conveyor and separated. A disc separator, used to separate grain from weed seeds, consists of a series of vertical metal discs with precisely engineered indentations in the sides that match the shape of the grain. As the discs rotate, the grain is lifted out and removed (Brennan et al., 1990). Screens (Section 3.2.1) are also used to remove contaminants from foods.

Contamination by metal fragments or bolts from machinery is a potential hazard in all processing. Raw materials may pass through metal detectors before processing and all packaged foods are checked for contamination. Details are given in Chapter 25. Ferrous metals are removed by either permanent magnets or electromagnets. Electromagnets are easier to clean (by switching off the power supply) but permanent magnets are cheaper. However, unless regularly inspected, permanent magnets may build up a mass of metal which is lost into the food all at once to cause gross recontamination (Anon., 1991).

Small-particulate foods may be automatically checked for contaminants using microprocessor controlled colour sorting equipment (also Section 3.2.2). For example, coffee beans are viewed in ultraviolet light to cause bacterial contaminants to fluoresce (Anon., 1982). More recent developments enable contaminants having the same colour, but a different shape to the product, to be removed (for example green stalks from green beans).

X-rays are used to detect metals and other types of solid contaminant in both raw materials and inside packaged foods. The X-rays pass through the food as it passes on a conveyor and are converted to visible light by a phosphor strip or screen. The light is magnified and transmitted by fibre optic cables to an image intensifier and video camera. The final image is displayed on a television monitor. The system activates a warning and also automatically rejects the contaminated item (Anon., 1984a; Williams et al., 1983). The system is limited to products that are larger than 15 cm and to date has been mainly applied to glass jar inspection. New developments include the use of solid-state, X-ray sensitive elements which collect a sample of information as the product passes over the

<table>
<thead>
<tr>
<th>Table 3.2</th>
<th>Summary of techniques used in foreign body food inspection</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technique</td>
<td>Wavelength</td>
</tr>
<tr>
<td>Magnetic</td>
<td>N/A</td>
</tr>
<tr>
<td>Capacitance</td>
<td>N/A</td>
</tr>
<tr>
<td>Microwave</td>
<td>1–100 mm</td>
</tr>
<tr>
<td>Nuclear magnetic resonance</td>
<td>1–10 mm + magnetic field</td>
</tr>
<tr>
<td>Infrared Optical</td>
<td>700 nm–1 mm</td>
</tr>
<tr>
<td>Ultraviolet</td>
<td>1–400 nm</td>
</tr>
<tr>
<td>X-rays</td>
<td>&lt;1 nm</td>
</tr>
<tr>
<td>Ultrasonics</td>
<td>N/A</td>
</tr>
</tbody>
</table>

N/A = not applicable.
From Graves et al. (1998).
sensors. This information is modified by sophisticated computer image processing techniques that can compare 300 million points of information from digital images per second, to create a two-dimensional image of the product. Applications include detection of stones, bone fragments, plastics, seafood shells and ceramics or concrete in addition to metals, and also bag-in-box packaging and metallised pouches (Chapter 25), and missing or under-filled packages (Greaves, 1997). Other techniques that are currently under development include nuclear magnetic resonance imaging, microwave, capacitance and ultrasonic detectors (Table 3.2) described by Graves et al. (1998).

3.2 Sorting

Sorting is the separation of foods into categories on the basis of a measurable physical property. Like cleaning, sorting should be employed as early as possible to ensure a uniform product for subsequent processing. The four main physical properties used to sort foods are size, shape, weight and colour.

The effectiveness of a sorting procedure is calculated using

\[
effectiveness = \frac{P \bar{x}_p R (1 - \bar{x}_r)}{F \bar{x}_f F (1 - \bar{x}_f)}
\]

where \( P \) (kg s\(^{-1}\)) = product flow rate, \( F \) (kg s\(^{-1}\)) = feed flow rate, \( R \) (kg s\(^{-1}\)) = rejected food flow rate, \( \bar{x}_p \) = the mass fraction of desired material in the product, \( \bar{x}_f \) = the mass fraction of desired material in the feed and \( \bar{x}_r \) = the mass fraction of desired material in the rejected food.

![Fig. 3.3](image)

Fig. 3.3 Retention of particles on sieves: (A) cumulative percentage, (B) mass fraction.
3.2.1 Shape and size sorting

The particle size distribution of a material is expressed as either the mass fraction of material that is retained on each sieve or the cumulative percentage of material retained (Fig. 3.3) (data from Sample problem 3.1). The mean overall diameter of particles (volume or mass mean diameter) is found using

\[ d_v = \frac{\sum d}{\sum m} \]

where \( d_v (\mu m) \) = volume or mass mean diameter, \( d (\mu m) \) = the average diameter and \( m \) (g) = mass retained on the sieve.

### Sample problem 3.1

A sieve analysis of powdered sugar showed the following results. Calculated the mass mean diameter of the sample.

<table>
<thead>
<tr>
<th>Sieve aperture (( \mu m ))</th>
<th>Mass retained (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>12.50</td>
<td>13.8</td>
</tr>
<tr>
<td>7.50</td>
<td>33.6</td>
</tr>
<tr>
<td>4.00</td>
<td>35.2</td>
</tr>
<tr>
<td>2.50</td>
<td>12.8</td>
</tr>
<tr>
<td>0.75</td>
<td>4.6</td>
</tr>
</tbody>
</table>

### Solution to Sample problem 3.1

The cumulative percentages are as follows.

To find the mass mean diameter, find \( d \) as follows.

<table>
<thead>
<tr>
<th>Average diameter of particles ( d (\mu m) )</th>
<th>( m ) (%)</th>
<th>( d )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.375</td>
<td>4.6</td>
<td>1.725</td>
</tr>
<tr>
<td>1.625</td>
<td>12.8</td>
<td>20.8</td>
</tr>
<tr>
<td>3.25</td>
<td>35.2</td>
<td>114.4</td>
</tr>
<tr>
<td>5.75</td>
<td>33.6</td>
<td>193.2</td>
</tr>
<tr>
<td>10.0</td>
<td>13.8</td>
<td>138.0</td>
</tr>
<tr>
<td>Total</td>
<td>100.0</td>
<td>468.125</td>
</tr>
</tbody>
</table>

From equation (3.2),

\[
\text{mass mean diameter} = \frac{468.125}{100} = 4.68\mu m
\]

Data plotted for cumulative % in Fig. 3.3

<table>
<thead>
<tr>
<th>Aperture size (( \mu m ))</th>
<th>Cumulative percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>12.50</td>
<td>13.8</td>
</tr>
<tr>
<td>7.50</td>
<td>47.4</td>
</tr>
<tr>
<td>4.00</td>
<td>82.6</td>
</tr>
<tr>
<td>2.50</td>
<td>95.4</td>
</tr>
<tr>
<td>0.75</td>
<td>100.0</td>
</tr>
</tbody>
</table>
The shape of some foods is important in determining their suitability for processing or their retail value. For example, for economical peeling, potatoes should have a uniform oval or round shape without protuberences. Cucumbers and gherkins are more easily packaged if they are straight, and foods with a characteristic shape (for example pears) have a higher retail value if the shape is uniform. Shape sorting is accomplished either manually or mechanically (for example the belt-and-roller sorter in Fig. 3.4, or the disc sorter (Section 3.1.2)) or by image processing.

Size sorting (termed sieving or screening) is the separation of solids into two or more fractions on the basis of differences in size. It is particularly important when the food is to be heated or cooled as the rate of heat transfer is in part determined by the size of the individual pieces and variation in size would cause over-processing or under-processing. Additionally, foods which have a uniform size are said to be preferred by consumers. Screens with either fixed or variable apertures are used for size sorting. The screen may be stationary or, more commonly, rotating or vibrating.

Fixed aperture screens
Two common types of fixed aperture screen are the flat bed screen (or sieve) and the drum screen (rotary screen or reel). The multideck flat bed screen (Fig. 3.5) has a number of inclined or horizontal mesh screens, which have aperture sizes from 20 \( \mu \text{m} \) to 125 mm, stacked inside a vibrating frame. Food particles that are smaller than the screen apertures pass through under gravity until they reach a screen with an aperture size that retains them. The smallest particles that are separated commercially are of the order of 50 \( \mu \text{m} \).

The capacity of a screen is the amount of food that passes through per square metre per second. The rate of separation is controlled by:

- the shape and size distribution of the particles
- the nature of the sieve material
- the amplitude and frequency of shaking
- the effectiveness of methods used to prevent blocking (or blinding) of the sieves.

These types of screen are widely used for sorting dry foods (for example flour, sugar and spices). The main problems encountered are:

- excessive moisture or high humidity, which causes small particles to stick to the screen or to agglomerate and form larger particles, which are then discharged as oversize
blinding, particularly if the particle size is close to that of the screen aperture.

- high feed rates, which cause the screens to become overloaded and small particles are discharged with the oversized particles.

Where vibration alone is insufficient to separate particles adequately, a gyratory movement is used to spread the food over the entire sieve area, and a vertical jolting action breaks up agglomerates and dislodges particles that block sieve apertures.

Many types of drum screen are used for sorting small-particulate foods (for example nuts, peas or beans) that have sufficient mechanical strength to withstand the tumbling action inside the screen. Drum screens are almost horizontal (5–10° inclination), perforated metal or mesh cylinders. They may be concentric (one inside another), parallel (foods leave one screen and enter the next (Fig. 3.6)) or series (a single drum...
constructed from sections with different sized apertures). All types have a higher capacity than flat bed screens and problems associated with blinding are less severe than with flat bed screens. The capacity of drum screens increases with their speed of rotation up to a critical point. Above this the food is held against the screen by centrifugal force and results in poor separation. Similarly there is an increase in capacity with the angle of the screen up to a critical angle. Above this the residence time is too short and products pass through without separation.

*Variable-aperture screens*

Variable-aperture screens have either a continuously diverging aperture or a stepwise increase in aperture. Both types handle foods more gently than drum screens and are therefore used to sort fruits and other foods that are easily damaged. Continuously variable screens employ pairs of diverging rollers, cables or felt-lined conveyor belts. These may be driven at different speeds to rotate the food and thus to align it, to present the smallest dimension to the aperture (Fig. 3.7).

Stepwise increases in aperture are produced by adjusting the gap between driven rollers and an inclined conveyor belt (Fig. 3.4). The food rotates and the same dimension is therefore used as the basis for sorting (for example the diameter along the core of a fruit).

![Fig. 3.7 Sorting lemons on a roller sorter.](Courtesy of Sunkist Growers.)
Image processing

Image processing is used to sort foods on the basis of length, diameter, number of surface defects and orientation of the food on a conveyor as well as colour (Section 3.2.2). It has been used for example with maize cobs, which pass beneath three video cameras, placed 120° apart above a conveyor belt. The images of the surface of the cob are recorded and stored in the memory of a microprocessor. The information is then analysed and compared with pre-programmed specifications for the product, and the cob is either rejected or moved into a group with similar characteristics. In another system a video camera views foods and an operator compares the shapes with an electronic template overlaid on a monitor screen. The template reduces operator fatigue and allows greater concentration on the selection process.

3.2.2 Colour sorting

Manual sorting by colour is still widely used but is increasingly expensive in both labour costs, operator training and the space required for sorting tables. There has therefore been considerable development of machine vision sorting systems which are said to have lower operating costs and greater accuracy than manual methods. These include monochrome (black and white), bichrome (4100 shades of red and green) and trichromatic or full colour (262 000 shades of red, green and blue, with optional infra-red). Each is controlled by a programmable logic controller (Chapter 2) which has pre-set programs for different products that are easily changeable by operators using a video display. They are used for example, to sort potatoes for defects and blemishes by identifying dark areas on the potato surface. Light sensitive cells in the camera (termed ‘pixels’) produce a voltage that is proportional to the intensity of light received. An electronic circuit that receives a lower voltage than the pre-set value can thus detect darker objects or areas which reflect less light than normal. The voltage produced in the electronic circuit can be adjusted to alter the sensitivity of detection. Up to 10 tonnes of product per hour pass beneath the cameras on conveyors operating at 150–180 m per min.

Defective items are removed by electronically controlled air jets that can operate for 20 milliseconds, thus covering 50 mm of the belt length in a single blast (Heffington and Nilsson, 1990). In another system, vegetables in free-fall are scanned 1000 times per second, as they leave a conveyor belt, using concentrated helium-neon or laser light beams and a high-speed rotating mirror. The machine detects differences in reflectivity between good product and unwanted material. Gangi et al. (1983) describe a similar system to sort tomatoes as they are discharged from a conveyor.

Small-particulate foods may be automatically sorted at high rates (up to 16 tonnes h⁻¹) using microprocessor controlled colour sorting equipment (Fig. 3.8). Particles are fed into the chute one at a time. The angle, shape and lining material of the chute are altered to control the velocity of the pieces as they pass a photodetector. The colour of the background and the type and intensity of the light used for illuminating the food (including infrared and ultraviolet options) are closely controlled for each product. Photodetectors measure the reflected colour of each piece and compare it with pre-set standards, and defective foods are separated by a short blast of compressed air. The computer can store 100 named product configurations to enable rapid changeover to different products using an operator touchpad. Typical applications include peanuts, Michigan Navy beans (for baked beans), rice, diced carrot, maize kernels, cereals, snackfoods and small fruits. Developments in colour measurement are described in detail by Brimelow and Groesbeck (1993) and advances in colour sorting described by Low and Maughan (1993).
A different type of equipment employs a sensor located above a conveyor belt, which views products as they pass beneath. The sensor detects up to eight colours and provides an alarm or control signal whenever a pre-selected colour passes the detector beam. It is also able to distinguish between different coloured foods which are to be processed separately. In a more sophisticated system, foods which have variations in colour over their surface are colour sorted by image processing. The foods are fed in rows on a roller conveyor beneath a video camera. The relative intensities of reflected red, green and yellow light are transmitted to the microcomputer which constructs a composite image of each piece of food, showing both the spread of colour and the mean colour of inspected foods. The computer compares the constructed image with pre-set specifications and activates a compressed air ejector or a mechanical deflector to remove rejected food. When this type of system is used to sort baked goods, it is also used to control directly the gas or electricity supply to the ovens, which is reported to reduce energy consumption in ovens by 20% (Philpotts, 1983). The sorter can be easily adapted to different foods, by operators using the microprocessor keypad (see also Chapters 2, 16 and 26).

3.2.3 Weight sorting
Weight sorting is more accurate than other methods and is therefore used for more valuable foods (for example eggs, cut meats and some tropical fruits). Eggs are sorted at
up to 12 000 h\(^{-1}\) into six to nine categories with a tolerance of 0.5 g. They are first graded by ‘candling’ (Section 3.3) and then pass to the weight sorter (Fig. 3.9). This consists of a slatted conveyor which transports the eggs above a series of counterbalanced arms. The conveyor operates intermittently and while stationary, the arms raise and weigh the eggs. Heavy eggs are discharged into a padded chute and lighter eggs are replaced on the conveyor to travel to the next weigher.

Aspiration and flotation sorting use differences in density to sort foods and are similar in principle and operation to aspiration and flotation cleaning. Grains, nuts and pulses are sorted by aspiration. Peas and lima beans are sorted by flotation in brine (specific gravity, 1.1162–1.1362). The denser, starchy, over-mature pieces sink whereas the younger pieces float.

The collation of foods which have variable weight, for example frozen fish fillets, into bulk packs which have a uniform declared weight is time consuming and laborious. It is normally performed by operators who select items of food from a pool of materials and collate them by trial and error into a pack which is as close as possible to the required weight. There is frequently a large give-away to ensure compliance with fill-weight legislation. Collation sorting is now performed automatically by a microcomputer. Items of food are weighed and placed in a magazine. Their weights are stored by a microcomputer which then selects the best combination of items to produce the desired number in a pack, with a minimum give-away. The foods are packed and the next best combination is selected until the limit on allowable weight cannot be achieved. Other examples of microprocessor-controlled weighing are described in Chapters 2 and 26.

Fig. 3.9  Egg sorter.
(Courtesy of Ben Nevis Packaging Ltd.)
3.3 Grading

This term is often used interchangeably with sorting but strictly means ‘the assessment of overall quality of a food using a number of attributes’. Sorting (that is separation on the basis of one characteristic) may therefore be used as part of a grading operation but not vice versa. Grading is carried out by operators who are trained to simultaneously assess a number of variables. For example, eggs are visually inspected over tungsten lights (termed ‘candling’) to assess up to twenty factors and remove those that are for example, fertilised or malformed and those that contain blood spots or rot. Meats, for example, are examined by inspectors for disease, fat distribution, bone to flesh ratio and carcass size and shape. Developments in meat inspection using image processing and computer analysis to assess a large number of factors, including bruising, skin colour and damage on chicken meat are described by Ade-Hall et al. (1996) (see also Chapter 2). Other graded foods include cheese and tea, which are assessed for flavour, aroma, colour, etc. Apples are graded with the assistance of coloured cards that show the required characteristics of different grades in terms of colour distribution across the fruit, surface blemishes and size and shape of the fruit.

In some cases the grade of food is determined from the results of laboratory analyses (for example wheat flour is assessed for protein content, dough extensibility, colour, moisture content and presence of insects). In general, grading is more expensive than sorting owing to the higher costs of skilled operators. However, many attributes that cannot be examined automatically can be simultaneously assessed, and this produces a more uniform high-quality product.

3.4 Peeling

Peeling is used in the processing of many fruits and vegetables to remove unwanted or inedible material, and to improve the appearance of the final product. The main consideration is to minimise costs by removing as little of the underlying food as possible and reducing energy, labour and material costs to a minimum. The peeled surface should be clean and undamaged. There are five main methods of peeling:

1. flash steam peeling
2. knife peeling
3. abrasion peeling
4. caustic peeling
5. flame peeling.

3.4.1 Flash steam peeling

Foods (for example root crops) are fed in batches into a pressure vessel which is rotated at 4–6 rpm. High-pressure steam \((1500 \times 10^5 \text{ Pa})\) is introduced and all food surfaces are exposed to the steam by the rotation of the vessel for a predetermined time, which differs according to the type of food. The high temperatures cause rapid heating of the surface layer (within 15–30 s) but the low thermal conductivity of the product prevents further heat penetration, and the product is not cooked. Texture and colour are therefore preserved. The pressure is then instantly released which causes steam to form under the skin, and the surface of the food ‘flashes off’. Most of the peeled material is discharged with the steam, and water sprays are needed only to remove any remaining traces. This
type of peeler is gaining in popularity owing to the lower water consumption, minimum product loss, good appearance of the peeled surfaces, a high throughput (up to 4500 kg h\(^{-1}\)) with automatic control of the peeling cycle, and the production of a more easily disposable concentrated waste (Anon., 1984b).

3.4.2 Knife peeling
Stationary blades are pressed against the surface of rotating fruits or vegetables to remove the skin. Alternatively the blades may rotate against stationary foods. This method is particularly suitable for citrus fruits where the skin is easily removed and there is little damage or loss of fruit.

3.4.3 Abrasion peeling
Food is fed onto carborundum rollers or placed into a rotating bowl which is lined with carborundum. The abrasive surface removes the skin and it is washed away by a copious supply of water. The advantages of the method include low energy costs as the process operates at room temperature, low capital costs, no heat damage and a good surface appearance of the food. Irregular product surfaces (for example ‘eyes’ on potatoes) may mar the appearance of the peeled product and require hand finishing. The limitations of the method are:

- a higher product loss than flash peeling (25% compared with 8–18% losses, for vegetables)
- the production of large volumes of dilute waste which are difficult and expensive to dispose of
- relatively low throughputs as all pieces of food need to contact the abrasive surfaces.

An exception is the peeling of onions where the skin is easily removed by abrasive rollers at production rates of up to 2500 kg h\(^{-1}\).

3.4.4 Caustic peeling
A dilute solution of sodium hydroxide (named lye) is heated to 100–120°C. In the older method of lye peeling, food is passed through a bath of 1–2% lye which softens the skin and the skin is then removed by high-pressure water sprays. Product losses are of the order of 17%. Although once popular for root crops, this method causes changes in the colour of some products and incurs higher costs. It is now largely replaced by steam or flash peeling. A development of lye peeling is named dry caustic peeling. Food is dipped in 10% sodium hydroxide and the softened skin is removed with rubber discs or rollers. This both reduces water consumption and product losses and gives a concentrated skin ‘paste’ which is more easily disposed of.

3.4.5 Flame peeling
Developed for onions, this peeler consists of a conveyor belt which carries and rotates the food through a furnace heated to 1000°C. The outer ‘paper shell’ and root hairs are burned off, and the charred skin is removed by high-pressure water sprays. Average product losses are 9%. 

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3.5 Acknowledgements

Grateful acknowledgement is made for information supplied by the following: Sortex Ltd, London E15 2PJ, UK; Loma Engineering Ltd, Farnborough, Hants GU14 0NY, UK; Spectron Instruments Ltd, Abingdon, Oxfordshire, UK; Gough and Co. Ltd, Hanley, Stoke on Trent, Staffordshire ST1 4AP, UK; Backus Sormac BV, Venlo, Holland; Goring Kerr, Windsor, Berkshire, UK; Ben Nevis Packaging Ltd, Trowbridge, Wiltshire BA14 8AB, UK; Sunkist Growers Ltd, California, USA; Flo-Mech Ltd, Peterborough PE2 0YA, UK.

3.6 References


