FOOD PROCESSING 2

Module- 34
Lec- 34

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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 UK, 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 which are available throughout the year, such as milk, there are established peaks and troughs in volume of production, as well as variation 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 synchronise their needs with raw material production.

The basic physical characteristics of foods and food products

Since the physical characteristics of plant and animal food materials affect how they are to be processed, handled, stored, and consumed, knowledge of these characteristics are important to engineers, processors and food scientists, plant and animal breeders, and other scientists.

The following provides a list of various properties -

Physical Characteristics

1. Shape
2. Size
Physical Characteristics

1. Shape
2. Size
3. Weight
4. Volume
5. Surface area
6. Density
7. Porosity
8. Color
9. Appearance
10. Drag coefficient
11. Center of gravity
Mechanical Properties

1. Hardness
2. Compressive strength
3. Tensile strength
4. Impact resistance
5. Shear resistance
6. Compressibility
7. Sliding coefficient of friction
8. Static coefficient of friction
9. Coefficient of expansion
   a. moisture
   b. thermal
10. Elasticity
11. Plasticity
12. Bending strength
13. Aerodynamic properties
14. Hydrodynamic properties

Properties of Raw Food Materials

- 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 final consumer, or the food processor).
• Geometric properties, colour, flavour, 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 methods and postharvest conditions, maturity, storage and postharvest handling also determine quality.
• The timing and method of harvesting are determinants of product quality. Manual labour is expensive, therefore mechanised harvesting is introduced where possible. Cultivars most suitable for mechanised harvesting should mature evenly producing units of nearly equal size that are resistant to mechanical damage.
• 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, hard texture and a lack of flavour and colour.
• 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.
• 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 flavour may be less suitable for canning than harder, less flavoursome cultivars, which can withstand rigorous processing conditions.
- Similarly, ripe, healthy, well coloured fruit may be perfect for fresh sale, but may not be suitable for freezing due to excessive drip loss while thawing.
Raw Material Properties

The main raw material properties of importance to the processor are

- Geometry,
- Colour,
- Texture,
- Flavour,
- Functional properties.

Geometric Properties

- Food units of regular geometry are much easier to handle and are better suited to high speed mechanised 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 harbour 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.

for example

- It may be important to determine how much mass or how many units may be filled into a square box or cylindrical can.

- 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.

- 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.
- 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 the optimum geometric characteristics: firstly the selection of appropriate varieties, and secondly sorting and grading operations.

**Colour**

- Colour and colour uniformity are vital components of 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 colour changes little during processing, and thus the colour of the raw material is a good guide to suitability for processing.
- For more severe processing, the colour may change markedly during the process. Green vegetables, such as peas, spinach or green beans, on heating change colour from bright green to a dull olive green. This is due to the conversion of chlorophyll to pheophytin.
- There are two approaches: i.e. procuring raw materials of the appropriate variety and stage of maturity, and sorting by colour to remove unwanted units.

**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 solubilisation of proteins.
• 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 recognised instrument is the tenderometer used to assess the firmness of peas.

**Flavour**

• Flavour is a rather subjective property which is difficult to quantify. Again, flavours are altered during processing and, following severe processing, the main flavours may be derived from additives.
• Hence, the lack of strong flavours may be the most important requirement. In fact, raw material flavour is often not a major determinant as long as the material imparts only those flavours which are characteristic of the food.
• Flavour is normally assessed by human tasters, although sometimes flavour can be linked to some analytical test, such as sugar/acid levels in fruits.

**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 11.5–14.0% protein is desirable for white bread and some wholewheat breads require even higher protein levels, 14–16%.
- 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.
Deterioration of Raw Materials

- All raw materials deteriorate following harvest, by some of the following mechanisms:
  - **Endogenous enzymes:** e.g. post-harvest 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:** deterioration in sensory quality by lipid oxidation, nonenzymic browning, breakdown of pigments such as chlorophyll, anthocyanins, carotenoids.
  - **Nutritional changes:** especially ascorbic acid breakdown.
  - **Physical changes:** dehydration, moisture absorption.
  - **Biological changes:** germination of seeds, sprouting.
  - **Microbiological contamination:** both the organisms themselves and toxic products lead to deterioration of quality, as well as posing safety problems.

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.

Damage to Raw Materials:

- External forces result in mechanical injury to fruits and vegetables, cereal grains, eggs and even bones in poultry. They occur due to severe handling as a result of careless manipulation, poor equipment design, incorrect containerisation 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 mechanisation in food handling must be carefully designed to minimise 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 moulds and rots.

Improving Processing Characteristics

• Selective breeding for yield and quality has been carried out for centuries in both plant and animal products. Until the 20th century, improvements were made on the basis of selecting the most desirable looking individuals, while increasingly systematic techniques have been developed more recently, based on a 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).
• Raw material quality, especially in relation to processing, has become increasingly important.

Selective Plant Breeding

• 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 flavour, texture and colour 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, e.g. 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 programmes have been used at different times to maximise 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. Hence, selective breeding could be used to tailor milk supplies to the manufacture of specific dairy products.

Genetic engineering

☐ Traditional breeding programmes 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, but there is enormous potential in genetically engineered raw materials for processing.

☐ The following are some examples which have been demonstrated:

- tomatoes which do not produce pectinase and hence remain firm while colour and flavour 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:
  (a) high levels of lauric acid to improve emulsification properties for use in confectionery, coatings or low fat dairy products,
  (b) high levels of stearate as an alternative to hydrogenation in manufacture of margarine,
  (c) high levels of polyunsaturated fatty acids for health benefits;
- wheat with increased levels of high molecular weight glutenins for improved bread making performance;
➢ fruits and vegetables containing peptide sweeteners such as thaumatin or monellin;
➢ ‘naturally decaffeinated’ coffee.

Storage of Raw Materials

☐ 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 nonlocal 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: firstly, 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 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:

➢ living organisms such as vermin, insects, fungi and bacteria: these may feed on the food and contaminate it;
➢ 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;
➢ physical processes, including damage due to pressure or poor handling, physical changes such as dehydration or crystallisation.
The main factors which 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 tissue damage. 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.

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. Nonclimacteric fruits, e.g. citrus fruit, pineapples, strawberries, and vegetables do not display this behaviour and generally do not ripen after harvest. Quality is therefore optimal at harvest, and the task is to preserve quality during storage.

**Typical Storage Conditions**

**Table 1 Storage periods of some fruits and vegetables under typical storage conditions.**

<table>
<thead>
<tr>
<th>Commodity</th>
<th>Temperature (°C)</th>
<th>Humidity (%)</th>
<th>Storage period</th>
</tr>
</thead>
<tbody>
<tr>
<td>Garlic</td>
<td>0</td>
<td>70</td>
<td>6–8 months</td>
</tr>
<tr>
<td>Mushrooms</td>
<td>0</td>
<td>90–95</td>
<td>5–7 days</td>
</tr>
<tr>
<td>Green bananas</td>
<td>11–15</td>
<td>85–90</td>
<td>10–30 days</td>
</tr>
<tr>
<td>Immature potatoes</td>
<td>4–5</td>
<td>90–95</td>
<td>3–8 weeks</td>
</tr>
<tr>
<td>Mature potatoes</td>
<td>4–5</td>
<td>90–95</td>
<td>4–9 months</td>
</tr>
<tr>
<td>Onions</td>
<td>−1 to 0</td>
<td>70–80</td>
<td>6–8 months</td>
</tr>
<tr>
<td>Oranges</td>
<td>2–7</td>
<td>90</td>
<td>1–4 months</td>
</tr>
<tr>
<td>Mangoes</td>
<td>5.5–14</td>
<td>90</td>
<td>2–7 weeks</td>
</tr>
<tr>
<td>Apples</td>
<td>−2 to 4</td>
<td>90–95</td>
<td>1–8 months</td>
</tr>
<tr>
<td>French beans</td>
<td>7–8</td>
<td>95–100</td>
<td>1–2 weeks</td>
</tr>
</tbody>
</table>
• 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 mould growth and subsequently must be stored under conditions which prevent infestation with rodents, birds, insects or moulds.
• 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.

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 $10^\circ$ C rise, or conversely that shelflife would double for each $10^\circ$ C C reduction. This is an oversimplification, as $Q_{10}$ may change with temperature. Most insect activity is inhibited below $4^\circ$ 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 $0^\circ$ 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 $3^\circ$ C, while bananas become brown when stored below $13^\circ$ 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 the starch/sugar balance in potatoes: in particular below 10 °C a build up of sugar occurs, which is most undesirable for fried products.

- 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, shelflife 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.

**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, whilst water loss results in economic loss and 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 mould 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.
Composition of Atmosphere

- Controlling the atmospheric composition during storage of many raw materials is beneficial. 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 flavours. In living produce, atmosphere control allows the possibility of slowing down metabolic processes, hence retarding respiration, ripening, senescence and the development of disorders. The aim is to introduce N2 and remove O2, allowing a build up of CO2.
- Controlled atmosphere storage technique allows year-round distribution of apples and pears, where controlled atmospheres in combination with refrigeration can give shelflives up to 10 months, much greater than by chilling alone.
- The particular atmospheres are cultivar specific, but in the range 1–10% CO2, 2–13% O2 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% O2 and 5% CO2 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 colour by storage in high O2 concentrations, which shifts the equilibrium in favour of high concentrations of the bright red oxymyoglobin pigment. At the same time, high levels of CO2 are required to suppress the growth of aerobic bacteria.

Other Considerations

- Odours 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. Odours 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.

**Transportation of Raw Materials**

• Food transportation is an essential link in the food chain. 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 nonlocal 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 wideranging 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.

**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 etc.;
- pesticides and fertilisers;
- mineral oil;
- microorganisms and their toxins.

• Cleaning is essentially separation 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 employed 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.

**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 are essentially size separators based on perforated beds or wire mesh. Larger contaminants are removed from smaller food items: e.g. straw from cereal grains, or pods and twigs from peas. This is termed ‘scalping’.

- Alternatively, ‘dedusting’ is the removal of smaller particles, e.g. sand or dust, from larger food units.

- The main geometries are rotary drums (also known as reels or trommels), and flatbed designs.

![Diagram of screening process](image)

Figure 1 Screening of dry particulate materials: (a) scalping, (b) dedusting.
Figure 2 9(a)Screen geometries: (b) principle of flatbed screen.
- Abrasion, either by impact during the operation of the machinery, or aided by abrasive discs or brushes, can improve the efficiency of dry screens. Screening gives incomplete separations and is usually a preliminary cleaning stage.

- Aspiration 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.

**Principle of aspiration cleaning**

- 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 this 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 or denser small stones. Very accurate separations are possible, but large amounts of energy are 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.

**Principle of aspiration cleaning**

![Figure 3 Principle of aspiration cleaning](image-url)
Magnetic cleaning

- Magnetic cleaning 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, for example cereal mills. The geometry of magnetic cleaning systems can be quite variable: particulate foods may be passed over magnetised drums or magnetised 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

- Electrostatic cleaning 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 it 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.

![Diagram of electrostatic cleaning](image)

**Figure 4** Principle of electrostatic cleaning.
Wet Cleaning Methods

- Wet methods are necessary if large quantities of soil are to be removed; and they are essential if detergents are used. However, they are 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 requirements and effluent volumes if accurately controlled.
- Sanitising 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. 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

- 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.
The two most common designs are drum washers and belt washers. Abrasion may contribute to the cleaning effect, but again must be limited in delicate units. Other designs include flexible rubber discs which gently brush the surface clean.

![Diagram of water spray cleaning](image)

**Figure 5  Water spray cleaning:**(a) spray belt washer,(b) drum washer.

**Flotation washing**

- 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.

  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 an 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.
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.
  - 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.

Figure 6 Principle of flotation washing.
- 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.

**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”. 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 kind 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 units of uniform size or colour. In addition, it is much easier to control processes such as sterilisation, dehydration or freezing in sorted food units; and they are also better suited to mechanised operations such as size reduction, pitting or peeling.

**Criteria and Methods of Sorting**

- Sorting is carried out on the basis of individual physical properties.
- *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

- Size sorting is less precise than weight sorting, but is considerably cheaper.
- The size and shape of food units are difficult to define precisely. Size categories could involve 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.
- The main categories of screens are fixed aperture and variable aperture designs.
- Flatbed and rotary screens are the main geometries of the 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 more gentle and are commonly used with larger, more delicate items such as fruit.
Feed into central screen

smallest

largest

a)

Widening gap between rollers

Smaller units fall here

Larger units move downhill where gap is larger and fall here

Driven Rollers

b)
Figure 7  Geometries of size sorting equipment ; (a) concentric drum screen. (b) roller size sorter. (c) belt and roller sorter.

Shape sorting & Density

- 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 discs 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.

- 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
Photometric properties may be used as a basis for sorting. In practice this usually means colour.

Colour is often a measure of maturity, presence of defects or the degree of processing. Manual colour sorting is carried out widely on conveyor belts 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 coloured, 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.

**Colour sorting**

Extremely high throughputs have been reported. By using more than one photocell positioned at different angles, blemishes on large units such as potatoes can be detected.

Colour 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 for the internal examination, or ‘candling’, of eggs.

**Grading**

Grading is classification on the basis of quality (incorporating commercial value, end use and official standards, and hence requires that some judgement 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 are designed to present the whole surface to the operator.

Trained manual operators are frequently used to judge the quality, and may use comparison to charted standards, or even plastic models. For example, a fruit grader could simultaneously judge shape, colour, evenness of colour 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 fertilisation, can be detected.

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.

**Food Preservation and Protection**

- Six basic methods: dehydration, heating, freezing, fermentation, chemical preservation, or irradiation.
- Dehydration (drying)
  - prevents rotting of meat
  - Inhibits germination/sprouting of stored grains/vegetables
  - inhibits the growth of microorganisms
- Heating
  - destroys bacteria causing disease/spoilage
  - Examples: canning, pasteurization, and cooking
  - heated to a specific temperature for a specific time
- Freezing
  - basically stops bacterial growth and enzymatic activity
- Fermentation
  - gradual chemical change caused by the enzymes of bacteria, molds, and yeasts
- Cheeses with a long shelf life are produced by lactic-acid fermentation
- Pickling—by treating foods with vinegar or some other acid

- Food additives have been
  - Used for thousands of years
  - Effective preservatives

- Irradiation
  - Exposing food to radiation source, most often Co\textsubscript{60} or Ce\textsubscript{137}
  - Beginning to be accepted in the food industry
  - Kill pathogenic bacteria and spoilage microorganisms on everyday type foods
  - Used on spices and other foods for over 50 years

- Processing methods
  - Employed to utilize technologies to reduce/eliminate microbial loads on foods