SELECTED ARTICLES

TROPICAL FRUITS AND VEGETABLES. AN ACCOUNT OF THEIR STORAGE AND TRANSPORT*

INTRODUCTION

IN this publication an attempt has been made to bring together an account of the storage and transport of a number of fruits and vegetables indigenous to, or capable of being grown in, the tropics. The successful cold storage of each commodity depends on a number of factors, including the variety, environmental conditions of growth, the maturity at which it is harvested, the rapidity and care with which it is removed to cold storage, the actual temperature, humidity and duration of storage, and the time required for distribution on removal from storage. Where available, information on these several topics has been included.

With rare exceptions tropical fruits are notoriously subject to wastage. Great care in handling and, almost invariably, the use of refrigeration are necessary before uniform supplies of attractive fruit can be made available on temperate markets.

Much of the literature on tropical fruit and vegetable storage is fragmentary and inconclusive, partly because the science of food preservation as a whole is yet in its infancy, partly because pre-storage factors exercise a profound influence on the subsequent storage life. Thus, a storage temperature found to be optimal for a particular fruit in one country may be quite unsuitable for the same fruit grown elsewhere. The investigator of such problems is, accordingly, brought into sharp contact with the many physiological problems pertaining to the development, ripening and senescence of fruits, and in particular with the effect of low temperatures on the processes of metabolism. In this paper, attention will be restricted to the major practical issues.

A surprising number of vegetables, usually regarded as temperate or warm temperate in habitat, have now been grown with a fair measure of success in the tropics. As progress is made in the breeding, selection and acclimatisation of new varieties, the production of such vegetables in the tropics will increase, if not for export at least for local consumption. The value of the short but highly productive cropping period, characteristic of tropical

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conditions, can be greatly increased where refrigeration facilities are available to extend the consumption period. So far the relevant storage literature is scanty, and, of necessity, many of the storage temperatures cited refer to produce obtained under temperate conditions. While such data may be used as a guide in arranging local storage trials, it will generally be found that tropical produce requires higher storage temperatures in order that chilling may be avoided.

The uses to which refrigeration may be put in the handling of tropical produce are many and various. Cold storage may be resorted to in order to avoid glut periods locally or unfavourable marketing periods abroad. Where intended for export, fruit may be harvested relatively immature, transported at a suitably low temperature (which retards but does not entirely arrest maturation processes) and subsequently ripened at a higher temperature. On the other hand, the fruit may be harvested when it is practically "eating-ripe," and held at a low temperature until required for immediate consumption. As a rule, rapid cooling after harvesting is desirable. In some instances the practice of pre-cooling fruit is adopted: by this term is inferred the rapid cooling of fruit to the required transport temperature prior to its being stowed in the refrigerated hold ; this procedure has the advantage of giving uniformity of temperature to bulk consignments, and cooling at rates generally in excess of that possible on shipboard.

The prime factor in the overseas transport of perishable tropical produce is, of course, the refrigerated ship. The absence of suitable shipping has been and still is the chief obstacle to the wider utilisation of tropical produce. The type of cold-storage installation is important. As the tissues of stored fruits and vegetables are still alive, they require environmental conditions which will permit of approximately normal, though retarded, maturation so that the appearance, flavour, texture, aroma and other qualities for which they are prized, will be preserved. In general, the equipment and design of refrigerated holds should be such as to permit of rapid cooling, the maintenance of the steady temperature, relative humidity, and, if necessary, gas concentrations optimal for the fruit in question. In particular, carriage at too low a temperature, resulting in various types of chilling, which may be manifest during storage or subsequent distribution, should be avoided. Where, as in the older type of refrigerated ship, the holds are cooled by wall-grids, the resulting lack of uniformity in temperature involves considerable danger of chilling in the fruit in proximity to the grids and fungal wastage in the fruit remote from the grids where temperatures are high. In modern fruit ships this system is no longer used, refrigeration being supplied in the form of circulating air cooled to the required temperature by passing over cold pipes (the battery or air-blast system). The circulating air, which in time becomes vitiated by the carbon dioxide of respiration and by volatile substances given off by the fruit—which may accelerate ripening—is periodically discharged and a fresh supply taken into circulation.

The part which refrigeration can play in local food economics in the tropics should not be overlooked. Every year sees an increase in the extent to which it is being applied in the preservation of perishable prcduce. Its rational use cannot fail to be profoundly beneficial not only in handling produce intended for export but also in the conservation of locally prcduced foodstuffs.

ARTICHOKES

Two distinct and botanically unrelated kinds of artichoke are known : the true artichoke, known as the globe or French artichoke (*Cynara scolymus—C. cardunculus*) is a thistle-like plant, native to the Mediterranean region, the edible portion being the unopened flower buds. The Jerusalem artichoke or girasole (*Helianthus tuberosus*), which is neither an artichoke nor native to Palestine—it is of N. American origin—is grown almost exclusively for the edible underground tubers.

THE GLOBE ARTICHOKE

The heads are cut when they have attained their greatest size prior to the appearance of the floral parts.

According to Rasmusson the life of artichokes can be prolonged by cold storage at 32° to 33·5° F. for an additional period of four months over ordinary storage.

THE JERUSALEM ARTICHOKE

The Jerusalem artichoke or girasole has long been in general use in many European countries. In the United States of America, on the other hand, the plant, though widely known, is little used, and only recently has been given serious attention as a source of raw material for the commercial production of fructose (laevulose) and alcohol. Though the plant is best adapted to temperate regions, it can also be grown with some measure of success in the tropics.

As the tuber periderm is thin and easily ruptured, a rapid loss of moisture takes place when tubers are exposed to room temperatures ; wastage due to micro-organisms may also be considerable. The best method of storage, in temperate countries, consists in leaving tubers in the ground and digging them as required. Among earlier references Rasmusson states that tubers in cold storage at 32° to 33·5° F. kept for four months longer than in ordinary storage. Traub *et al.* in storage trials, observed that artichoke tubers may be successfully stored either as a truck crop or as propagating stock at 32° to 35° F. and relative humidity of 89 to 92 per cent. Under these conditions, tubers were found to have a larger amount of water-soluble carbohydrate per unit green weight than tubers left in the ground over winter. At temperatures above 40° F., stored tubers lose moisture rapidly, shrivel, and are so subject to diseases that the entire consignment may sometimes be lost.

Trinidad-grown tubers, subjected to air-blast refrigeration at 45° F., showed marked symptoms of desiccation (perhaps accompanied by some chill

injury). In still air at 60° F. tubers kept in good condition for two to three weeks but thereafter became mouldy.

ASPARAGUS

All the common varieties of this vegetable have been derived from one species, *Asparagus officinalis*, the genus being native to the Old World. Very full accounts are now available of the methods of planting, cultivating, harvesting and preparing for market.

Large, well-developed crowns or rootstocks are essential to the production of good asparagus. The spears or shoots are cut once or twice per day, according to the rate of growth. If white asparagus is desired the shoots must be cut just as they force their way through the surface of the soil as they quickly become green on exposure to light. In Europe nearly all of the asparagus sold in the fresh condition is white, but in the United States of America, it may be marketed with the spears entirely blanched, almost entirely blanched, with a green tip, or green throughout except for the butts. The green product is now becoming increasingly popular.

During the progress of the cutting season there is an increase in the sugar content of the shoots and a decrease in the protein and lignin. Photosynthesis carried on by shoot itself is thought to be a factor in the recorded sugar increase.

STORAGE OF PROPAGATING CROWNS

Propagating crowns, when hauled from the field, should be placed on a dry floor or on well drained ground. The best storage temperature is about 40° F. but, provided the atmosphere is dry and air circulation among the crowns adequate, storage for long periods at higher temperatures is also feasible. If the crowns become moist either from external dampness or from "sweating" in the heaps, they soon decay. Excessive desiccation of the crowns should be avoided.

PACKING

Fresh asparagus may be packed loose in the crate or bunched and crated, the latter procedure being the more usual. In the large producing areas in California, well equipped packing houses are provided for the several operations of grading, bunching and wrapping.

Tests in Georgia with asparagus wrapped with films of moisture-proof cellulose have shown that the loss in weight during storage is materially reduced and the storage life at ordinary temperatures prolonged. Recent work in Germany indicates the value of cellophane wrappers in the conservation of asparagus.

QUALITY CHANGES AFTER HARVESTING

Defects developing after harvesting include excessive wilting, elongation of the spears and opening up of the heads, rotting due to fungal and bacterial pathogens, and general deterioration in quality. Bisson, Jones and Robbins

have analysed the several factors involved, standardised samples being stored at 33°, 41°, 56°, 77° and 95° F., and examined microscopically and chemically at intervals of 24 hours. Their results show that green asparagus should be bunched, packed and placed under refrigeration—just above 32° F.—as soon after harvesting as possible, since certain changes in structure and chemical composition, which affect the edible quality, take place with great rapidity.

Asparagus spears grow in length and increase in weight in the crate if the butts are resting on moist moss. The growth rate is least at 33° F. but increases with temperature. The greatest increase in length takes place during the first 24 hours after cutting, hence the necessity for rapid cooling. During storage at higher temperatures, 75° to 95° F., mould appears on the spears within a few days. A loss in reducing substances and in total sugars takes place at all temperatures, especially from 56° to 95° F., the maximum rate of loss occurring during the first 24 hours.

At all storage temperatures there is a definite increase in the amount of fibrous material. This could be demonstrated microscopically and also by estimating the amount of crude fibre present. The increase in fibrous material takes place most rapidly immediately after harvesting. Its formation is accelerated at the higher and to some extent arrested at the lower temperatures. The initial toughness of the spears may therefore be accentuated by unfavourable storage conditions.

PRECOOLING AND COLD STORAGE

It has been seen that asparagus loses much of its food value, and therefore its saleability, within a few hours after cutting unless it is placed in storage at a relatively low temperature. According to Platenius, Jamison and Thompson no other vegetable deteriorates so rapidly as asparagus at ordinary temperatures. If the bunches are stood on damp packing and stored at 32° F. immediately after cutting, this commodity should keep in good condition three to four weeks. If received at the storage plant after a long haul from a distant point of production it cannot be expected to keep longer than three to six days.

In California the larger consignments, at the height of the season, are precooled before being loaded into refrigerated cars, the cars being re-iced as required during the transport period. According to Hanna it usually takes from 8 to 12 hours to bring the temperature down to 40° F. All-green asparagus, which has a higher respiration rate than spears with white butts, takes longer to cool. Temperatures of 33° F. and R. H. of 90 per cent., 32° to 35·5° F. and R. H. of 80 per cent. are cited as being suitable for asparagus storage over periods of 21 to 50 days. Platenius *et al.* quote a storage temperature of 32° F. and R. H. of 95 to 98 per cent. as affording a maximum storage period of one week. The use of ozone in asparagus storage has been considered by Kochs in Germany; in these experiments the

duration of storage at various low temperatures could not be prolonged beyond two to three weeks.

GAS STORAGE

In gas storage experiments, Brooks *et al.* found that asparagus exposed to early treatment with carbon dioxide (*i.e.*, during cooling) showed improved appearance, keeping quality and flavour over untreated control lots. " Asparagus exposed to 25 to 30 per cent. of carbon dioxide at temperatures of 60° to 70° F. for 18 to 24 hours had a better flavour than asparagus held at the same temperature without carbon dioxide and as good as or better flavour than asparagus held at 32° or 40° F. for the same period. Asparagus that was exposed to 25 to 30 per cent. of carbon dioxide for 48 hours or to 40 per cent. or more of carbon dioxide for 24 hours was sometimes found to have an objectionable flavour." Thornton has reported a browning of the outer bud scales and the development of water-soaked areas as asparagus exposed to 50 to 80 per cent. of carbon dioxide for 3 days. Early treatment with carbon dioxide was also effective in controlling fungal rotting.

AVOCADOS

The avocado, also known as the avocado pear, ahuacate, zaboca, alligator pear, midshipmen's butter, &c., is derived from several species of Persea (Lauraceae) indigenous to the West Indies, Central and South America, upwards of 400 varieties having now been recognised and named. In California and Florida the industry is extensive, large consignments of fruit being sent by rail to the centres of population throughout the United States. The fruit is also grown for export in Cuba, Porto Rico and Hawaii. Attempts to build up an export industry are now being made in British West Indian Islands. The fruit is prized for its rich nutty flavour and for its high oil and protein content. According to one authority the avocado promises to become one of the five great food fruits of the tropics of both hemispheres within a generation.

PICKING AND PACKING

The maturity at which fruits are picked is determined by the length of storage life required, but immature fruits should be avoided as they tend to be inferior in flavour on subsequent ripening.

As avocado varieties show profound variations in respect of size, shape, colour, skin-texture and other characters, only local experience can prescribe the exact picking maturity for any particular variety. In California fruits are tested in the laboratory for oil content—which increases with maturity—as a means of determining when picking should take place, but this criterion, though helpful, is not absolute. Though fruit intended for storage is picked in a firm and inedible condition, nevertheless it must have reached a stage of maturity which will permit of normal ripening. Where a storage life of 20 to 25 days is required (*e.g.*, 14 to 18 days in cold storage during overseas transport, and 7 to 10 days for ripening and distribution) colouring varieties, *i.e.*, with red, purple or pale yellow skins, grown under West

Indian conditions, may be picked when they show the first trace of colouring. With green varieties the precise picking maturity is more difficult to determine and depends largely on personal judgment. The investigations of Stahl indicate that specific gravity tests may be useful in determining picking maturity.

Picking is done by means of citrus clippers, the fruits being carefully placed in padded field boxes to avoid bruising during transport to the packing shed. In California and Florida the fruits are washed and graded by machinery for weight, and packed in single layers with excelsior in flat 13-lb. boxes, ten packing sizes being recognised according to the size and shape of the fruit. The ideal avocado for export has been described as a spherical fruit weighing approximately 1 lb.

In Florida the lug commonly used holds approximately 15 lb. of fruit, and has inside dimensions of $15'' \times 13'' \times 3\frac{1}{4}''$, $3\frac{3}{4}''$ or $4\frac{1}{4}''$ according to the size of the fruit. Tomato crates $12'' \times 12'' \times 24''$ (ventilated crates capable of holding about 40 lb.) may also be used, with a light wadding of excelsior to support the fruits and minimise bruising. Wrapping individual fruits and close packing with wood-wool, excelsior, &c., should be avoided to eliminate the tendency to self-heating. Where very mature fruit has to be railed long distances in hot weather, special crates bunkered with 12 to 20 lb. of ice according to the type of construction are fused.

STORAGE TEMPERATURE AND DURATION OF STORAGE LIFE

Among earlier investigations, Condit reported that Mexican avocado varieties, cultivated in California, kept well for one month in cold storage but subsequently deteriorated through shrivelling and decay; the Challenge variety was stored satisfactorily at 32° F. for six weeks; softening took place more rapidly in fruit held at 36° F. than at 32° F. Overholser dealing with avocados grown in California, found that a temperature of 40° F. was satisfactory for all varieties tested except the Fuerte which required 45° F. to prevent blackening of the skin. In general a temperature of 32° F. was too low as it led to discolouration of the flesh, though indications were obtained that some varieties might be satisfactorily held at 32° to 35·6° F. Under proper storage conditions some varieties could be kept for approximately two months, others for five to six weeks, and others for four weeks. Quick storage after harvesting and care in handling improved the keeping quality of fruits. Fruits picked just before commencement of softening kept best and attained excellent quality.

As early as 1907 Higgins in Honolulu referred to the successful export of avocados in cold storage to San Francisco (approximately seven days) with subsequent distribution by rail. More recently Harold found that Hawaiian avocados may be stored green at 36° F. for six to eight weeks, thereafter ripening satisfactorily in two to five days. Wilcox and Hunn have recorded the successful storage of Hawaiian avocados at 32° F. and 36° F., fruit having kept in good condition for periods up to 65 days.

Edwards and Guerrero have described trial shipment of avocadcs between Guam, Marianne Islands, and Manila. The fruit, held at 40° F. during the voyage of 16 days, was discharged in good condition.

The earlier records dealing with varieties grown in the West Indies are scanty. Unsuccessful attempts to export fruit from Porto Rico are mentioned by Griffith and Shill has briefly described experiments with small lots of fruit held at 45° to 50° F. in Dominica with subsequent removal to tropical temperatures (average 85° F.). After being held in cold storage from 6 to 10 days, the fruit, on exposure to the higher temperatures, ripened up with such rapidity as to make for considerable loss, internal blackening being a characteristic feature.

Californian fruit, if intended for the local market, is held in storage at ordinary temperatures until sufficiently soft for consumption. If required, fruit may also be held in cold storage at 40° to 45° F., some varieties having been kept in good condition for as long as two months. Fruit to be despatched by rail to eastern United States markets is precooled at 40° to 45° F. for 48 hours and then placed in refrigerated cars, this class of fruit being still firm when it reaches the hands of the retailer. Provided it has been properly selected and treated, shipment to the eastern seaboard by way of the Panama Canal has also been shown to be a commercial possibility.

In 1933 and 1934 investigations conducted in Trinidad on upwards of thirty West Indian seedling varieties showed that only a few could be held at a temperature of 40° F. for 20 to 25 days without sustaining low temperature injury. On the other hand, a higher storage temperature, *e.g.*, 50° F. was found inapplicable because of the tendency of fruits to ripen before the required storage life had been achieved. These general conclusions referring to the storage of seedling varieties have been confirmed by work in Jamaica.

Even at relatively low temperatures, maturation processes slowly continue so that fruits ultimately become ripe and finally over-ripe. In the few varieties which are sufficiently cold-resistant or tolerant of low temperatures, such ripening apparently takes place in a more or less normal manner, the flesh at maturity being of good flavour and free from internal breakdown, discolouration or other obvious abnormalities. On the other hand, in the majority of varieties, *i.e.*, those which do not possess adequate cold resistance, maturation processes also continue but it is evident that the metabolic trend is abnormal. Thus although such fruits eventually become soft in cold storage, inspection of the flesh at once shows that chill effects have been induced. The range in genetical constitution exemplified by avocado varieties is strikingly demonstrated in the matter of cold-resistance : this extends from varieties subject to chilling after 15 days at 53° F. to those which ripen normally during 40 days at 40°F.

CHILLING

The possibility of developing an export industry in avocados in the West Indies and elsewhere where delicate varieties intolerant of low temperatures are cultivated, largely rests on the question of cold resistance. In

varieties subject to chilling at 45° F. evidence of low temperature injury may be observed at an early stage, the flesh becoming discoloured while fruits are still hard and unripe; despite the presence of this pathological condition, however, such fruits continue to ripen, and ultimately become quite soft, with further accentuation of the internal discolouration. Short of killing tissues outright by freezing therefore, it may be inferred that vital processes are involved both during the initiation and subsequent development of chill effects.

Various manifestations of chilling occur in fruit exposed to air-blast refrigeration. Necrosis of the skin in proximity to the stem-end, or brown, circular or confluent blemishes distributed over the skin, may sometimes be observed. Skin necrosis, however, is not usual, the large number of varieties showing internal chill effects being normal as regards external appearance. Internal chill effects are easily observed. While still firm, the flesh on cutting is seen to have acquired a slightly dark, smoky or brownish discolouration. In some varieties this is chiefly located next the stone, in others it may occur in the tissue mid-way between stone and skin. Again, in some instances the incipient chill symptoms may take the form of thin streaks as seen in longitudinal section, in others as isolated circular patches distributed towards the middle and distal regions of the fruit. Chilling of the flesh becomes accentuated with the onset of final maturity and culminates in a more or less general discolouration of the entire tissue to a smoky-brown, chocolate-brown or black appearance. Low temperature injury has also been described as giving the flesh a greyish appearance. In Californian avocados, Horne has described a darkening of the flesh sometimes associated with frost injury on the tree but in other instances due to other causes as yet uninvestigated.

In some varieties, either in conjunction with, or in the absence of discolouration of the flesh, the vascular strands which run longitudinally through the fruit may lose their clear, inconspicuous hyaline character and acquire a characteristic brown or blackish necrosed appearance by which they are rendered very conspicuous. In the matter of flavour, palatability in some varieties is only slightly impaired, whereas in others the nutty quality of the normally ripened fruit is replaced by a pasty, insipid flavour, or more or less acrid flavours may be induced.

Chilling is a complicated phenomenon in which various factors are involved. Among others the temperature and duration of storage are important: some varieties ripen normally after 20 days at 45° F. whereas during storage at this temperature for an additional ten days chill effects develop. The maturity of fruit at the time of storage is also of critical importance: fruits stored immature only show chill effects after long exposure to the low temperature, *i.e.*, after a certain stage in ripeness has slowly been reached, whereas fruits of the same variety stored more mature may show

chill effects in a relatively short time. In general, the evidence available indicates that fruits are most subject to chilling during the initiation of ripening.

GAS-STORAGE

Collectively the data obtained from gas-storage experiments show that by using subnormal concentrations of oxygen alone, or in conjunction with high concentrations of CO_2, a definite deceleration can be induced in the maturation of avocados. The range of tolerance to such treatments, however, varies from variety to variety, being comparable though not necessarily parallel to the response of different varieties to low temperatures. In varieties unsuited to gas-storage, external and internal damage may be sustained without the intervention of micro-organisms. In other varieties, although no direct physiological injury may be apparent, the fruits subsequently prove much more susceptible to the inroads of storage pathogens. Others, again, show surprising tolerance of gas-storage conditions and would undoubtedly lend themselves to commercial preservation by this method. It is interesting to note that in this category are varieties subject to chilling and consequently unsuitable for transport at low temperatures. Overholser showed that Fuerte avocados which could only be held for ten days at 70° to 80° F., and for one month at 45° F., could be kept in good condition for two months at 45° F., provided they were maintained in an atmosphere of four to five per cent. oxygen and not more than four to five per cent. CO_2. Furthermore he observed that excessive concentrations of CO_2 did not result in the production of objectionable flavours, but prevented softening of the flesh, so that it remained tough even after removal from storage.

BANANAS

Bananas rank as one of the most important crops throughout tropical and sub-tropical regions and in some countries constitute the major source of agricultural wealth. In the course of a few decades, from small experimental shipments, a large and important export trade has developed in different parts of the world.

From the point of view of cold storage, the banana is in many ways unique even among tropical plants : it produces bunches all the year round, thereby obviating the need for storage over long periods ; bunches are harvested quite green and for most markets less than full grown ; they are transported for long distances, mostly without any crating or other protection, and are eventually ripened up in a few days under controlled conditions in specially constructed rooms. A knowledge of the correct stage of maturity for harvesting and the precise conditions for transport and ripening is essential to the production of attractively coloured, well-flavoured fruit.

As a rule the banana has to be transported over long distances before it is available for consumption in temperate lands. Not only is the bunch habit conducive to bruising, but the onset of final maturity can only be delayed

to a certain extent by refrigeration. The fruit when approaching ripeness is very susceptible to fungal attack and, in consequence, considerable rotting may sometimes take place before the normal pericd of commercial handling has elapsed.

VARIETIES OF COMMERCE

The principal varieties of ccmmerce are the Gros Michel, cultivated extensively in Jamaica and in Central and South America, and the Cavendish, Canary or Dwarf variety grown in the Canary Islands and Brazil for export to Britain and Europe, in Queensland for distribution in other parts of Australia, in Samoa for export to New Zealand, and in a number of African colonies and protectorates for export to Europe. The Lacatan or Giang Fig variety, is exported in small quantities from Brazil to Europe. There is some trade in the Giant Governor between the French Antilles and France. Many other varieties, possessing great delicacy of flavour and texture, are also known but so far, because of transport and ripening difficulties, they have only been used for local consumption. The Red banana which is occasionally seen on British and American markets is chiefly valuable for decorative purposes ; actually it is rather coarse and of mediocre flavour.

CLASSIFICATION OF FRUIT FOR EXPORT

In Central and South America and the West Indies, export bunches are divided into *classes* according to the number of " hands " or clusters on the stem and into *grades* according to maturity. A nine-hand bunch is taken as the standard, bunches of 8, 7 and 6 hands being priced at $\frac{3}{4}$, $\frac{1}{2}$ and $\frac{1}{4}$ respectively that of the standard or " count " bunch. In the Canary industry, a recognised system of lettering (*e.g.*, G. *gigantic*, Ex., *extra*, Esp., *especial*) indicates the type and quality of fruit contained in the crates. Other systems of classification are also encountered.

The usual grade of fruit shipped from Jamaican or Caribbean plantations to British and Continental markets is described as " standard " or " thin $\frac{3}{4}$-full"; less mature fruit is described as " thin "; for the more distant American markets fruit is reaped " heavy $\frac{3}{4}$-full " and for nearer markets " full." " Standard $\frac{3}{4}$-full " fruit is, as nearly as can be conveyed by verbal description, fruit which is beginning to fill out (so as to give a circular cross-section) but in which the ridges are still conspicuous. The less mature the fruit the longer, other things being equal, will be its storage life. It cut too immature, however, bunches ripen badly or not at all. In some varieties, *e.g.*, the Giant Governor, the size and appearance of the bunch, relative to the Gros Michel, are misleading as a guide to maturity. Thus, unless bunches are cut at a stage corresponding to " full " in the Gros Michel, they fail to ripen normally after the usual period in cold storage.

ORGANISATION IN THE BANANA INDUSTRY

The banana industry is dependent for its success on a very elaborate but precise organisation. This may be illustrated by a simple example. In

Central America a ship may leave with a cargo of 100,000 Gros Michel bunches, the total length of time elapsing between the commencement of reaping and the closing of the hatches being 36 hours or less. It is known that undue delay at this stage is liable to result in excessive wastage later.

On the plantations an exact schedule is followed so that reaping operations and local transport may be effected in the shortest possible time. Where wharfside facilities are available, mechanical elevators are used to charge the fruit into the holds. To convey the fruit to its destination, specially constructed ships with holds cooled by air-blast refrigeration have been designed. Finally, an efficient distributing system, involving the use of carefully controlled ripening rooms, ensures that fruit at the correct stage of maturity is constantly available to consumers in all parts of the country.

METHODS OF HANDLING FRUIT

In handling bananas a number of different methods have been evolved. These fall into two definite categories in which the fruit—

(i) travels carefully packed in crates or other containers, or

(ii) is stowed "naked," or simply protected by a paper bag, in bulk.

(i) *Crated Fruit.*—The export of crated bananas is best exemplified by the industry in the Canary Islands. There the chief variety of commerce is the Dwarf, Canary or Cavendish variety, a plant yielding an attractive sweet fruit esteemed on British and European markets. Not only is the Canary banana very susceptible to bruising because of its thin skin, but the disposition of the individual fingers, and the shape of the bunch as a whole, contribute in a large measure to its liability to mechanical injury. For these reasons the export industry has been developed on a system of careful handling, packing and crating.

To ensure the production of attractive fruit for export, the bunches receive attention from the time they are "shot" or "born" in the plantation. As soon as the young bunch (inflorescence) emerges, the number of the month is stamped on the stalk to facilitate estimating the time of maturing. The large bracts associated with the hands, the perianth-remains, and the terminal bud of male flowers, are removed at an early stage to get rid of potential sources of fungal infection. In due course, as the bunch becomes heavy, a strut is inserted under the slightly inclined trunk to give it support. The bunches of fruit are carefully reaped and conveyed by various means, on the head, on pack animals, or even on aerial rope-ways, to packing sheds. There the bunches are graded and packed into wooden crates or cardboard drums. The hexagonal crates are usually lined with straw or banana trash (old dried leaves); the bunch, wrapped in cotton-wool and covered with paper, is then carefully placed in position and firmly fixed by pressing the straw or trash around it. The slatted top of the crate is then nailed down. Such crates may contain one or several bunches. When three bunches are being crated together two are placed parallel and one transversely. Packing

fruit in cardboard drums is used chiefly in the export to Spanish markets where less handling is involved.

The crating adopted in the Canary Islands entails considerable expense. On the other hand, wastage due to mechanical injury and fungal activity is at a minimum. Further, as the period of ocean transport is relatively short, consignments of fruit can be stowed as ordinary cargo without refrigeration. In Britain the bunches are usually allowed to ripen in the crates, but on the Continent it is the customary practice to hang them up for ripening.

In Martinique and Guadeloupe large cases 1·5 m. by 1·25 m., padded with straw and capable of holding 24 wrapped bunches (weighing 600 kg.) have also on occasion been used for the Giant Governor and Cavendish varieties.

The Canary Islands system, more or less modified, has been adopted in Italian and French Somaliland, French Guinea and the French Antilles where the Cavendish is also the variety of commerce.

In Queensland, where the industry is also based on the Cavendish variety, fruit for local consumption is handled in the bunch. Bananas intended for the southern markets, on the other hand, are cut from the bunches and packed in wooden cases for transport by rail. The fruit, packed as "hands," "clusters" of about four fingers, or "singles" (this is the most common method), is ripened without removal from the case.

> "The hands are cut from the bunches and the individual fruits are cut or broken off and packed into paper-lined cases. The cases which measure internally 24¾ in. by 12 in. by 12 in., have solid ends, and sides composed of two or three pieces of wood fitting closely together. The top and bottom are formed of two or three slats with gaps at the edges and between them, of about ½ inch. In packing, the paper lining closes up these openings unless, as is customary in summer, it is torn at the gaps after the lids have been nailed down."

The cases are then sent by rail to Sydney, Melbourne and Adelaide, journeys of approximately two, four and five days respectively. There is also some trade to Western Australia chiefly by boat from Melbourne, making a total journey of 11 days. Consignments are also carried on the trans-continental railway, a total journey of ten days. The bananas on arrival in the southern cities are still green and must be ripened artificially. The overland transport of crated fruit, during summer and winter, from Queensland to other parts of Australia has its own particular problems and difficulties. These have been the subject of official investigations but their specialised nature precludes discussion here.

The advantages of the Queensland system are those of economy of packing and freight, the utilisation of fruit from small bunches, and the carriage of varieties in which the finger is too readily detached from the stem for transport

in whole bunches. The disadvantages lie in the more rapid and uneven ripening of consignments and the higher incidence of fungal wastage due to pathogens gaining access through the cut finger stalks (*i.e.*, "black-end" or "finger-stalk" rot and "squirter" disease). It has been suggested that, to some extent, wastage might be curtailed by precooling the bunches prior to the cutting or breaking off of the fingers and packing in pre-cooled crates.

In the export industry from Samoa to Wellington, New Zealand, the fruit is packed as "singles" in cases containing approximately 90 lb. During the ocean voyage of 11 days, although the holds are refrigerated, this method of handling may lead to a considerable amount of wastage.

Bunches for export from Formosa to Japanese markets are cut up into hands and packed in bamboo baskets giving a pack of approximately 100 lb. weight.

(ii) *Transport of "Naked" Fruit.*—The extensive export industry from Caribbean banana-lands to American and European markets is based on the Gros Michel banana. Not only has this variety a sufficiently tough skin to withstand the bruising consequent on normal handling but its strikingly cylinderical bunch habit enables it to be stowed "naked" in bulk without undue loss resulting from mechanical injury. Crating is precluded by high labour and freight charges, and by the enormous quantities of fruit shipped. On some plantations, however, all bunches are enclosed in stout paper bags in order to minimise mechanical injuries. The supremacy of the Gros Michel in the world's markets is due to its suitability for transport in bulk, and its good appearance and flavour on ripening.

Following the lines successfully adopted in Caribbean banana plantations, and industry using the Dwarf Cavendish (or Canary) and Giant Fig varieties has been inaugurated round the port of Santos in Brazil. Prior to reaping, paper pads containing trash are inserted as required between the first, second and third hands; a stout perforated paper bag is then slipped over the bunch and tied at the neck. The bunch is harvested and shouldered or headed out to the nearest tram-line. From there bunches are conveyed to the riverside, where they are loaded on to specially built barges. The latter are then towed down the rivers or along the coast to the ships. Loading is achieved by means of mechanical conveyors, or, if the ship is lying out at sea, by large basket crates operated by the ship's winches. Stowage is in bulk as described below for the Gros Michel, refrigeration being supplied in the form of a cold air blast.

For Cavendish fruit grown in the Canary Islands, French Guinea, Guadeloupe and Martinique, the stout paper bag is not considered adequate for the protection of bunches, and a more elaborate wrapping in cotton-wool wadding, kraft-paper and straw has been adopted (Kervegant). A somewhat similar protection is given to fruit exported from Hawaii to the United States.

Handling and Stowage of Large Consignments.—Practical experience and scientific investigation have shown that it is of the utmost importance to reduce to the minimum the time between reaping fruit and charging it into the holds and commencement of refrigeration. This is usually 36 hours or less. The importance of exact shipping schedules and shore organisation has already been emphasised. Before being loaded into the holds, bunches are inspected on the wharfside and all stem-ends are retrimmed and treated with a fungicide to minimise rotting by fungal organisms. Bunches which pass the inspectors are placed on specially designed, adjustable conveyors which, working on the endless-belt system, carry the bunches into the holds. There they are removed by a gang of workers and stowed compactly in the bins into which the hold space is divided. As a rule, two or three tiers of fruit are stacked with the bunches—large end downwards—in a vertical position ; a top layer occupying a more or less horizontal position, is used to fill up any remaining space. As soon as a hold is charged the hatches are closed and sealed and refrigeration is commenced.

CONDITIONS DURING OVERSEAS TRANSPORT

Bananas cut approximately " ¾-full," if left at tropical temperatures, would ripen up in the course of five to eight days. Refrigeration is accordingly, essential to the overseas transport of the banana, firstly to delay ripening and senescence, and secondly, to curtail the activity of rot-producing organisms.

Cooling of fruit is achieved by means of air-blast refrigeration, the holds being precooled prior to stowing the cargo. Experience has shown that 53° F. is the temperature best suited to the storage of ¾-full Gros Michel bunches where the period of ocean transport is about 16 to 18 days. This temperature should be attained as quickly as possible so as to check the activity of fungi, but it is important that the delivery air temperatures should not fall below 53° F. or the fruit will be chilled. Once or twice per day, according to requirements and opportunity, the air circulating in the holds is completely blown out, so as to avoid adverse effects which might result from the excessive accumulation of carbon dioxide or volatile substances. Fruit intended for the nearer American ports is exported from the Caribbean region in ventilated holds without refrigeration.

The relative humidity in fully charged banana holds is usually high, ranging from 80 per cent. almost to saturation. Sometimes it is in the region of 95 per cent.—a degree of humidity which encourages the superficial growth of moulds and mutual contamination of fruits. From the point of view of wastage control, therefore, a reduction in the relative humidity would be advantageous provided it was not such as to cause excessive dehydration with concomitant shrivelling.

During transport, the banana holds are inspected daily by the ship's officers and all bunches showing evidence of ripening are removed. Otherwise

accelerated ripening of green bunches by volatile substances given off by the ripe fruit may be experienced.

STORAGE TEMPERATURE

Precise knowledge of the carrying temperatures best suited to different varieties and grades of fruit is essential to avoid chill effects.

For the Gros Michel it has been shown that chilling was not produced by :

(i) cooling to 52° F., no matter how rapidly, provided the temperature of the delivery air was not below 52° F. ;

(ii) exposure of fruit to 52° F. for 4 days and then to 53·6° F. for 4 days and then to 53·6° F. for 11 days ;

(iii) exposure of fruit to 53·6 °F. for as long as 24 days.

From storage trials conducted at 51° to 52° F. it was found that chilling is a cumulative effect of duration of exposure, and is not the result of rapid cooling to such temperatures. In practice the Gros Michel banana is usually transported at a temperature of 52° F., and may be cooled to this temperature as quickly as possible, provided the delivery air does not fall below this temperature.

From studies conducted on fruit grown in Trinidad the Dwarf or Cavendish variety appears to be slightly more cold-resistant than the Gros Michel. The Lacatan (or Giant Fig) and the Congo on the other hand, are less cold-resistant and require a hold temperature of 58° to 60° F. in order that chill effects may be avoided. For the Giant Governor the storage temperature lies in the vicinity of 56° to 58° F. The hybrid varieties I.C. 1. and I.C. 2, bred from the Gros Michel as female parent and a wild seeded variety as male parent, behave like the Gros Michel in cold storage. The Red banana carries well in storage at 53° F. A variety known as Fillbasked ripens well after being stored at 53° F.

SYMPTOMS OF CHILLING

Certain physiological maladies, such as "green-ripeness"—as the name implies, the yellow skin-colour is poorly developed while the pulp within is soft and fully matured—may be caused by too high ripening temperatures. More commonly, however, the physiological diseases of commerce are due to "over-refrigeration" or chilling on shipboard.

In green bananas chilling may be difficult to recognise externally ; it has been identified in a general way by an increased development of brown streaks in the sub-epidermal tissues, this characteristic colouration being associated with the mucilage ducts. During ripening, chilling is easily recognised by several abnormalities :

(i) delayed ripening, and, in severe cases, complete failure to ripen ;

(ii) hardening of the central placenta—more pronounced in the Cavendish than in the Gros Michel;

(iii) assumption of a dull yellow colour instead of a healthy bright one ; in the Gros Michel, as ripening proceeds, the dull yellow is replaced entirely by a dull russet colour, which later darkens ; a dark mottling, associated with desiccation of the tissues, may also occur ; this russetting of the whole bunch has not been noticed in the Cavendish, even when kept for 50 days at 52° F. ; (in point of fact, it is sometimes rather difficult to recognise chilling in this variety, as fruit picked at an immature stage shows, on ripening, hardness of centre, dullness of colour, a tendency to browning—not typical Gros Michel russetting—characteristics which might be mistaken for chill effects; when definite chilling is produced in Cavendish types, including the Lacatan and Giant Governor, it is readily recognised during ripening at 70° F. by the assumption of a dull, sooty, ashen colour ; green fruits also show a characteristic browning, particularly in the region of wounds or abrasions) ;

(iv) complete loss of banana flavour or the presence of a strange " cold-storage flavour " ;

(v) " green-ripeness " and " hard-ripeness."

LIMITS OF CHILLING

The following experimental treatments have yielded evidence of chilling :

(*a*) *Gros Michel*, (i) exposure of 14 days at 52° F. ; (ii) exposure of 9 days at 51° F. ;

(*b*) *Cavendish*, exposure of 13 days at 51° F.

Provided standard fruit is used, chilling can readily be avoided by paying attention to the temperature of the air-blast at the delivery side. The fact that rapid cooling to 53° F., by delivering air at that temperature, can be practised without danger of chilling permits of wastage control by curtailing fungal growth.

It has been found that heavy ¾-full Gros Michel bunches are more susceptible to chilling during long ocean voyages than standard ¾-full, and that the Giant Governor and Lacatan varieties are subject to chilling at temperatures below 56° to 58° F. Olney has recorded chilling as occurring in Gros Michel bunches (imported into the United States and therefore most probably heavy ¾-full) held at a temperature of 54·6° F.

Young *et al.* experimenting with the Cavendish variety in Australia (Brisbane) obtained the following data on susceptibility to low temperature injury.

(*a*) Storage at temperatures down to 45° F. for four days did not in any way affect the appearance of green bananas.

(*b*) Storage at 50° F. for periods up to four days caused a delay of up to one day in the subsequent colouring of the bananas, but apart from this there was no appreciable effect on the ripening.

(*c*) Storage at 45° F. for two days caused a delay in colouring of about one day, but apart from this there was no appreciable effect on the ripening of the fruit.

(*d*) Storage for four days at 45° F. had no appreciable effect on the subsequent ripening of the pulp of the bananas, but it caused a considerable delay in the colouring, and the fruit had a definitely greenish colour when fully ripe.

(*e*) Storage at 33° F. for 1½ days, or at 40° F. for 3½ days, produced a definite change in the appearance of the green bananas.

(*f*) Storage at temperatures below 45° F. had a more marked effect on the subsequent colour development than storage at 45° F., and it also tended to reduce the life of the fruit after ripening.

The cooling necessary to bring about "chilling" appears to vary with the temperature conditions under which the fruit is grown, winter-grown fruit being considerably less affected by low temperatures than summer-grown fruit. On the other hand, winter-grown fruit is more sensitive to high temperatures in the ripening rooms than summer-grown fruit.

Chilling has usually been attributed to exposure to cold conditions during transport, but it appears that a considerable proportion of it is due to exposure to low temperatures on the plantation probably before the fruit is cut from the plant.

Collectively the observations set out in this section indicate that, during the overseas transport of fruit, it is not only necessary to apply refrigeration at the tropical end but, during winter, it may be necessary to supply heat to the holds as the temperate regions are approached. In modern ships provision is made for this contingency.

THE EFFECT OF QUALITY ON STORAGE AND RIPENING

The quality of bananas varies considerably according to variety, the conditions under which they have been grown, and the procedure adopted during storage and ripening. Thus although the Gros Michel is the principal variety of commerce, it is not the variety most esteemed by connoisseurs, the Cavendish being preferred for its more sugary pulp and the Lacatan for its aroma, texture and sweetness. There are also many varieties used for local consumption throughout the tropics compared with which the Gros Michel is a relatively coarse fruit.

Within any one variety, such as the Gros Michel or Cavendish, considerable variation in quality may also occur. Thus the Cavendish variety as grown in the Canary Islands is a relatively small, sugary fruit whereas, under the

moist tropical conditions in the Caribbean region, the fruit is much larger and, according to general opinion, of poorer flavour.

The size of the fruit grown in any one locality cannot always be taken as an indication of quality but in general it may be accepted that large bunches of fruit are usually of good quality and keep better during storage than small bunches; the appearance on ripening is also better. In Australia it has been found that poor quality fruit requires more careful treatment in the ripening-rooms than good fruit. It has been shown, for example, that poor fruit is more adversely affected by high temperatures than is good material. In chilling experiments conducted in Trinidad indications were obtained that large, vigorous bunches were less susceptible to low temperature injury than poorer bunches. In Queensland it has been found that Cavendish bananas grown on a shale or clay soil deteriorated much more quickly and were generally inferior to fruit grown on good soils of volcanic origin.

WASTAGE IN BANANA SHIPMENTS

Wastage, sometimes very considerable, is a feature of all banana shipments. From the time of cutting bunches are subject to the inroads of a large number of fungal organisms. Some of these have already been established during development, and remain as latent infections until the fruit is entering on the final phase of maturation. A large number of the fruit-rotting fungi, however, gain access through the various cuts and bruises inseparable from reaping and transport operations. These develop slowly during the cold-storage transport period and rapidly when the fruit is taken to the higher temperatures prevailing in ripening rooms. Delay in applying refrigeration to harvested bunches greatly accelerates the onset and intensity of wastage. Hence the recommendation that the time between reaping of bunches and cooling to 53° F. be curtailed to the minimum. The several aspects of disease, attributable to a varied and extensive fungal flora, have been classified as follows: main-stalk rot; cushion infections; finger-stalk rot; and finger diseases.

In the matter of fungal wastage the Cavendish and Lacatan (Giant Fig) varieties are considerably more susceptible than the Gros Michel. A seasonal drift may sometimes be observed in the incidence of rotting, as in Brazilian Cavendish consignments. Other factors, including those of soil and climate, also predispose fruit to a greater or less susceptibility to the several pathogens. Manurial treatment may also be important. Thus when the Cavendish variety is grown on poor soils with the help of fertilizers in Trinidad, the tendency of bunches to suffer from mechanical injury and fungal penetration is greatly accentuated. Cargoes which have been chilled *en route* show increased fungal wastage during subsequent ripening.

TRANSPORT BY LAND

On arriving at the port of destination, the fruit is discharged by means of mechanical conveyors, and is placed in specially constructed fruit cars or

waggons for distribution. Where refrigeration is necessary, as in the United States, the waggons are maintained at a temperature of 54° F. Attention has already been directed to the special conditions of overland transport involved in Queensland banana industry.

RIPENING

On being discharged from the holds, the bunches, still mostly green, have next to be ripened. This is done in special ripening-rooms usually at a temperature of 66° to 68° F. or less according to the demand for ripe fruit. Each bunch is suspended with the lower or distal end uppermost by a rope attached to the ceiling. Fruit which is ripe or nearly ripe on being discharged from the holds is retailed immediately. In well-equipped modern ripening-rooms the installation includes apparatus for the control of temperature and humidity.

At the time of reaping the storage material in the green banana is almost entirely starch, approximately 30 per cent. by weight being present, as against only 0·7 to 0·8 of sugars. Ripening is characterised by many changes, including the yellowing of the skin, the transformation of all or practically all the starch into soluble sugar, the oxidation of tannins, the softening of the fruit, the transformation of insoluble pectose (protopectin) into soluble pectin, and the production and liberation of various volatile substances which give the ripe fruit its characteristic aroma and flavour. Later, when the fruit is tending towards the over-ripe condition, the skin become covered with a dark brown mottling and alcohol begins to accumulate in the pulp. At this stage the fruit is usually exploited by various fungal pathogens. The rate at which these changes take place depends chiefly on the maturity of the fruit and the temperature of the ripening-room but other factors are also involved.

Ripening Temperatures.—Reynolds cites the following temperatures for fruit received in the United States of America :—

56° F.	.. ..	holding ripe fruit
58° F.	.. ..	holding green bananas
62° to 66° F.	.. ..	normal ripening
68° F.	.. ..	forced or fast ripening
72° F.	.. ..	danger of cooking

These values refer, of course, to the heavier grades of Gros Michel fruit. For standard ¾-full bunches received in Britain, normal ripening temperatures range from 60° to 70° F., according to circumstances, a starting temperature of 68° F. being commonly used.

In Australia, green Cavendish fruit may be stored, during the summer months, in ripening-rooms for three days at temperatures of 53° to 58° F. provided the atmosphere is quite free from ethylene ; partially ripe, cased bananas may be held for three days at 55° to 60° F. during which time they colour slowly but remain in good condition for some time after removal.

Uncrated fingers or fruit in the bunch should not be cooled below 62° F. During the winter months (average air temperature 50° to 60° F.) green bananas may be stored for periods up to seven days outside the ripening-rooms in any dry place, provided no traces of coal-gas are present.

As a rule, during the earlier stages, a high R.H. (85 per cent.) is maintained in the ripening-rooms, but once the fruit is "sprung," *i.e.*, showing a definite yellowing and signs of active ripening, the R.H. is reduced to 70 to 75 per cent. to harden the fruit and to curtail the activities of superficial fungi. If the humidity is too low, evaporation from the fruit tends to be excessive and as a result the peel develops a poor colour and a somewhat withered or desiccated appearance. The quality of the ripe fruit may also suffer. During the hardening period at a lower R.H. the temperature may also be reduced. Bananas ripened at a high temperature—temperatures of 72° to 85° F. are sometimes used to force ripening—are of poorer flavour and tend to deteriorate rapidly. Where high temperatures are used the period of exposure should be very brief, 12 hours or less. High relative humidities (above 85 per cent.) are also to be avoided, particularly where cased fruit is being ripened. The following table, based on crated fruit (Australian) held in ripening rooms at 68° F. shows the effect of high humidity on the temperature of cased bananas.

AUSTRALIAN CAVENDISH VARIETY (CRATED)

(AFTER YOUNG, BAGSTER, HICKS AND HUELIN)

Temperature of room	Humidity %	Case temperature after 2½ days
68°F.	80	76·0°F.
68°F.	85	77·2°F.
68°F.	90	78·5°F.

These differences are attributable to the fact that the increased humidity causes less transpiration from the fruit with a reduction in the cooling effect due to evaporation.

The Cavendish variety suffers from exposure to high temperatures in the ripening-room, yielding an ultra-soft fruit of unpleasant flavour, odour and colour (pale greenish yellow) generally described by the trade as *boiled*. The ripening of this variety in Australia has been made the subject of intensive research. For practical purposes the following stages of ripeness have been described :—

(i) hard green; (ii) sprung, *i.e.*, when the fruit still appears hard and green but has gained a definite flexibility; (iii) colour shows, *i.e.*, when the first tinges of yellow appear; (iv) half colour, *i.e.*, when

the green and yellow both appear ; (v) green tip, *i.e.*, when the fruit is full yellow except at the extreme lower end ; sometimes there is no definite " green tip " stage, the fruit colouring evenly to yellow ; (vi) full colour ; there is sometimes some persistence of green at the flower end, but a fairly definite " full colour " stage can always be recognized ; (vii) full ripe, *i.e.*, clear yellow with signs of dark marking (flecking) ; (viii) flecked, *i.e.*, markings well developed ; (ix) deteriorating, *i.e.*, when pulp begins to soften.

In general, a temperature of 68° F. has been found suitable for the ripening of the Cavendish variety as grown under Australian conditions. But because of difference in the quality of fruit from different areas, production under summer and winter conditions, &c., a considerable elaboration of the ripening technique, involving the use of ethylene or unburnt coal gas as an accelerant, has been found necessary. For a full account the reader is referred to the original memoir of Young and his colleagues.

Accelerated Ripening.—It has been found that traces of ethylene, one of the ingredients of coal-gas, exercise an accelerating action on the ripening of various fruits, including the banana. It has also been shown that various fruits give off volatile substances, now known to include ethylene. Hence arises the action of ripening or ripe fruit in promoting the maturation of green fruits in close proximity and the need for eliminating volatiles from the atmosphere of storage rooms or holds in which fruit has to be maintained in the green condition. When quick ripening is required, however, ethylene or unburnt coal-gas, in very small concentrations, may be used to advantage on a commercial scale. Indeed, it has been found impossible to ripen Queensland Cavendish varieties satisfactorily unless traces of accelerating substances are present in the atmosphere of ripening-rooms.