R. H. BOOTH and FELICITY J. PROCTOR

Considerations Relevant to the Storage of Ware Potatoes in the Tropics

Tropical Products Institute,
Gray's Inn Road,
London WC1X 8LU.

Introduction

With a total production approaching 300 million tons, the potato (*Solanum tuberosum* L.) is the most abundantly produced foodcrop, exceeding even the cereal crops. It is grown largely as a carbohydrate staple food and also for industrial purposes, but is regarded in addition as a 'prestige' crop in many tropical regions. The bulk of the world production derives from temperate regions but a considerable and increasing tonnage is grown in the tropics (Table 1). In India, for example, potato production has more than doubled during the past decade (Boulware, 1969), rising from less than two million metric tons annually to over four.

TABLE 1. WORLD PRODUCTION OF POTATOES (FAO, 1970)

	Europe		North America		Latin America		Asia		Africa		Oceania		World total	
Year	1966	1970	1966	1970	1966	1970	1966	1970	1966	1970	1966	1970	1966	1970
Total Production (metric ton x 10^{-3})	136,296	125,976	16,417	17,169	7,621	9,709	12,645	13,716	1,508	2,234	975	891	292,915	299,495
Area (ha x 10^{-3})	7,849	7,296	723	705	1,010	1,144	1,234	1,302	251	319	52	50	22,981	22,516
Yield (kg/ha x 10^{-2})	174	173	227	244	76	85	108	110	60	70	188	178	128	133

Originally a native of high altitude tropical regions of Chile and Peru, the potato does not usually thrive well in the more humid tropical lowlands, but can be grown with varying measures of success in tropical and sub-tropical regions provided rainfall and temperature are not excessive, especially at altitudes of at least 1500 m (Caesar, 1967). At low tropical altitudes satisfactory yields can be obtained provided rainfall is appropriately distributed (Doku, 1967) or irrigation is possible.

When potatoes are to be stored for 'ware' purposes it is essential that their initial quality be as high and the storage environment as optimal as possible. Loss of quality during storage can be caused by factors including light, loss of water, disease, pest attack, physiological disorders and sprouting. However, the storage environment cannot be considered in isolation; it is necessary to take into account pre-harvest factors which influence the suitability of tubers for storage. It may be convenient to regard the storage period itself as having three distinct phases: drying, curing and holding period, though the first two phases sometimes may be indistinguishable, and the latter may be subdivided into a dormant and a sprouting phase.

This paper is an attempt to gather together some of the information relevant to the storage of 'ware' potatoes in the tropics. Most of this information has been derived from the much more extensive research which has been undertaken on this crop in the temperate regions; further, a number of pre-harvest factors which affect storage life are considered.

Variety

Varieties differ in their inherent keeping quality (Pushkarnath, 1964). For example, Karmarkar and Joshi (1941), studying eight different varieties in India, found that the endogenous period of dormancy varied from 10 to 30 weeks at 4°C. Similarly Burton (1963) found that the period of dormancy could be as little as 8 or as much as 28 weeks after harvest depending on variety. Thus although storage at high ambient temperatures may require expensive refrigeration to provide the necessary storage conditions and environment, selection of varieties with long periods of dormancy may also prove advantageous (Singh and Lal, 1972). Whilst the appreciable variation in response of European varieties to tropical environments (Bodlaender, 1963) allows a wide choice in selecting suitable varieties from existing well-proven and high-yielding ones, Pushkarnath (1967) strongly urges the replacement of the varieties originally introduced from Europe into India with locally bred varieties. He concluded that the yields of the former varieties, adapted as they were to long summer day temperate environments, were usually unsatisfactory under the shorter winter days of subtropical climates. The use of local varieties had obvious advantages but great care is needed to prevent degeneration of seed stocks, by either virus or physiological alteration, which can rapidly nullify any yield advantages (Lazo and Balaoing, 1965). Thus, although breeding and selecting of new potato varieties specifically for the tropics should be encouraged (Simmonds, 1971), this is very costly and in some countries it will probably remain necessary to import yearly fresh stocks of varieties selected in temperate regions (Ganesan and Caesar, 1965). Suitability for storage should always be taken into consideration when selecting varieties.

Cultural practices

Cultural practices, through their effects on the micro-environment of the growing plant, can affect the storage qualities of potatoes. Weather has two major effects, first in its influence on the growth of healthy plants and second in its action on pests and diseases. In many tropical regions, two or more crops of potatoes can be produced annually; those produced in the wet season frequently do not store as well as those produced in the dry season (Anon., 1941). The overall growth of the potato is influenced by such factors as the nature, condition and physiological age of the 'seed', and date, depth and density of planting. Cultivation practices such as fertiliser application, the use of irrigation, and of haulm destruction, have a more direct effect on storage quality. Whilst the application of farmyard manure and nitrogenous fertiliser generally increases yield, excessive application may have an adverse effect on storage life by reducing the percentage dry matter in the tubers (Burton, 1966; Holliday, 1963). Holliday (1963) also reports that under many conditions high levels of potassium application tend to reduce after-cooking blackening; iron, chlorine and ammonium ions are also indirectly involved in blackening. It is, however, difficult to generalise as fertiliser application and soil type react in many ways and have differing effects on tuber quality; indeed Kimbrough (1929) reported that applications of various fertilisers had no apparent influence on subsequent keeping quality of potatoes, although some variation was observed in the proximate composition of the tubers.

Potatoes in general respond well to irrigation. Although varieties differ in their response, they grow best when the soil is kept close to field capacity (a soil is at field capacity when it is holding its maximum quantity of water against free drainage), the maximum response occurring when the tuber swelling stage is reached. Irrigation not only affects tuber yield and dry matter content but it also affects the incidence of some diseases, and hence post-harvest behaviour.

Whilst mechanical or chemical destruction of the haulm is usually necessary in the prolonged growing season of maincrop potatoes in temperate regions, it is less often needed under the shorter growing periods of the tropics. When late blight is present it may, however, even in the tropics, be advisable to destroy the haulm in order to reduce the probability of tuber infection. When late blight is not present destruction of the haulm well before harvest adversely affects yield, while destruction of the haulm immediately before harvest results in the harvesting of immature tubers. Under hot, dry conditions very rapid chemical destruction of the haulm can lead to stem end discoloration of the tubers. Haulm destruction may therefore, under certain conditions, be disadvantageous both to yield and storage.

Before tubers are placed in storage as much as possible of the adhering soil should be removed from the crop as this impedes ventilation, encourages tuber rots, and reduces the efficacy of any chemical treatments.

Harvest maturity

With any particular variety, the longer the growing season the higher the yields and the higher the dry matter content of the tubers is likely to be. Dry matter content has important effects on both the subsequent cooking and processing qualities of the tubers. Tubers with a low dry matter content do not disintegrate when boiled or steamed but have a firm consistency and are termed 'waxy'. On the other hand tubers with a high dry matter content disintegrate when boiled, have a soft consistency and are very 'mealy', dry and coarse. Individuals vary in their preferences for cooking qualities of tubers. Tubers intended for processing (other than canning) should have a high dry matter and low reducing sugar content for the development of good colour. Thus, since immature tubers generally have a high reducing sugar content and low dry matter it is particularly important that tubers intended for processing should only be harvested when mature. It must, however, be borne in mind that dry matter content is affected by environment and variety as well as by harvest maturity (Howard, 1963). The extent of mechanical damage, which is an important factor in both quality and suitability for storage, depends to a considerable extent on the maturity of the tubers when harvested. Immature tubers are much more prone to superficial mechanical damage than mature ones.

The effects of tuber size on dormancy and keeping qualities were examined by Karmarkar and Joshi (1941). It was found that in storage at 4°C size had no effect upon dormancy, but at 20°C large tubers commenced sprouting before medium-sized ones, and medium-sized ones before small. It was impossible, however, to conclude whether or not this was a direct effect of size or simply a reflection of the different degrees of physiological maturity of the different sized tubers. They further reported that immature tubers lost water and shrivelled more rapidly in storage than did mature tubers. Abeygunawardena *et al.* (1964) also found that small tubers sprouted later than large ones, and that water loss increased appreciably with a decrease in tuber size, presumably because of the greater surface area per unit weight in addition to possible maturity factors. Similarly, Ariyanayagam (1958) found significant differences in water loss from tubers of different sizes.

Appleman *et al.* (1928) found that after 1 week at 22°C, shrinkage of immature tubers was approximately twice as great as that of mature tubers although later, after 5 weeks, there was little difference between the shrinkage rates. They also reported that at lower temperatures, immature tubers lost water faster and for a longer period of time; this was probably due to delayed cork formation. Smith (1933) did not report such great differences between mature and immature tubers, but found that immature tubers decayed more rapidly than mature ones in addition to showing somewhat higher water loss (Table 2). It was concluded by Singh and Mathur (1938a), however, that although weight loss during storage decreases with increasing maturity, immature tubers may in some circumstances store better than mature tubers as they keep longer without sprouting. Where sprouting can be controlled or prevented it is nevertheless advisable to store fully mature tubers. Thus, if it is desired to harvest tubers for storage before the end of the normal growing season the haulm should be burnt off well in advance in order to allow the tubers to mature.

TABLE 2. EFFECT OF DEGREE OF MATURITY ON THE LOSS IN WEIGHT AND DECAY OF POTATOES IN STORAGE (SMITH, 1933)

Degree of maturity	Percentage loss in weight due to:							
	Shrinkage (1)*	Decay (1)	Shrinkage (3)	Decay (3)	Shrinkage (5)	Decay (5)	Shrinkage (7)	Decay (7)
Immature	2.67	1.38	3.63	2.31	5.02	2.58	6.66	3.23
Mature	2.23	0.71	3.25	1.06	4.31	1.59	5.25	1.73

*Numbers in parentheses indicate the number of months in storage.

Handling

The condition and health of the produce at the time that it is placed in store is usually the most important single factor governing the success or failure of storage. It has often been stressed that mechanical injuries to tubers during harvesting and handling operations have a major influence on storage quality of tubers. The Potato Marketing Board (undated b), in a recent survey in the United Kingdom, showed that 33% of the ware crop was so seriously damaged on the farm that it was fit only for stockfeed. Of this damage 14% occurred during lifting, 8% during loading into store and a further 11% on 'dressing out' of storage. Additionally, 12% loss from physical damage occurred during transit from farm to shop. Quite apart from the direct losses caused by such gross mechanical damage, roughly handled tubers lose weight more rapidly in storage, respiration rate is increased, and the starch–sugar balance is altered compared with carefully handled, undamaged tubers (Karmarkar and Joshi, 1951; Twiss, 1963). Roughly handled tubers also decay more readily than carefully handled ones (Table 3).

TABLE 3. INFLUENCE OF MANNER OF HARVESTING AND HANDLING POTATOES ON PHYSIOLOGICAL LOSS IN WEIGHT AND DECAY DURING STORAGE (SMITH, 1933)

Treatment	Percentage loss in weight*											
	S(1)	D(1)	T(1)	S(3)	D(3)	T(3)	S(5)	D(5)	T(5)	S(7)	D(7)	T(7)
Carefully handled	1.79	0.29	2.08	2.25	0.66	2.91	3.14	1.23	4.37	4.33	1.16	5.49
Normally handled	2.66	1.12	3.78	4.24	1.46	5.70	5.47	1.95	7.42	6.16	2.29	8.45

*S = shrinkage, D = decay, T = total weight loss; numbers in parentheses indicate number of months in storage.

A form of handling damage which occurs frequently is bruising. Unless very severe, bruising is frequently invisible externally but is manifest internally as flattened spheroidal blue-grey discoloured patches usually about 0.5–1.0 cm in diameter centring on the vascular region of the tuber flesh; this is generally referred to as internal bruising or blue spot. In general, Burton (1966) reports the incidence of internal bruising to be high after dry growing seasons when the tubers are less turgid at harvest and have higher dry matter content.

It was also found by Boyd (1951) that as tubers wilted during storage they became more susceptible to internal bruising. Variety and differences in potassium and tyrosine levels of tubers have also been shown to influence the incidence of internal bruising (Ophuis *et al.*, 1958; Burton, 1966). Handling temperature also has an effect, less internal bruising being evident following handling at high temperatures (30°C) than at low temperatures (2°C). Soil type and fertiliser treatment may affect both the potassium and total dry matter content of tubers and so influence indirectly the occurrence of internal bruising.

Thus, the machinery and methods of working used during handling operations can profoundly influence, directly and indirectly, the quality of subsequently stored potatoes: unsuitable machinery or incorrect methods of working cause unnecessary damage to tubers, and so enhance loss in storage.

Drying and curing

In order that drying and curing may be successfully accomplished potatoes should ideally be stored under conditions where ventilation, temperature and humidity are controlled. Potatoes harvested under moist conditions should preferably be dried as soon as possible after loading into store by the use of forced draught ventilation; this is best accomplished when the ambient relative humidity is low, so that the air will have a high drying power. Care should be taken to avoid condensation of moisture in the upper layers of tubers; this is usually achieved by covering the tubers with a layer of straw or other suitable material. Forced draught ventilation should only be continued until the crop has been dried, as the over-use of such ventilation at this stage can cause excessive moisture loss, apart from being economically wasteful.

Undue loss of weight and danger of loss from disease are both minimised if the growth of wound cork is encouraged as soon as the potatoes have been placed in storage, and immediately following any handling operations. The conditions which favour rapid development of wound cork are temperatures around 15°C and a relative humidity in the range 85–90% (Artschwager, 1927; Burton, 1966). The high respiration rate of freshly harvested tubers, even when mature, causes a rapid rise in temperature as soon as ventilation is restricted, and evaporation from the fresh wounds and from any attached moist soil soon results in high relative humidities so that conditions suitable for curing are easily obtained. These conditions which favour wound healing also favour the general thickening of the periderm (Twiss, 1963). The process of wound healing involves suberisation of the cut surface, followed by the formation of wound periderm. Varieties differ in the rate of wound periderm development under given conditions and in the thickness of the periderm produced; the nature and position of the periderm also depends upon the nature of the injury. In general, superficial cells at cut surfaces were found to suberise after 1 day at 21°C or above, after 2 days at 15°C, after 3 days at 10°C, after 5–8 days at 5°C, and after 8 or more days at 2.5°C. Initiation of wound periderm 1 day after suberisation at 15°C or above was observed but no periderm formation was detected within 10 days at 5°C or below. These results were obtained under humid conditions while under drier conditions both suberisation and periderm formation were delayed (Artschwager, 1927). Similarly, Smith (1933) reported suberisation on the second day in tubers stored at 20°C but not until the sixth day in tubers held at 8°C; wound periderm was noted on the third day at 20°C but was not observed in tubers at 8°C even after 12 days. The losses, both through shrinkage and decay of cured and uncured tubers, were also compared (Table 4). Tubers cured for 8–12 days at 17–20°C lost considerably less weight in subsequent storage at 13°C than those prestored for the same length of time at a temperature of 4–7°C. The amount of loss due to decay was also much less in cured tubers (Table 4).

TABLE 4. INFLUENCE OF PRESTORAGE TEMPERATURE AND HUMIDITY ON THE PHYSIOLOGICAL LOSS IN WEIGHT AND DECAY OF POTATOES DURING STORAGE (SMITH, 1933)

Prestorage conditions	Percentage loss in weight*											
	S(1)	D(1)	T(1)	S(3)	D(3)	T(3)	S(5)	D(5)	T(5)	S(7)	D(7)	T(7)
High temperature, high humidity	2.08	0.25	2.33	3.04	0.64	3.68	4.20	1.43	5.63	5.08	1.50	6.58
Low temperature, low humidity	2.37	1.16	3.53	3.45	1.50	4.95	4.41	1.75	6.16	5.41	1.95	7.36

*S = shrinkage, D = decay, T = total weight loss; numbers in parentheses indicate number of months in storage.

It is well established that curing can reduce the incidence of certain tuber rots through the formation of wound periderm, which acts as a physical barrier and inhibits the penetration of pathogens into the tuber flesh; it will nevertheless be of little value unless undertaken immediately after handling operations, as otherwise the pathogens will have become established before the wound periderm is formed. The risk of initiating bacterial soft rot is, however, possibly greater during the curing period than at any other time during controlled-environment storage.

Most sprout suppressants have an inhibitory effect on periderm formation and so their introduction into the store should if possible be delayed until the wound healing process is complete.

Influence of storage temperature and humidity during the holding period

(i) On water loss and respiration

Humidity and more especially temperature have profound effects on the quality of stored potatoes, affecting the rate and extent of water loss, respiration rate, the degree of sprouting, dry matter content and many aspects of tuber physiology, as well as the incidence and severity of many tuber diseases.

All water lost before tubers are sold means a loss of income to the grower because of the loss of weight. Water loss in excess of 10% may also affect quality to the extent of rendering the tubers unmarketable. Two factors govern the rate at which water is lost during the storage period, the drying power or vapour pressure deficit (VPD) of the air surrounding the tubers, and the resistance of the skin to the transmission of water vapour (Twiss, 1963; Burton, 1966). The drying power of the air surrounding the tubers remains at a low level for as long as the air remains still; ventilation practices which involve more than the necessary minimum of air exchange thus inevitably increase water loss. The VPD of the air surrounding the tubers is influenced by its humidity and temperature: at any given relative humidity the VPD increases with increase in temperature, and conversely at any given temperature the VPD decreases with an increase in relative humidity (Appendix 1). The greatest shrinkage losses of potatoes occur during the first month after harvest and again from the time when tubers begin to sprout. The shrinkage during the first month appears to be due largely to excessive evaporation and high rate of respiration associated with injured and unsuberised surfaces of the tubers. The effect of storage temperature and humidity on the loss of weight by tubers has been studied by many workers. Butler (1919) recorded percentage weight losses of 2.9, 7.2 and 11.7% at storage temperatures of 3.5, 8.5 and 15.5°C respectively after a 5-month storage period. Stuart *et al.* (1929) found that losses in weight over a 6–7-month storage period were consistently lower at 2.2 than at either 0 or 4.4°C. Karmarkar and Joshi (1941) found that although tubers lost more weight when stored at -1°C, there was little difference between the losses in weight at 2.2 and at 4.4°C (Table 5). The curing process which favours wound healing and the thickening of the periderm and thus

TABLE 5. PERCENTAGE LOSS IN WEIGHT OF STORED POTATOES (KARMARKAR AND JOSHI, 1941)

Months in store	Percentage loss in weight after storage at:		
	-1°C	2.2°C	4.4°C
1	2.56	2.66	2.99
3	8.04	5.60	5.71
5	12.95	7.20	7.13
7	Black heart	8.55	9.06
9	Black heart	10.69	12.11*
11	Black heart	12.27	12.11*

*Sprouting.

reduces water loss by evaporation through the skin has already been discussed. The temperature and humidity at which the tubers are held for the few (8–12) dyas prior to storage has a great influence on weight loss (Table 4). It was also consistently shown (Smith, 1933) that after periods of 1–8 months storage tubers which have been carefully handled and stored initially for 10 days under warm moist conditions (treatment 1) lost less water than those which have been less carefully handled and stored under cool moist conditions (treatment 2) prior to storage (Table 6).

TABLE 6. PHYSIOLOGICAL LOSS IN WEIGHT OF POTATOES IN STORAGE (SMITH, 1933)

Treatment*	Percentage loss in weight after storage time (months) indicated			
	1	3	5	7
1 1930/31	1.33	1.75	3.17	4.08
2 1930/31	3.08	3.92	4.00	7.72
1 1931/32	1.67	2.00	3.12	4.16
2 1931/32	2.83	4.41	5.66	6.33

*See text.

The highest rate of respiration of the tubers occurs immediately after harvest, decreasing rapidly even if the tubers are placed at comparatively high temperatures. Respiration increases again with the resumption of growth subsequent to the dormant period. The highest rates of respiration occur in immature tubers that have been roughly handled. The loss in weight of potatoes due to loss of carbon dioxide and dry matter in respiration is nevertheless very small in comparison with the loss caused by evaporation of water (Appleman *et al.*, 1928; Smith, 1933; Singh and Mathur, 1938a, 1938b; Burton, 1966), and so is relatively less important.

(ii) On dormancy and sprouting

Sprout growth does not normally start immediately after harvest and there is usually a time lag, the dormant period, which may last several weeks before growth resumes. Its duration depends upon the variety, the growing conditions prior to harvest, the severity of handling during harvesting, the maturity of the tubers and the incidence of tuber disease, as well as upon storage conditions. The major factor which influences the length of the dormant period after harvest is the storage temperature. Burton (1966) has emphasised the complex nature of dormancy and pointed out that the effect of temperature may be variable, depending upon many factors which may be limiting growth at a particular time. Wright and Peacock (1934) and Burton (1963) found that in general with British and American varieties the higher the storage temperature over the range of about 4–22°C the shorter was the residual dormant period. Schippers (1956a, 1956b) made extensive studies of 40 varieties at temperatures ranging from 3 to 20°C. He showed that on average raising the storage temperature from 10 to 20°C shortened the residual dormant period by only 18% while lowering the temperature from 10 to 5°C lengthened the period by 67%, and from 10 to 3°C by over 150%. Burton (1966) reports that storage for about a month at a temperature as low as -1°C, just above the freezing point of the potato, may lead to a very much prolonged dormant period and may even permanently impair the ability to sprout.

Several workers (Rosa, 1928; Thornton, 1939; Emilsson, 1949) have reported that the dormant period after harvest is shorter when the humidity of the storage atmosphere is high; also that exposure to light prolongs the dormancy of mature tubers although it may shorten that of immature tubers (Appleman, 1914). Davidson (1958), however, could demonstrate no effect of light and only little effect of humidity upon the length of time elapsing between harvest and the first appearance of visible sprouts. Sprouting could be induced in certain varieties if the concentration of oxygen in the storage atmosphere was reduced; Thornton (1939) and Kidd (1919) recorded an oxygen concentration of 5–10% as being optimal for sprouting. More recently Burton (1966) showed that increasing the carbon dioxide concentration in the storage atmosphere has no apparent effect on the length of the dormant period but pointed out (Burton 1952a, 1952b) that in addition to carbon dioxide, small quantities of other volatile compounds are evolved during respiration and that when these are allowed to accumulate in the storage atmosphere they will suppress sprout growth. Little is known of the biochemical reasons for dormancy although many workers have observed many physiological changes in the tuber during storage. Many factors such as hormone content (Appleman, 1918; Hemberg, 1954; Okazawa, 1959), presence of sulphur, particularly sulphydryl, compounds (Hammett, 1929; Miller, 1931; Emilsson, 1949) and rate of respiration (Emilsson, 1949; Todd, 1953; Burton 1958b) have all been suggested as being the trigger in the breakage of dormancy but Burton (1966) suggests that the balance or imbalance of a whole complex of factors is probably involved.

The immediate sequel of the breakage of dormancy is sprout growth. There is no apparent connection between the length of the dormant period and the subsequent rate of sprout growth. The main factors which influence the rate and form of sprout growth are variety, previous storage history, physiological age, temperature, humidity and composition of the air (Burton, 1966). Although varieties differ somewhat in their response to different storage temperatures, sprout growth is generally extremely slow at temperatures below 5°C. An increase in storage temperature causes an increase in growth (Krijthe, 1946) up to an optimum of about 20°C, above which the rate of growth again decreases as shown below (Burton, 1958b):

Storage temperature	(°C)	10	15	20	25
Sprout growth	(g/tuber)	1.17	3.07	4.70	2.45
Sprout growth	(% total wt)	1.18	2.74	4.45	2.50

The humidity of the storage atmosphere can also affect the rate and in particular the form of sprout growth (Burton, 1966). The degree of branching is greater under dry conditions and the production of adventitious roots greater under humid conditions. It has also been shown that sprout growth, once it has commenced, is stimulated by increases in carbon dioxide (Burton, 1958b) and decreases in oxygen tension (Kidd 1919; Barker, 1936; Thornton, 1939; Burton, 1958b). As an increase in storage temperature causes changes in the carbon dioxide and oxygen concentrations in solution in the cell sap, Burton (1958b, 1961) has suggested that these may account for the effect of temperature upon sprout growth. The appearance of sprouting is accompanied by increased respiration. The form of sprout growth is greatly influenced by both the quantity and type of illumination; the morphology of the developing sprout under various conditions has been described and illustrated by Krijthe (1946).

(iii) On starch–sugar relationships

Storage temperature influences many physiological processes in the tuber; of particular practical importance is the starch–sugar balance. As long ago as 1882 Müller-Thurgau found that storage below 6°C increased the content of sugar. Since this time it has been well established by many workers that both sucrose and reducing sugars accumulate at low temperatures, though not necessarily in the same proportions at different temperatures. Typical figures for sucrose and reducing sugar content of tubers stored for 4 weeks at various temperatures are given in Table 7 (Burton, 1965).

TABLE 7. SUGAR CONTENT OF TUBERS STORED FOR ONE MONTH AT DIFFERENT TEMPERATURES (AFTER BURTON, 1965)

Storage temperature (°C)	Sucrose	Reducing sugars
	(g/100 g fresh weight)	
2.2	1.4	1.8
4.4	0.4	1.3
5.8	0.3	0.9
10.0	0.15	0.4
15.5	0.15	0.3

The mechanism of this low-temperature sweetening is complex, involving time–temperature–concentration relationships (Burton, 1966). Potatoes which have become sweet at low temperature may be de-sweetened by storage for 2 weeks or so at a higher temperature of 15–20°C or a somewhat shorter period at an even higher temperature of 21–24°C. This process, known as reconditioning, involves both reconversion of some of the free sugar to starch and the consumption of some in respiration, with the overall result that the sugar content falls (Twiss, 1963). However, reconditioning is rarely complete and tends to be uneven. When in a highly sweet condition, tubers are of reduced acceptability for ordinary table use and are also unsuitable for processing.

In addition to the increase in sugar content caused by exposure to low temperatures the concentration of sugars also exhibit an upward trend after very prolonged storage even at higher temperatures. This appears to be a symptom of senescence and has been termed senescent sweetening (Barker, 1939; Burton, 1966). It starts earlier and is more rapid at higher storage temperatures occurring after 4 months storage at 15°C (Barker, 1938).

In addition to alterations in the starch–sugar balance many other changes occur in the dry matter of the tuber during storage. A reduction in ascorbic acid content of freshly harvested tubers occurs, during storage, at a rate which varies with storage temperature and maturity (Twiss, 1963). Other vitamins and nitrogenous compounds are also lost during storage but their rate of loss is not known to be affected by storage temperature.

(iv) On disease

Both storage temperature and humidity have a profound effect on the incidence and severity of storage diseases of potatoes. In general, growth of both fungi and bacteria are favoured by warm humid conditions and their growth may be restricted by low-temperature storage. In storage it is particularly important to prevent moisture from condensing on the tubers as this greatly enhances the spread of several diseases, in particular the bacterial soft rots.

It may thus be seen that many factors are concerned in determining the optimum storage temperature and humidity and that these all influence the ultimate quality of the produce. If high-quality tubers are to be obtained following storage it is essential that both these parameters be appropriately controlled.

Sprout suppression

When potatoes are stored at temperatures high enough to avoid undesirable accumulation of sugar, sprout growth occurs quite vigorously. Chemical methods to suppress sprout growth are available and are in use commercially. Most of the chemical suppressants employed are active in the vapour phase; they may be dispersed on an inert filler such as kaolin or talc which is dusted on the tubers as they are put into store, or are mixed with the tubers in a granular formulation; alternatively, the active chemical may be vapourised and blown through the stored tubers. The former two methods of application have the advantage that the suppressive effect is continuously maintained by the slow evaporation of the active chemical, but the latter method is simpler to apply where suitable machinery is available. With solid state application, the level must be sufficient to maintain an active concentration for the desired length of storage, while when using the fumigation method a second application is possible if necessary. Chemicals used for sprout control include the methyl ester of α-naphthaleneacetic acid (MENA), tetrachloronitrobenzene (tecnazene), isopropyl *N*-phenylcarbamate (propham), isopropyl *N*-chlorophenylcarbamate (chlorpropham), and 3,5,5-trimethylhexan-1-ol (nonanol).

MENA can be applied as a dust with an inert filler, in impregnated paper distributed among the tubers (Marth and Schultz, 1950), sprayed on the tubers in a volatile solvent (Stuivenberg and Veldstra, 1942), applied during preparation for marketing in washing water or wax emulsions (Findlen, 1955) or introduced among stored potatoes in the vapour phase (Sawyer and Dallyn, 1957). The recommended rates of application, depending on the method adopted and the proposed duration of storage, vary from 14 to 40 g of the ester per 1000 kg potatoes (Burton, 1966) although under South Australian conditions of common shed storage, Edwards (1949) found the heavier dust treatment of around 80 g per 1000 kg tubers to be optimal.

Tecnazene (TCNB) was first introduced as a sprout suppressant by Brown (1947). It is applied as a dust containing 5–6% a.i. at the rate of about 100 g of the TCNB per 1000 kg potatoes. It is not such an effective sprout suppressant as the other substances described, but is the only chemical inhibitor that can safely be used to delay the sprouting of seed potatoes. Propham (IPPC) is a very effective sprout inhibitor at concentrations of between 7 and 54 g per 1000 kg (Rhodes *et al.*, 1950). Mixed with an inert filler to give a concentration of about 2% it can be applied as a dust at harvest time at a rate of 1–2 kg per 1000 kg (Downie, 1952); alternatively, the dust may be blown through potatoes in store, or the active chemical introduced as a vapour (Ophuis, 1956). In South Australia, Edwards (1952) compared the effectiveness of a number of sprout suppressants including MENA, maleic hydrazide (MH) and IPPC, and found IPPC to be the most effective, giving complete control of sprouting and a 50% reduction in weight loss as compared with untreated controls after 3 months storage. Under cold wet conditions, however, IPPC may aggravate skin blemishes, though this effect may be minimised by allowing an interval of 4–6 weeks between lifting and treatment.

Chlorpropham (CIPC) may be applied as a dust or as granules (Marth and Schultz, 1950) at a rate of 20–30 g a.i. per 1000 kg, as a dip or spray, but more commonly is applied as an aerosol in methanolic solution either alone or mixed with a proportion of IPPC, or by vapourising the liquid chemical at about 200°C and introducing the vapour into the recirculated air stream, recirculation being continued for 24–48 h (Burton, 1966). The latter method achieves successful sprout suppression with as little as 10 g CIPC per 1000 kg potatoes (Sawyer, 1959, 1961). Low concentrate dips of below 5000 ppm (manufacturers recommend 10,000 ppm) should be avoided as they not only fail to control normal sprouting but encourage internal sprouting (Hruschaka and Heinze, 1967; Ewing *et al.*, 1968). Treated tubers should not be processed or utilised in any way for at least 3 weeks after the final application of CIPC.

Nonanol was found by Burton (1958a, 1958c) completely to prevent sprout growth at 10°C at a concentration of 0.1 g/l of air. Being a liquid, nonanol cannot be introduced directly among the potatoes to evaporate slowly as can some of the solid suppressants. The usual method of application is ventilation of the potatoes with air containing the required concentration of nonanol vapour, the liquid being vapourised by allowing it to drip on to a hot plate in the air stream. Unlike the other compounds discussed, nonanol does not prevent the breaking of dormancy but instead kills the young sprouts as soon as they appear (Burton, 1966). Growth resumes 2 or more weeks after treatment, so that repeated applications are needed. To avoid any residual odours stores should be ventilated with fresh air either naturally or by fan for at least 48 h before 'dressing' (i.e. grading and sorting) the potatoes for sale.

All the above chemicals except TCNB inhibit the development of wound cork. So, although the gross water loss associated with sprouting may be prevented by the application of suppressants, weight loss may often still be disappointingly high because of the greater loss from unsuberised wound and tuber skin surfaces. Inhibitors therefore should preferably be applied some weeks after harvest, after curing is complete. In addition to the above suppressants for post-harvest application, there is one chemical, maleic hydrazide, which is applied pre-harvest to the growing crop as a foliar spray, when it is translocated to the tubers and inhibits sprout growth during subsequent storage. It is usually applied in aqueous solution as the water-soluble diethanolamine or sodium salt at a rate of 2–5 kg/ha, using a high-volume sprayer (Burton, 1966). If applied less than 3 weeks before the death of the foliage, inhibition may not be completely effective, while if applied more than 5 weeks before harvest, yield may be adversely affected. Maleic hydrazide, like most other sprout inhibitors, prevents the development of wound periderm.

Van Niekerk (1960) showed in South Africa that effective sprout suppression and consequently a reduction in weight loss could be obtained over an 8-month storage period in a thatched roof structure during which the temperature ranged from 10 to 20°C and the relative humidity from 34 to 70% RH by the use of a mixture of IPPC and CIPC. In Venezuela, Colmenares and Chicco (1968) showed that a 10-s dip in 0.75 or 1.0% CIPC solution gave excellent sprout inhibition over a 5-month storage period with ambient temperature ranging from

12 to 18°C and relative humidity between 73 and 91% RH. Effective sprout inhibition can also be obtained by storing tubers in CIPC-treated paper bags (Nylund and Ayres, 1964): after 32 days storage at 14°C potatoes in CIPC-treated bags lost only 0.4–0.8% in weight due to sprouting while those in untreated bags lost 2.0%; after 46 days the losses were 0.7–1.1% in treated and 2.9% in untreated bags.

In the USA, according to Mosher (1968), the three most important suppressants are MH, used largely by processors, CIPC, the most potent and widely used of all inhibitors and TCNB, which although the weakest inhibitor now in use does not inhibit suberisation, and can also be used on seed potatoes.

The use of chemical sprout inhibitors gives rise to the presence of residues of the chemical in the tubers, which are the subject of legislation in most countries. All the substances listed above have been accepted by some, but not necessarily by all of the responsible authorities. In some countries tolerance levels have been established for some of the chemicals, but there are many differences between their regulations. Therefore before any chemical treatment can be recommended for use on foodstuffs the appropriate food or health authorities of the countries concerned should be consulted. In all cases the chemicals should only be used in strict accordance with the approved manufacturers' instructions.

In addition to chemical methods of sprout suppression, gamma-irradiation has been used. Complete inhibition of sprouting may be obtained by irradiating tubers with gamma-rays at 5,000–20,000 rad (Sparrow and Christensen, 1954; Burton and Hannan, 1957) but Sawyer (1956) reported increased rotting and Burton *et al.* (1959) reported hastened senescence following high dosage rates. The use of this method of sprout suppression is unlikely to be economic in many situations (Ley *et al.*, 1961), although it has been applied commercially in Canada (Errington and MacQueen, 1961).

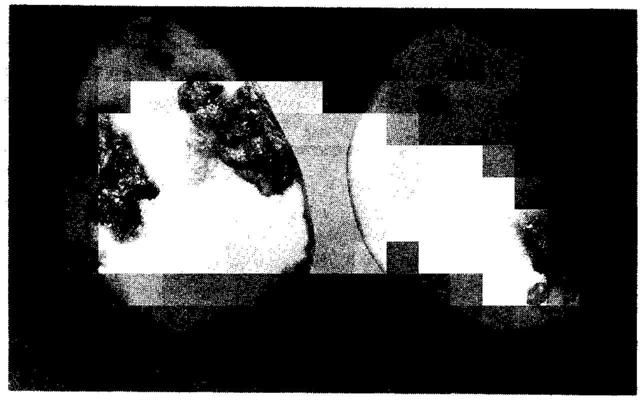
Market and storage pests, diseases and disorders

Pests

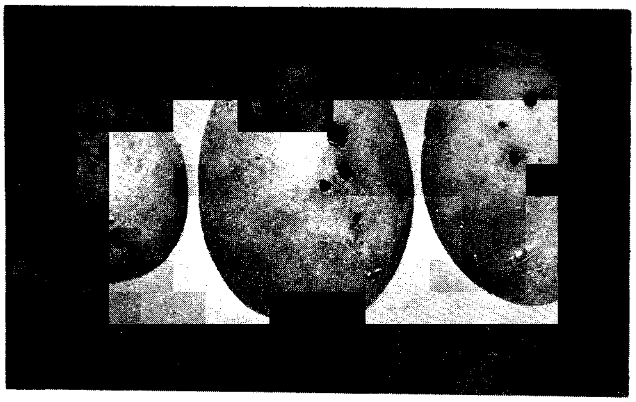
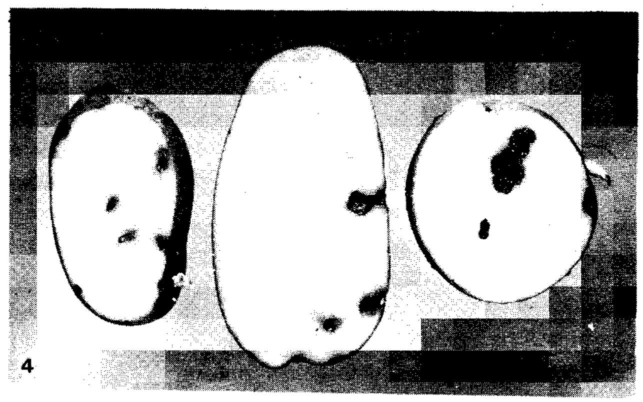
The potato crop is attacked in the field by a wide variety of animal pests which cause damage to the leaves, stems, roots, and tubers of the growing crop. The biology and control of such pests has been well documented (Shands and Landis, 1964; Smith, 1968; Shands *et al.*, 1969); both Smith (1968) and Shands and Landis (1964) list over 100 potato pests and describe over 20 of the more important ones in some detail.

One of the most destructive post-harvest pests of potatoes is the potato tuber moth (*Gnorimoschema operculella* Zell.). The larvae or caterpillars of this moth infest the tubers in the field, but most of the damage occurs during storage when, if the temperature is high enough, the moth is able to reproduce and eventually release moths to restart infestations. Where the larvae have been feeding unsightly tunnels choked with excrement occur throughout the tuber flesh. Damage to the crop may be kept to a minimum by both cultural and chemical means. Infested seed should never be used, tubers should not be exposed in the field, stores and storage containers should be cleansed and sterilised before use, and stores should be well screened to prevent entry of adult moths. Infested potatoes in storage may be treated with methyl bromide or other fumigants if proper facilities and expertise are available (Mackie and Carter, 1937; Lubatti and Bunday, 1958; Pradhan *et al.*, 1960; Gostick *et al.*, 1971). Control measures in the field before harvest with any of a number of insecticides should be started when the caterpillars are first noticed webbing the leaves together (Button and Koch, 1959; Bacon, 1960: Yathom and Brosh, 1964; Yathom and Meisner, 1966).

Other field pests, which cause damage primarily to the growing crop, but which may also continue to cause damage in the stored crop and render the tubers less marketable include slugs (Figs 1 and 2), wireworms (Figs 3 and 4), millipedes and occasionally cutworms. Whilst most nematodes are only of importance on the growing crop, the root-rot nematode (*Ditylenchus destructor* Thorne) does cause damage to stored tubers. Small discoloured spots or holes first appear on the tubers where nematodes are present; these develop into grey or brown granular lesions followed by drying and cracking of the tuber surface. Control may be achieved by strict sanitation practices or by disinfecting soils with various nematicides (Thorne, 1945; Darling, 1957). Rodents may present a severe hazard to stored potatoes in some circumstances. If the store structure does not provide adequate protection, conventional rodent proofing and control measures may be applied, as appropriate.

Figs. 1 and 2. Slug damage to potato tubers. *1*, External symptoms; *2*, internal symptoms [photos by courtesy of National Institute of Agricultural Botany (NIAB)].

Figs. 3 and 4. Wireworm (Elateridae) damage to potato tubers. *3*, External symptoms; *4*, internal symptoms (photos by courtesy of NIAB).

Diseases

Diseases are the most common cause of storage losses of potatoes. There is no absolute division of diseases into those which affect the growing crop and those which affect stored tubers; many do both. The Index of Plant Diseases in the United States (Anon., 1960) lists 90 bacteria and fungi, 30 viruses, and 40 non-parasitic diseases of the potato. Blodgett and Rich (1949) include 68 diseases and disorders of potato tubers in the Pacific North West of USA, Folsom *et al.* (1955) report about 60 in Maine, USA, Torres *et al.* (1970) report 32 diseases in Peru, and Rao (1969) lists over 50 in India and gives a very full and useful bibliography of potato diseases with particular reference to that country. The more common diseases in India have been further described by Nagaich and Dutt (1972). In addition to the above, disease surveys have been carried out in many regions, which show that the incidence and severity of the numerous diseases varies considerably between geographic and climatic regions. Some of the more important and widespread diseases that are particularly destructive during storage are briefly discussed below. Others of minor or local importance are mentioned in reference works on potato diseases such as Burton (1966), Butler and Jones (1949), McKay (1955), Richardson and Booth (1970), Smith (1968) and Whitehead *et al.* (1953). An extensive bibliography of the potato in Latin America is given by Montaldo (1969).

1. Diseases causing major decay

Bacterial diseases are generally more important in tropical regions, particularly in the humid tropics, than in temperate regions. Probably the most important and widespread of these diseases is bacterial wilt or brown rot caused by *Pseudomonas solanacearum* (E. F. Smith) E. F. Smith-Brown. Infection usually takes place initially through injured roots and spreads to the tubers through the stolons. In the early stage of the disease the bacteria are confined to the vascular tissue which results in wilting and leads ultimatly to collapse of the plant. Infected tubers are characterised by a brown vascular ring which, when squeezed, exudes a white slimy liquid containing bacteria. During storage a more extensive rot of the tuber flesh may occur resulting in the total collapse of the tubers and leaving only a liquifying mass (Kelman, 1953; Thurston, 1963; Buddenhagen and Kelman, 1964; Robinson and Ramos, 1964). Bacterial ring rot caused by *Corynebacterium sepedonicum* (Spieck & Koth) Skapt

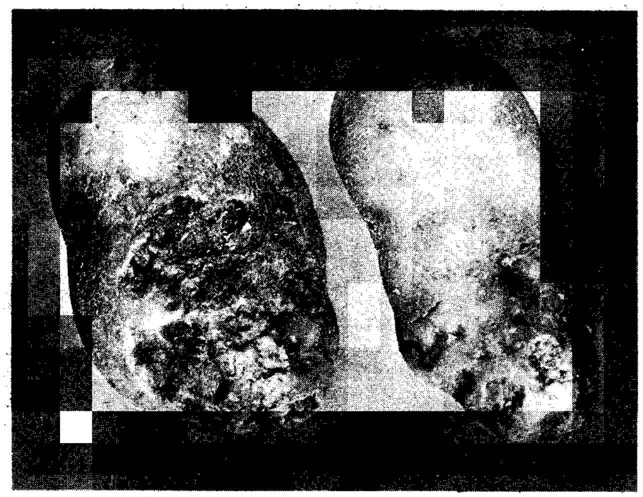
& Burkh. exhibits similar symptoms to brown rot. This disease is highly contagious and is readily spread by contaminated equipment and by insects. Control may be achieved by strict sanitation procedures; furthermore varieties are known to differ in their resistance (Bonde and Covell, 1950), and where the disease is prevalent, the more susceptible varieties should be avoided.

Blackleg (*Pectobacterium carotovorum* var. *atrosepticum* van Hall) appears to be less important in the tropics than in temperate regions where it is most prevalent under cold moist conditions. The storage of infected tubers may lead to severe losses (Pethybridge and Murphy, 1911). Bacterial soft rot caused by *Pectobacterium carotovorum* (Jones) Waldee (Dowson, 1957) causes serious losses to damaged tubers and may also be a problem especially with immature tubers if they are harvested under warm climatic conditions and if they are packaged whilst still wet from washing. Soft rotting bacteria do not usually invade undamaged tubers unless they are covered with a film of moisture. Under these conditions, the bacteria can enter through the lenticels and cause extensive rotting at storage temperatures above 10°C. The optimum temperature for the development of these rots is 25–30°C.

The most universally widespread and devastating disease of potatoes is blight [*Phytophthora infestans* (Mont) de Bary]. In addition to reducing yields by prematurely killing the foliage (Figs 5 and 6), further losses result from rotting of the tubers both in the field and during storage. Blight in the field becomes particularly serious under conditions of high humidity and temperatures of 10–20°C. Spread of infection to the tubers is not by direct internal growth of hyphae down the stem from infected foliage, but by conidia (spores) falling to the ground from such foliage and infecting exposed tubers through the lenticels or eyes, or being washed by rain down to tubers below ground. Tubers also frequently become infected during harvesting by being brought into contact with infected foliage. Subsequent storage losses may vary considerably from year to year according to the prevalence of the disease in the field. Infected tubers exhibit a brown or purplish discoloration of the skin, spreading inwards to give reddish-brown granular markings in the tuber flesh (Figs 7 and 8). Under good storage conditions this rot will remain dry and there is no evidence to suggest that the disease normally spreads from infected to disease-free tubers in store. However, tissue death caused by blight paves the way for secondary infections, usually of a bacterial nature. The storage losses which are ultimately traceable to blight infection are thus often much greater than those caused specifically by this disease.

Fig. 5. Potato field showing in the foreground the complete destruction by blight (*Phytophthora infestans*) of the susceptible variety Katahdin; resistant Ulster Torch and Pentland Crown varieties are in the background (photo by courtesy of NIAB).

Fig. 6. Symptoms of blight caused by *Phytophthora infestans* on the underside of a potato leaf (photo by courtesy of NIAB).

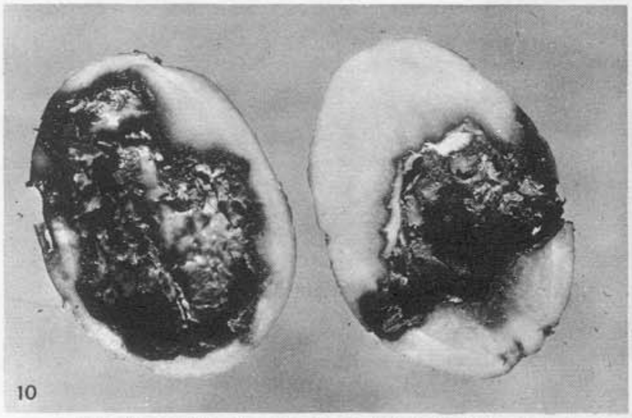


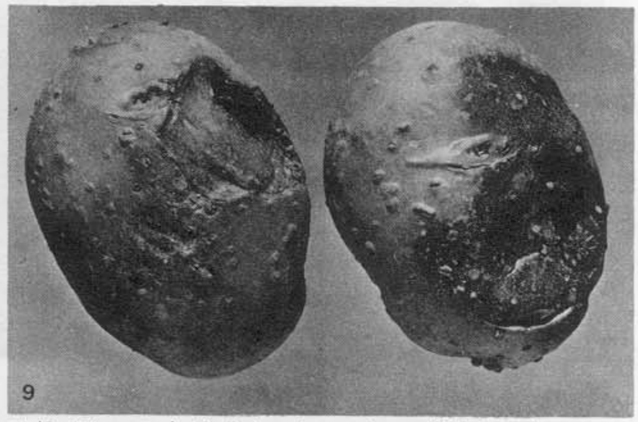
Figs. 7 and 8. Potato tubers infected with blight (*Phytophthora infestans*). *7*, External symptoms; *8*, internal symptoms (photos by courtesy of NIAB).

Early blight or target spot [*Alternaria solani* (Ell. & G. Martin) Sor.] is principally a foliage disease but also affects stored tubers. The disease is associated with hot (20–26°C) dry growing conditions alternating with occasional periods of rain or high humidity. Tuber lesions, which develop during storage, are usually small, sunken, decayed spots which frequently have a metallic sheen. The flesh is generally only affected to a shallow depth. Watery wound rot (*Pythium* spp.) may cause severe losses in storage and is most common in tubers lifted prematurely under hot conditions. As the name implies the fungus invades the tubers where they have been bruised or otherwise damaged; it has not been found in tubers still attached to the plant. Infected tubers may rot extremely rapidly; a watery liquid exudes from them leaving the tuber flesh soft and pulpy (Figs 9 and 10).

Pink rot (*Phytophthora erythroseptica* Pethy) derives its name from the fact that on cutting and exposure to air the flesh of infected tubers turn salmon-pink and ultimately black (Fig. 11). Badly affected tubers develop a rubbery consistency and exude liquid when squeezed. Tubers become infected in the field through the stolon and the disease is favoured by excessive soil moisture and hot growing conditions. Like blight, pink rot does not spread from diseased to healthy tubers in store, but losses in storage of previously infected tubers may nevertheless be severe.

Fusarium or dry rot is caused by infection of the tubers with any of several *Fusarium* species. The species responsible vary with locality, but are commonly either *F. caeruleum* (Lib.) Sacc., *F. sambucinum* Fuchel, or *F. avenaceum* (Fr.) Sacc. Tubers are not attacked whilst still attached to the plant, the infection occurring largely through wounds caused during lifting, grading, and other handling operations. Tubers become more susceptible to attack as they mature. Susceptibility increases further during early storage and the symptoms of this disease do not usually become obvious until several months after harvest. The skin of diseased tubers typically becomes wrinkled in irregular concentric folds and commonly bears white, pink or bluish pustules of spore-bearing





Figs. 9 and 10. Potato tubers infected with watery wound rot (*Pythium* spp.). *9,* External symptoms; *10,* internal symptoms (photos by courtesy of NIAB).

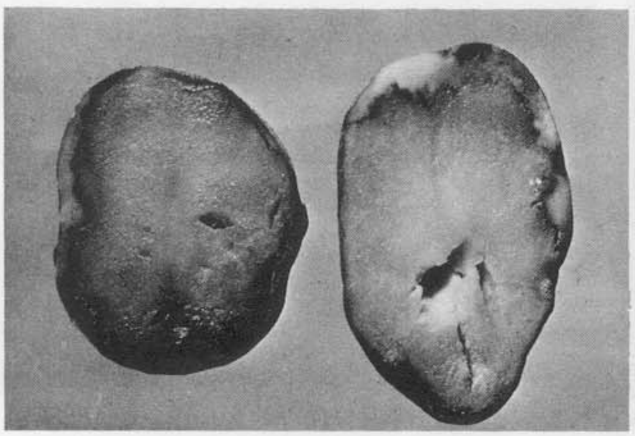


Fig. 11. Internal symptoms of pink rot (*Phytophthora erythroseptica)* in potato tubers (photo by courtesy of NIAB).

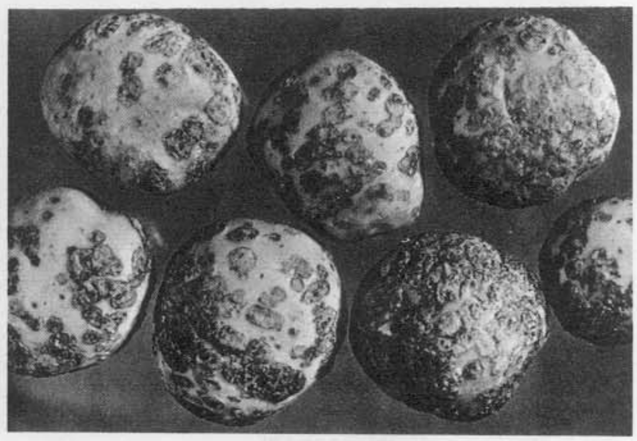


Fig. 12. Symptoms on potato tubers of scab caused by *Streptomyces scabies* (photo by courtesy of NIAB).

mycelium. Internal diseased tissue appears brown and dry, with cavities containing sporulating mycelium. This disease is favoured by dry warm soils and is most common following harvesting under dry conditions when wounding is more prevalent. The disease can also spread from infected to healthy tubers in storage.

Charcoal rot [*Macrophomina phaseolli* (Maubl) Ashby] may cause severe storage losses in particular areas. Infection most commonly occurs through wounds caused at harvesting but may also take place through lenticels and eyes. Infected tubers show black blotches on the surface and the tuber flesh beneath these areas becomes black. Damage caused by this disease is frequently accentuated by secondary infections of bacterial soft rots. Sclerotium tuber rot (*Sclerotium rolfsii* Sacc) spreads during warm and dry weather and can cause heavy losses both in the field and in store. Diseased tubers in storage become coated with thick white mycelial strands of the causal fungus and numerous small sclerotia frequently develop. Storage rots due to this organism are markedly more severe following excessive damage to the tubers. An important latent storage rot which occurs in certain temperate countries and which could also affect tubers in refrigerated storage in the tropics is gangrene (*Phoma* spp.). Infection occurs largely through wounds inflicted during lifting and grading and the rot develops gradually during subsequent cold storage. It can be the cause of serious losses, especially at low storage temperatures.

2. Blemish diseases

In addition to the above-mentioned storage rots of tubers, loss of market quality may also result from a number of surface or blemish diseases which render the tubers less attractive in appearance, even though the degree of actual damage is small. Such diseases include powdery and common scab, black and silver scurf and wart disease. Powdery scab [*Spongospora subterranea* (Wallr) Lagerh.] is favoured by high soil moisture and low temperatures. Infection, resulting in an unattractive skin, occurs on the growing tubers through the lenticels and first appears as purplish dots on the surface of young tubers. These spots increase in size and ultimately rupture, liberating masses of spore balls and leaving a scabby surface. Occasionally and in certain varieties tuber flesh is attacked and wart-like cankers produced. The disease does not usually develop further during storage. Common scab [*Streptomyces scabies* (Thaxter) Waksman & Henrici] is most severe in dry light soils and high temperatures – the conditions opposite to those favourable to powdery scab. Infection occurs initially through young lenticels in the growing tubers and eventually leads to the formation of scabs. These scabs are variable in form but most commonly are angular and corky; they may be raised or depressed, single or in groups covering the whole tuber surface (Fig. 12). There is no internal damage and the scabs do not develop further after harvesting.

Black scurf (*Rhizoctonia solani* Kuhn) derives its name from the occurrence of black fungal resting bodies (sclerotia) on the skin of infected tubers. These sclerotia render the tubers unsightly and will not wash off although they may be scratched off. There is no internal damage and no spread or growth of the fungus occurs in storage. Silver scurf (*Helminthosporium solani* Durieu & Montague) is very common on tubers grown in infested soils. Infected tubers become more or less covered with silvery lesions, which, especially with coloured skinned varieties, results in a serious loss of colour which affects the appearance and marketability. The condition is most severe in fully mature tubers that have been grown in dry soils. When infected tubers are stored in a dry atmosphere they tend to dry out and lose water more rapidly than healthy tubers, while under warm humid storage conditions the disease may continue to develop.

Wart disease [*Synchytrium endobioticum* (Schilb) Percival] renders tubers completely unmarketable. Infection usually occurs early in the season at the 'eyes' and the surrounding cells are then stimulated into active division giving rise to characteristic warts; by harvesting time such warts may have enlarged to more than the original size of the tubers. This disease is favoured by a high soil moisture, being most severe in warm (10–20°C) damp seasons, and is much reduced in very dry seasons. In several countries, wart disease is the subject of regulations designed to reduce its occurrence and spread.

Virus diseases are of considerable economic significance during the production of the potato crop and can significantly affect yields but only in a few cases do they seriously affect tuber quality. The most serious of these diseases is spraing caused by tobacco rattle virus whose symptoms appear as brown corky arcs and spots in the flesh of the tubers which renders them unmarketable as ware potatoes. The virus is nematode-transmitted and found mainly in light sandy soils. Similar symptoms may also be caused on occasion by potato mop top virus, and potato leaf roll virus can sometimes cause a vascular necrosis in the tubers. Other viruses may result in the tubers being small, misshapen and cracked.

3. Control measures

Disease control may be discussed under three headings: cultural, varietal and chemical control methods. Much can be done to decrease the incidence and severity of most diseases by adhering to well-established cultural practices. It is essential that high standards of field and storage hygiene be maintained. Diseased plant material should be destroyed, and all tools, machines, stores, containers etc. should be kept scrupulously clean. Since many disease organisms may be carried from one growing season to the next on seed tubers, only sound disease-free tubers should be used as planting material. Many pathogens are soil-borne and their incidence may therefore be minimised by adequate crop rotation. Several of the storage rots are caused primarily by wound parasites, so that their incidence may be minimised by handling the tubers carefully and by encouraging wounds to heal by proper curing. In certain cases it has been shown that diseases can be effectively checked through proper manipulation of pre-harvest cultural factors; for example, the incidence and severity of common scab can be reduced to a minimum by the use of well-timed irrigation (Lapwood *et al.*, 1971).

In addition to control by the direct manipulation of cultural practice, disease control may sometimes be achieved by the technique of disease avoidance or escape. Escape from disease may be accomplished by careful selection of suitable disease-free regions and seasons, or by avoiding land known to be contaminated with particular pathogens. Another recent development in the control of tuber-borne diseases is propagation by the use of 'stem cuttings' (Hardie, 1970), a technique whereby disease-free seed tubers can be produced. However, whilst this method may be useful in decreasing inoculum levels generally, many tuber diseases are at least partly soil-borne so that even initially disease-free material may rapidly become re-infected (Booth, 1970a).

Potato varieties differ in their resistance to disease. This is well established in the case of blight (Müller, 1953; Lapwood, 1963; Van der Plank, 1966; Gallegly, 1968; Malcolmson, 1969; Black, 1970), bacterial wilt (Nielson and Haynes, 1960; Robinson, 1968; Rowe and Sequeira, 1970), common scab (McKee, 1963; Booth, 1970b), spraing (Richardson, 1970) and wart disease (Black, 1935) and is also believed to occur with several other diseases. In areas where these diseases are known to be prevalent the selection of varieties exhibiting a high level of resistance is highly desirable.

Some tuber diseases such as blight and early blight, which are also important foliar diseases, can be controlled by the use of eradicative or protective pre-harvest fungicides, applied as sprays or occasionally as dusts. Amongst the most successful have been various copper and tin compounds and some dithiocarbamates (Holmes, and Storey, 1962; Evans, 1968; Calo, 1969; Seneviratne, 1970). In the case of some tuber-borne diseases disinfection of the seed tubers with an organomercurial fungicide can reduce the incidence and severity of subsequent losses, but with soil-borne diseases little or no commercial success has been achieved by the soil application of fungicides. Post-harvest application of fungicides for the control of storage diseases has been little used with ware potatoes (Cates and Van Blaricom, 1961) but the recent development of several systemic fungicides of low toxicity such as thiabendazole or benomyl may prove beneficial (Hirst *et al.*, 1969). An important consideration in the post-harvest use of these fungicides is that such use may legally constitute the incorporation of a food additive. Chemicals for post-harvest use must be rigorously screened for toxicological safety before use, and only used in strict accordance with the food-additive regulations of the country or countries concerned.

Physiological disorders

Probably the most serious physiological disorder of potatoes stored in the tropics is black heart. Black heart is caused by asphyxiation of the cells due to lack of oxygen which is greatest when tubers are stored at high temperatures with inadequate ventilation (Bennett and Bartholomew, 1924). As the name implies, the centre or heart of the tuber turns black (Fig. 13). Greening of ware potatoes, due to exposure to light for several days or longer, is important because tubers which have turned green taste bitter and may be poisonous (Liljemark and Widoff, 1960). As well as leading to chlorophyll formation, exposure to light frequently results in an increase in the alkaloid (solanine) content of the tubers (Willimott, 1933). Greening may occur before harvest as a result of insufficient 'earthing up' leading to exposure of the tubers, but more often occurs following harvesting or during storage where insufficient care has been taken to avoid long exposure to either natural or artificial light. The nature and incidence of blue spot or internal bruising has already been discussed above and is a common disorder of roughly handled tubers.

Prolonged exposure to temperatures near to below freezing produces a variety of tuber symptoms ranging from a slight discoloration of the vascular ring to a complete black coloration of the affected areas followed by collapse of the tissue as it thaws out (Wright and Diehl, 1927). In the tropics, such damage may result from malfunction or faulty operation of refrigerated stores, causing the produce to be kept at excessively low temperatures.

Secondary growth usually results in some irregularity in the tubers. Effects vary to some extent with the variety, although any one variety may exhibit practically every form under certain conditions (Burton, 1966). The most common forms are hollow heart, knobbiness, chain tuberisation and jelly end rot. Secondary growth is the result of interrupted growth of the tubers, usually due either to high temperatures or drought, growth of an abnormal nature being resumed after the period of stress (Fig. 14).

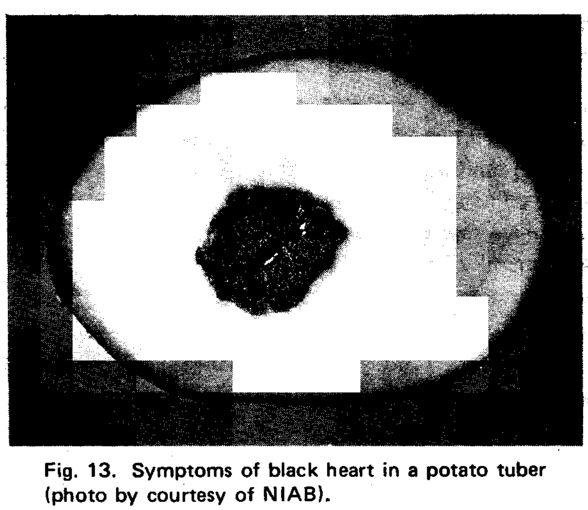


Fig. 13. Symptoms of black heart in a potato tuber (photo by courtesy of NIAB).

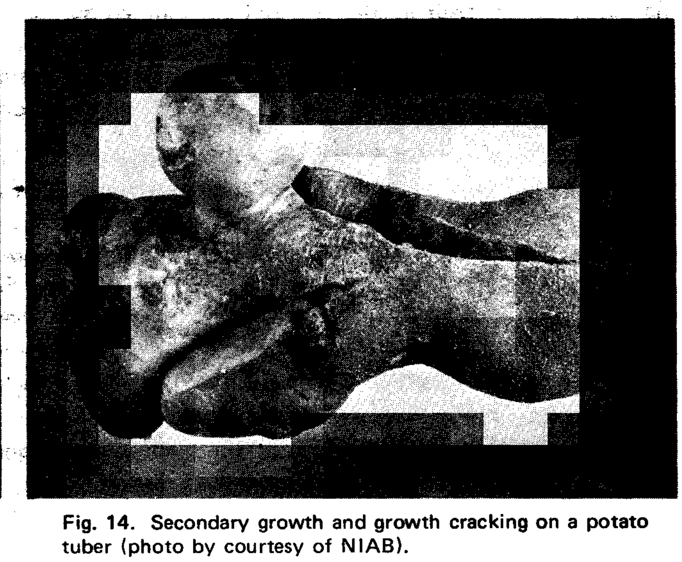


Fig. 14. Secondary growth and growth cracking on a potato tuber (photo by courtesy of NIAB).

Storage methods and structures

The two main requirements of a system of storage are: (1) that it should allow a weight of saleable potatoes as near as possible to the weight of potatoes placed in store to be available following the required storage period, and (2) that these should be of acceptable quality to the consumer. The storage method chosen to meet these requirements should naturally be selected to yield maximum returns on the investment made and different techniques will be appropriate in different circumstances. On the basis of the principles and storage factors already discussed it is seen that the technical requirements of potato storage can be somewhat self-contradictory. Optimum storage temperature may range from 4 to 10°C depending on length of storage life required, health of tubers, control of sprout growth, and the ultimate use of the tubers. Storage at low temperatures should normally be preceeded by a curing period although in exceptional circumstances this may not apply. The relative humidity should be as high as possible, subject to the requirement of avoiding condensation on the tubers. The ventilation and air circulation should be the minimum required to prevent over-heating, excessive variation in temperature, and undesirable accumulation of carbon dioxide, as excessive ventilation normally results in heavy water loss from the tubers.

There are numerous and varied types of structure in which these requirements may be met with differing degrees of adequacy. The degree to which these technical storage needs are satisfied, and hence the storage method and structure to be selected, are also influenced by climatic, economic and social factors. These include availability of capital, price and availability of building materials, variation in climate, labour costs, and fluctuations in demand (and therefore in market price of potatoes). The most appropriate method of storage should not be regarded therefore as an absolute optimum, but rather a compromise made between a number of conflicting requirements.

The simplest method of storage is the potato clamp or pit, which has been extensively used in Europe. By this method tubers are piled out of doors in inverted V-shaped ridges and covered with straw and soil. This method proved satisfactory in preventing serious wastage under European conditions without demanding high capital expenditure. However, little control over the storage environment can be achieved and with the advent of a demand for high-quality potatoes throughout the year this method is becoming obsolete in Europe. Under some tropical conditions, where capital is scarce and the demand for quality not yet so critical, this method and modifications of it, such as clamps with increased ventilation by ducts, may still prove useful and worthy of investigation. Details of clamp storage and the problems involved are discussed by Burton (1966).

In order to obtain a greater control over the storage environment and thus the final quality of the stored tubers, potatoes must be stored in permanent structures. There are many types of buildings which can give good results when used as potato stores. These range from highly sophisticated, purpose-built refrigerated stores, through simpler purpose-built constructions to converted buildings such as cellars, barns, caves etc. Again the choice of building will vary according to local requirements and conditions, both technical and economic. There are, however, certain basic principles to which all stores should conform. The walls of the store should be draught- and light-proof and provide adequate insulation. If the potatoes are to be stored in bulk then the walls must be strong enough to withstand the pressure. Tubers should not be stacked in bulk to a depth greater than 3–4 m (10–12 ft), the exact depth depending on the degree of ventilation and environmental control available. It is most desirable to cover the top of stacks with a layer of straw about 0.5 m deep. This straw layer excludes the light, provides additional insulation and absorbs condensation. In addition to the straw covering there should also be a considerable volume of free head space above the stack, so that the walls should be at least 1 m higher than the intended height of storage in buildings with a pitch roof and 2 m higher in buildings with a horizontal ceiling. In terms of capacity it can be taken that one ton of potatoes occupies approximately 1.5–1.6 m^3 (54–56 ft^3). Buildings must be provided with adequate means of ventilation and ducts should be provided under the potatoes. These ducts allow for forced draught ventilation and enable the introduction of sprout-inhibiting vapours. It should be remembered that in terms of water loss from the tubers it is better to ventilate for a short time at a high rate than at a low rate for a longer period. To facilitate the most advantageous use of forced draught ventilation and as a guide to the behaviour of the tubers in storage it is necessary that accurate temperature records be kept; for this purpose it is desirable to have a maximum and minimum thermometer in the store and thermometers suspended in the stack at regular intervals. As a useful guide the maximum temperature of the stack tends to be about 1°F above the average temperature of the store air for every foot of the height of the stack (about 1.5°C/m).

Several systems of refrigeration are available and again the choice will be largely governed by local conditions and available facilities, especially with regard to maintenance. In order to maintain a high humidity in the refrigerating air and also to avoid chilling some of the potatoes to too low a temperature, it is preferable to use a refrigeration plant with a large heat exchanger, delivering air almost continuously through the tubers, at a temperature not lower than 1°C below the potato temperature. Alternatively, much colder air may be introduced into the humid recirculated store air. If circumstances dictate the use of discontinuous refrigeration, direct ventilation at a high rate with air several degrees colder than the potatoes may be employed, but cannot be expected to give such uniform temperatures along the produce as effectively as continuous refrigeration (Burton, 1966).

More detailed information on storage methods and the designs of storage structures may be gained from Anon. (undated), Stuart (1930), Smith (1933, 1968), Edgar *et al.* (1945), Werner (1945), Monteaux (1950), Amaral (1955), Anquez (1955), Burton (1955, 1966), Ophuis (1956), Wilson and Twiss (1960) and Potato Marketing Board (undated a, 1967a, 1967b, 1971a, 1971b).

References

ABEYGUNAWARDENA, D. V. W., CAESAR, K. and DE VAZ, C. R. (1964). Factors affecting storage losses and the dormancy period of potato. *Trop. Agric., Ceylon* 120: 125–142.

AMARAL, J. D. (1955). *A conservacao de batata.* 396 pp. Lisbon.

ANON (undated). *Almacenamiento de papa en silos semi-subterraneos.* 80 pp. Instituto de Investigaciones Tecnologicas, Bogota, Colombia.

ANON. (1941). *Report on the marketing of potatoes in India and Burma.* Agricultural Marketing in India, Marketing Series No. 30.

ANON. (1960). *Index of plant diseases in the United States.* U.S.D.A. Agricultural Handbook No. 165.

ANQUEZ, M. (1955). La conservation par le froid du plant de pomme de terre. *Génie rur.* 1955: 327–328.

APPLEMAN, C. O. (1914). Biochemical and physiological study of the rest period in the tubers of *Solanum tuberosum. Bull. Md agric. Exp. Stn* No. 183.

APPLEMAN, C. O. (1918). Special growth-promoting substances and correlation. *Science, N.Y.* 48: 319–320.

APPLEMAN, C. O., KIMBROUGH, W. D. and SMITH, C. L. (1928). Physiological shrinkage of potatoes in storage. *Bull. Md agric. Exp. Stn.* No. 303, pp. 159–175.

ARIYANAYAGAM, D. V. (1958). Variety and cultural trials with potatoes. *Trop. Agric., Ceylon* 64: 73–124.

ARTSCHWAGER, E. F. (1927). Wound periderm formation in the potato as affected by temperature and humidity. *J. agric. Res.* 35: 995–1000.

BACON, O. G. (1960). Control of the potato tuber worm in potatoes. *J. econ. Ent.* 53: 868–871.

BARKER, J. (1936). The influence of carbon dioxide and oxygen in the atmosphere on the sugar content and sprouting of potatoes. *Rep. Fd Invest. Bd* 1935, pp. 118–123.

BARKER, J. (1938). Changes of sugar content and respiration in potatoes stored at different temperatures. *Rep. Fd Invest. Bd* 1937, pp. 175–177.

BARKER, J. (1939). The effect of temperature-history on the sensitivity of the sugar/starch balancing system in potatoes. *Rep. Fd Invest. Bd* 1938, pp. 193–195.

BENNETT, J. P. and BARTHOLOMEW, E. T. (1924). The respiration of potato tubers in relation to the occurrence of black heart. *Tech. Pap. Calif. agric. Exp. Stn* No. 14, pp. 1–35.

BLACK, W. (1935). Studies on the inheritance of resistance to wart disease (*Synchytrium endobioticum*) in potatoes. *J. Genet.* 30: 127–146.

BLACK, W. (1970). The nature of inheritance of field resistance to late blight (*Phytophthora infestans*) in potatoes. *Am. Potato J.* 47: 279–288.

BLODGETT, E. C. and RICH, A. E. (1949). Potato tuber diseases, defects, and insect injuries in the Pacific North-west. *Pop. Bull. Wash. agric. Exp. Stn* No. 195.

BODLAENDER, K. B. A. (1963). Influence of temperature, radiation and photoperiod on development and yield. In *The growth of the potato.* Ed. J. D. Ivins and F. L. Milthorpe. 328 pp. Butterworths, London.

BOOTH, R. H. (1970a). Tuber diseases of seed potatoes. *J. natn. Inst. agric. Bot.* 12(Suppl.): 72–76.

BOOTH, R. H. (1970b). Testing varietal reaction of potatoes to common scab (*Streptomyces scabies)* under controlled conditions. *J. natn. Inst. Agric. Bot.* 12: 119–123.

BONDE, R. and COVELL, M. (1950). Effect of host variety and other factors on pathogenicity of potato ring-rot bacteria. *Phytopathology* 40: 161–172.

BOULWARE, J. H. (1969). Potatoes, a promising food crop in India. *Foreign Agric.* 7: 5–6.

BOYD, A. E. W. (1951). The internal blackening of potatoes caused by bruising. *J. hort. Sci.* 26: 148–156.

BROWN, W. (1947). Experiments on the effect of chlorinated nitrobenzenes on the sprouting of potato tubers. *Ann. appl. Biol.* 34: 422–429.

BUDDENHAGEN, I. and KELMAN, A. (1964). Biological and physiological aspects of bacterial wilt caused by *Pseudomonas solanacearum. A. Rev. Phytopath.* 2: 203–230.

BURTON, W. G. (1952a). Physiological effects of the volatile products of respiring potatoes. *Nature, Lond.* 169: 117.

BURTON, W. G. (1952b). Studies on the dormancy and sprouting of potatoes. III. The effect upon sprouting of volatile metabolic products other than carbon dioxide. *New Phytol.* 51: 154–161.

BURTON, W. G. (1955). Storage. In *Potatoes. Bull. Min. Agric. Fish Fd, Lond.* No. 94. 112 pp.

BURTON, W. G. (1958a). Experiments on the use of alcohol vapours to suppress the sprouting of stored potatoes. *Eur. Potato J.* 1(1): 42–51.

BURTON, W. G. (1958b). The effect of concentrations of carbon dioxide and oxygen in the storage atmosphere upon the sprouting of potatoes at 10°C. *Eur. Potato J.* 1(2): 47–57.

BURTON, W. G. (1958c). Suppression of sprouting in buildings. *Agriculture, Lond.* 65: 299–305.

BURTON, W. G. (1961). The physiology of the potato: problems and present status. *Proc. 1st trienn. Conf. Eur. Ass. Potato Res.,* Braunschweig, 1960, pp. 79–117.

BURTON, W. G. (1963). Concept and mechanism of dormancy. In *The growth of the potato.* Ed. J. D. Ivins and F. L. Milthorpe. 328 pp. Butterworths, London.

BURTON, W. G. (1965). The sugar balance in some British potato varieties during storage. *Eur. Potato J.* 8: 80–91.

BURTON, W. G. (1966). *The potato. A survey of its history and of factors influencing its yield, nutritive value, quality and storage.* 2nd edn. European Association for Potato Research. Veenman & Zonen, Wageningen.

BURTON, W. G. and HANNAN, R. S (1957). Use of gamma-irradiation for preventing the sprouting of potatoes. *J. Sci. Fd Agric.* 12: 707–715.

BURTON, W. G., HORNE, T. and POWELL, D. B. (1959). The effect of gamma-irradiation upon the sugar content of potatoes. *Eur. Potato J.* 2: 105–116.

BUTLER, E. J. and JONES, S. G. (1949). *Plant pathology.* 979 pp. MacMillan, London.

BUTLER, O. (1919). The effect of the environment on the loss of weight and germination of seed potatoes during storage. *J. Am. Soc. Agron.* 11: 114–118.

BUTTON, J. A. and KOCH, L. E. (1959). Potato moth control. *J. Dep. Agric. West. Aust.* 8: 653–656.

CAESAR, K. (1967). *Ecological problems of potato growing in low altitudes, with special reference to conditions in Ceylon.* 122 pp. Verlag Th. Mann Gribtl., Hildesheim.

CALO, R. B. (1969). Test of some fungicidal sprays in the control of late blight of potato. *Philipp. J. Pl. Ind.* 34: 109–121.

CATES, F. B. and VAN BLARICOM, L. O. (1961). The effect of several compounds on post-harvest decay of potatoes. *Am. Potato J.* 38: 175–181.

COLMENARES, S. C. and CHICCO, G. R. (1968). Storage of potatoes treated with CIPC. *Proc. Am. Soc. hort. Sci., Trop. Region* 12: 47–54.

DARLING; H. M. (1957). Control of the potato rot nematode in Wisconsin. *Phytopathology* 47: 7.

DAVIDSON, T. M. W. (1958). Dormancy in the potato tuber and the effects of storage conditions on initial sprouting and on subsequent sprout growth. *Am. Potato J.* 35: 451–465.

DOKU, E. V. (1967). Root crops in Ghana. *Proc. Int. Symp. Trop. Root Crops.* Vol. 1(III), pp. 39–68.

DOWNIE, W. A. (1952). Maintenance of quality of stored table potatoes. *J. Dep. Agric. Vict.* 50: 61–66.

DOWSON, W. J. (1957). *Plant diseases due to bacteria.* 2nd edn. 232 pp. Cambridge.

EDGAR, A. D., JEFFERSON, C. H. and WHEELER, E. J. (1945). Potato storages for Michigan. *Spec. Bull. Mich. agric. Exp. Stn* No. 320. 39 pp.

EDWARDS, G. R. (1949). Prevention of sprouting and loss of weight in stored potatoes. *J. Agric., S. Aust.* 53: 49–57.

EDWARDS, G. R. (1952). Chemical treatments assist potato storage. *J. Agric., S. Aust.* 56: 131–132.

EMILSSON, B. (1949). Studies on the rest period and dormant period in the potato tuber. *Acta agric. suec.* 3: 189–284.

ERRINGTON, R. F. and MACQUEEN, K. F. (1961). Gamma irradiation of potatoes to inhibit sprouting. *Gamma irradiation in Canada* 2: 56–58.

EVANS, E. (1968). *Plant diseases and their chemical control.* 288 pp. Blackwell Scientific Publications.

EWING, E. E., LAYER, J. W., BOHN, J. C. and LISK, D. J. (1968). Effects of chemical sprout inhibitors and storage conditions on internal sprouting of potatoes. *Am. Potato J.* 45: 56–71.

FAO (1970). *Production Yearbook, 1970.* 24, Food and Agriculture Organisation, Rome.

FINDLEN, H. (1955). Effect of several chemicals on sprouting of stored table potatoes. *Am. Potato J.* 32: 159–167.

FOLSOM, D., SIMPSON, G. W. and BONDE, R. (1955). Maine potato diseases, insects, and injuries. *Bull. Me agric. Exp. Stn* No. 469.

GALLEGLY, M. E. (1968). Genetics of pathogenicity of *Phytophthora infestans. A. Rev. Phytopath.* 6: 375–396.

GANESAN, S. and CAESAR, K. (1965). Testing of potato varieties suitable for Ceylon. *Trop. Agric., Ceylon* 120: 59–70.

GOSTICK, K. G., HEUSER, S. G., GOODSHIP, G. and POWELL, D. F. (1971). Bromide residues in potatoes fumigated with methyl bromide. *Potato Res.* 14: 312–315.

HAMMETT, F. S. (1929). The chemical stimulus essential for growth by increase in cell number. *Protoplasma* 7: 297.

HARDIE, J. L. (1970). Tomorrow's potato at the 'Highland'. *Scott. Agric.* 49: 105–108.

HEMBERG, T. (1954). Studies on the occurrence of free and bound auxins and of growth inhibiting substances in the potato tuber. *Physiologia Pl.* 7: 312–322.

HIRST, J. M., HIDE, G. A. and GRIFFITH, R. L. (1969). Control of potato tuber diseases with systemic fungicides. *Proc. 5th Br. Insectic. Fungic. Conf.,* Brighton. Vol. 2, pp. 310–314.

HOLLIDAY, R. (1963). Effects of fertilizer upon potato yields and quality. In *The growth of the potato.* Ed. J. D. Ivins and F. L. Milthorpe. 328 pp. Butterworths, London.

HOLMES, T. D. and STOREY, I. F. (1962). Comparative trials of copper, dithiocarbamate and organo-tin fungicides for potato blight control in Lincolnshire, 1958–1961. *Pl. Path.* 11: 139–146.

HOWARD, H. W. (1963). The significance of breeding in improving quality and yield. In *The growth of the potato.* Ed. J. D. Ivins and F. L. Milthorpe. 328 pp. Butterworths, London.

HRUSCHKA, H. W. and HEINZE, P. H. (1967). External and internal sprouts in potatoes dipped in low-concentration CIPC—water emulsions. *Am. Potato J.* 44: 51–55.

KARMARKAR, D. V. and JOSHI, B. M. (1941). Investigations on the cold storage of potatoes. *Misc. Bull. Coun. agric. Res. India* No. 45.

KELMAN, A. (1953). A bacterial wilt caused by *Pseudomonas solanacearum. Tech. Bull. N. Carol. agric. Exp. Stn* No. 99. 194 pp.

KIDD, F. (1919). Laboratory experiments on the sprouting of potatoes in various gas mixtures (nitrogen, oxygen, and carbon dioxide). *New Phytol.* 18: 248–252.

KIMBROUGH, W. D. (1929). Effect of fertiliser on yield and quality of Irish potatoes and water melons. *A. Rep. Ala. agric. Exp. Stn.*

KRIJTHE, N. (1946). De invloed van de bewaring van aardappelknollen op den bouw van de knoppen en op de ontwikkeling tot volwassen plant. *Meded. LandbHoogesch. Wageningen* 47: 6.

LAPWOOD, D. H. (1963). Potato haulm resistance to *Phytophthora infestans.* IV. Laboratory and field estimates compared, and further field analyses. *Ann. appl. Biol.* 51: 17–28.

LAPWOOD, D. H., WELLINGS, L. W. and HAWKINS, J. H. (1971). Irrigation as a practical means to control potato common scab. *Pl. Path.* 20: 157–163.

LAZO, F. D. and BALAOING, V. G. (1965). Comparative yield tests on foreign and native-grown Irish potato seed tubers. *Philipp. J. Pl. Ind.* 30: 17–19.

LEY, F. J., CLARKE, I. D. and BURTON, W. G. (1961). *A study of the feasibility in the United Kingdom of a radiation process for the inhibition of sprouting in stored potatoes.* O.E.E.C. Study Group on Food Irradiation. (Also published by H.M.S.O., 1962. 20 pp.)

LILJEMARK, A. and WIDOFF, E. (1960). Greening and solanine development of white potato in fluorescent light. *Am. Potato J.* 37: 377–389.

LUBATTI, O. F. and BUNDAY, G. (1958). Fumigation of agricultural products. *J. Sci. Fd Agric.* 9: 360–366.

MACKIE, D. B. and CARTER, W. B. (1937). Methyl bromide as a fumigant, a preliminary report. *Bull. Calif. Dep. Agric.* 26: 153–162.

MALCOLMSON, J. F. (1969). Factors involved in resistance to blight (*Phytophthora infestans* (Mont.) de Bary) in potatoes and assessment of resistance using detached leaves. *Ann. appl. Biol.* 64: 461–468.

MARTH, P. C. and SCHULTZ, E. S. (1950). Effect of growth regulators on sprouting of stored table stock potatoes and on waste piles for control of diseases. *Am. Potato J.* 27: 23–32.

MCKAY, R. (1955). *Potato diseases.* 126 pp. Irish Potato Marketing Company Ltd., Dublin.

MCKEE, R. K. (1963). Scab resistance of potato varieties. *Pl. Path.* 12: 106–109.

MILLER, L. P. (1931). The influence of sulphur compounds in breaking the dormancy of potato tubers. *Contr. Boyce Thompson Inst. Pl. Res.* 3: 309–312.

MONTALDO, A. (1969). *Bibliografia Latinoamericana sobre papas.* 177 pp. Universidad Central de Venezuela, Maracay, Venezuela.

MONTEAUX, A. (1950). L'utilisation du froid pour la conservation des plants de pommes de terre. *Revue prat. Froid, Paris* 5(11): 29–30.

MOSHER, P. N. (1968). Extend marketing period with sprout inhibitors. *Am. Veg. Grow.* 45: 36–37.

MÜLLER, K. O. (1953). The nature of resistance of the potato plant to blight — *Phytophthora infestans. J. natn. Inst. agric. Bot.* 6: 346–360.

MÜLLER-THURGAU, H. (1882). Ueber Zuckeranhaufung in Pflanzentheilen in Folge niederer Temperatur. *Landw. Jbr* 11: 751–828.

NAGAICH, B. B. and DUTT, B. L. (1972). Common potato diseases in India. *Indian Fmg* 21: 20–26.

NIELSON, L. W. and HAYNES, F. L. (1960). Resistance in *Solanum tuberosum* to *Pseudomonas solanacearum. Am. Potato J.* 37: 260–267.

NYLUND, R. E. and AYRES, L. C. (1964). Sprout inhibition of table stock potatoes with CIPC-treated paper bags. *Am. Potato J.* 41: 341–348.

OKAZAWA, Y. (1959). Studies on the occurrence of natural gibberellin and its effects on the tuber formation of potato plants. *Proc. Crop Sci. Soc. Japan* 28: 129.

OPHUIS, B. G. (1956). Moderne luchtgekoelde aardappelbewaarplaasten. *Landbouwmechanisatie* 7: 72–78.

OPHUIS, B. G., HESEN, J. C. and KROESBERGEN, E. (1958). The influence of temperature during handling on the occurrence of blue discolourations inside potato tubers. *Eur. Potato J.* 1(3): 48–65.

PETHYBRIDGE, G. H. and MURPHY, P. A. (1911). A bacterial disease of the potato plant in Ireland. *Proc. R. Ir. Acad.* 29B: 1–37.

POTATO MARKETING BOARD (undated a). *Potato storage: some guides to success.* Potato Marketing Board, London.

POTATO MARKETING BOARD (undated b). *Potato damage on the farm. Potato loss from damage in transit. Potato damage prevention.* Potato Marketing Board, London.

POTATO MARKETING BOARD (1967a). Investigations on different methods of storing potatoes. *Rep. Sutton Bridge Exp. Stn* No. 1. 12 pp.

POTATO MARKETING BOARD (1967b). Investigations on the effects of varying degrees of environmental control on the storage of potatoes. *Rep. Sutton Bridge Exp. Stn* No. 2. 18 pp.

POTATO MARKETING BOARD (1971a). Storage design and equipment for environmental control in potato stores. *Rep. Sutton Bridge Exp. Stn* No. 6 (two parts).

POTATO MARKETING BOARD (1971b). The harvesting, handling and storage of potatoes in bulk and boxes. *Rep. Sutton Bridge Exp. Stn* No. 7. 9 pp.

PRADHAN, S., RHAMBHANI, H. J., and WADHI, S. R. (1960). Fumigation of infested potatoes. *Indian J. Ent.* 22: 181–189.

PUSHKARNATH (1964). *Potato in India – varieties.* 466 pp. Indian Council of Agricultural Research, New Delhi.

PUSHKARNATH (1967). Potato culture in India. III. New potatoes for old. *Indian Fmg* 16: 4–7.

RAO, V. G. (1969). Diseases of potato in India. *Labdev. J. Sci. Tech.* 7B: 254–262.

RHODES, A., SEXTON, W. A., SPENCER, L. G. and TEMPLEMAN, W. G. (1950). Use of isopropylphenylcarbamate to reduce sprouting of potato tubers during storage. *Research, Lond.* 3: 189–190.

RICHARDSON, D. E. (1970). The assessment of varietal reactions to spraing caused by tobacco rattle virus. *J. natn. Inst. agric. Bot.* 12: 112–118.

RICHARDSON, D. E. and BOOTH, R. H. (1970). Potato diseases. *Fmr Stk Breed.* (Suppl.). 24 pp.

ROBINSON, R. A. (1968). The concept of vertical and horizontal resistance as illustrated by bacterial wilt of potatoes. *Phytopathol. Pap.* No. 10. 37 pp. Commonwealth Mycological Institute.

ROBINSON, R. A. and RAMOS, A. H. (1964). Bacterial wilt of potatoes in Kenya. *E. Afr. agric. For. J.* 30: 59–64.

ROSA, J. T. (1928). Relation of tuber maturity and of storage factors to potato dormancy. *Hilgardia* 3: 99.

ROWE, P. R. and SEQUEIRA, L. (1970). Inheritance of resistance to *Pseudomonas solanacearum* in *Solanum phureja. Phytopathology* 60: 1499–1501.

SAWYER, R. L. (1956). Effect of irradiation on potatoes for processing. *Proc. 7th Am. Potato Utiliz. Conf.* pp. 3–5.

SAWYER, R. L. (1959). Sprout inhibition. In *Potato processing.* Ed. W. F. Talburt and O. Smith. Ch. 6. Avi Publishing Company Inc., Westport.

SAWYER, R. L. (1961). Relation of chloro-IPC for sprout inhibition to internal sprouting of potatoes. *Am. Potato J.* 38: 203–207.

SAWYER, R. L. and DALLYN, S. L. (1957). Vaporized chemicals control sprouting in stored potatoes. *Farm Res.* 23(6): 6.

SCHIPPERS, P. A. (1956a). De invloed van de temperatuur op de duur van de rustperiode. *Publ. Aardappelbew. Wageningen,* Ser. A, No. 108. 13 pp.

SCHIPPERS, P. A. (1956b). De duur van de rust periode van een veertigal aardappelrassen, bewaard bij verschillende constante temperaturen. *Publ. Aardappelbew. Wageningen,* Ser. A, No. 112. 10 pp.

SENEVIRATNE, S. N. De S. (1970). Spraying trials on potato blight control with organo-tin and other fungicides. *Trop. Agric., Ceylon* 126: 15–30.

SHANDS, W. A. and LANDIS, B. L. (1964). *Potato insects.* U.S.D.A. Agriculture Handbook No. 264.

SHANDS, W. A., LANDIS, B. L. and REID, W. J. (1969). Controlling potato insects. *Fmrs' Bull. U.S. Dep. Agric.* No. 2168.

SIMMONDS, N. W. (1971). The potential of potatoes in the tropics. *Trop. Agric., Trin.* 48: 291–299.

SINGH, R. P. and LAL, G. (1972). A potato variety that keeps well. *Indian Fmg* 21:41.

SINGH, B. N. and MATHUR, P. B. (1938a). Studies in potato storage. II. Influence of stage of maturity of the tubers and the storage temperature for a brief duration immediately after digging on physiological losses in weight of potatoes during storage. *Ann. appl. Biol.* 25: 68–78.

SINGH, B. N. and MATHUR, P. B. (1938b). Studies in potato storage. III. Respiration of potato tubers during storage. *Ann. appl. Biol.* 25: 79–87.

SMITH, O. (1933). Studies of potato storage. *Bull. Cornell agric. Exp. Stn* No. 553.

SMITH, O. (1968). *Potatoes: production, storing, processing.* 642 pp. Avi Publishing Company, Inc., Westport.

SPARROW, A. H. and CHRISTENSEN, E. (1954). Improved storage quality of potato tubers after exposure to Co^{60} gammas. *Nucleonics* 12(8): 16–17.

STUART, W. (1930). Potato storage and storage houses. *Fmrs' Bull. U.S. Dep. Agric.* No. 847.

STUART, W., LOMBARD, P. M. and PEACOCK, W. M. (1929). Comparative influence of different storage temperatures on weight losses and vitality of seed potatoes. *Tech. Bull. U.S. Dep. Agric.* No. 117.

STUIVENBERG, J. H. M. VAN and VELDSTRA, H. (1942). De practische toepassing van remming der spuitvorming bij aardappelen door behandeling met groeisloffen in dampvorm. *Landbouwk. Tijdschr., s-Gray.* 54: 611–632.

THORNE, G. (1945). *Ditylenchus destructor* n. sp., the potato root nematode, and *Ditylenchus dipsaci* (Kuhn 1857) Filipjev, the teasel nematode (Nematoda: Tylenchidae). *Proc. helminth. Soc. Wash.* 12: 27–34.

THORNTON, N. C. (1939). Oxygen regulates the dormancy of the potato. *Contr. Boyce Thompson Inst. Pl. Res.* 10: 339–361.

THURSTON, H. D. (1963). Bacterial wilt of potatoes in Colombia. *Am. Potato J.* 40: 381–390.

TODD, G. W. (1953). Enzyme studies on dormant and active potato tubers. *Physiologia Pl.* 6: 169–186.

TORRES, H., FRENCH, E. R. and NIELSEN, L. W. (1970). Potato diseases in Peru. *Pl. Dis. Reptr* 54: 315–318.

TWISS, P. T. G. (1963). Quality as influenced by harvesting and storage. In *The growth of the potato.* Ed. J. D. Ivins and F. L. Milthorpe. 328 pp. Butterworths, London.

VAN DER PLANK, J. E. (1966). Horizontal (polygenic) and vertical (oligogenic) resistance against blight. *Am. Potato J.* 43: 43–52.

VAN NIEKERK, B. P. (1960). Potatoes can be stored for eight months. *Fmg S. Afr.* 36: 20–23.

WERNER, H. O. (1945). Potato storage structures for Nebraska. *Hort. Prog. Rep. Neb. agric. Exp. Stn* No. 7.

WHITEHEAD, T., McINTOSH, T. P. and FINDLAY, W. M. (1953). *The potato in health and disease.* 3rd edn. 744 pp. Oliver & Boyd, Edinburgh.

WILLIMOTT, S. G. (1933). An investigation of solanine poisoning. *Analyst* 58: 431–438.

WILSON, A. R. and TWISS, P. T. G. (1960). Bulk storage of potatoes in buildings. *Bull. Min. Agric. Fish Fd, Lond.* No. 173. 35 pp.

WRIGHT, R. C. and DIEHL, H. C. (1927). Freezing injury to potatoes. *Tech. Bull. U.S. Dep. Agric.* No. 27. 23 pp.

WRIGHT, R. C. and PEACOCK, W. M. (1934). Influence of storage temperature on the rest period and dormancy of potatoes. *Tech. Bull. U.S. Dep. Agric.* No. 424. 22 pp.

YATHOM, S. and BROSH, S. (1964). Insecticide trials for the control of the potato tuber moth, *Gnorimoschema operculella* Zell., in Israel. *Hassadeth* 44: 983–986.

YATHOM, S. and MEISNER, J. (1966). Insecticide trials against the potato tuber moth, *Gnorimoschema operculella* Zell. *Israel J. Ent.* 1: 167–177.