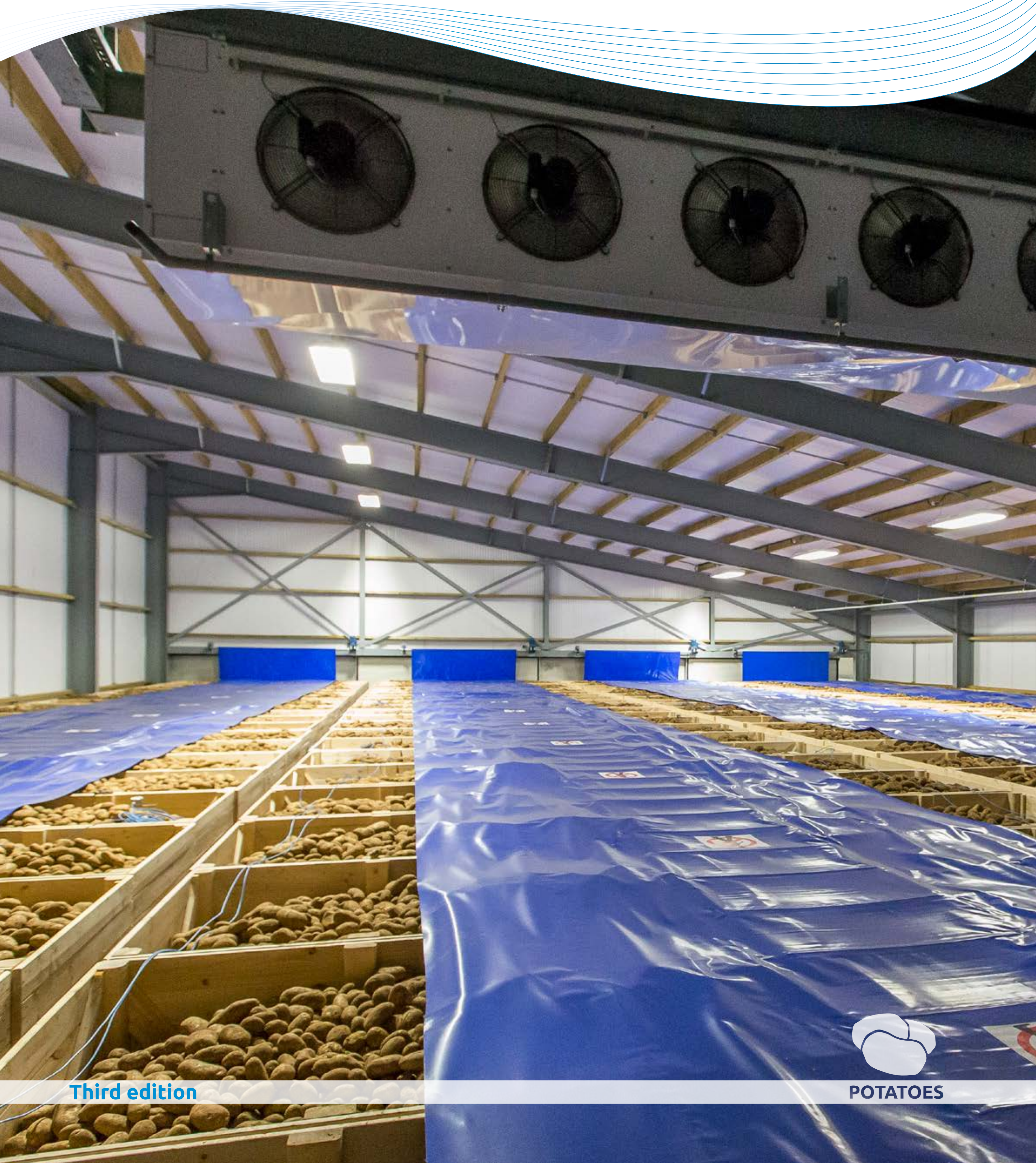
SUTTON BRIDGE
CROP STORAGE RESEARCH

AHDB

Potato store managers' guide



Third edition

POTATOES

Contents

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Introduction

Adrian Cunnington
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Potato storage is a key element of modern-day potato production, looking to fulfil the demands of many markets. It can be practised successfully but it must also be acknowledged that storage poses a risk. Its success depends on how well that risk is managed and, ultimately, whether the customer for the crop in question is delivered the quality for which they are prepared to pay.

So, ensuring a store runs efficiently is a critical part of managing the potato production system. Inevitably, there are cost pressures on all components of the supply chain and, therefore, it is just as important to minimise operating costs in storage as it is to maximise returns from the enterprise.

To this end, having good control of the store is crucial so that it only incurs cost when delivering a benefit. This control extends to such aspects as servicing and calibrating the store equipment before use, loading the store correctly, operating the ventilation system and ensuring the airflow is optimised, minimising air leakage, and so on.

Store management is a complex process and there are multiple points at which problems and inefficiencies can occur and jeopardise the prospect of success.

This guide seeks to provide guidance throughout the various steps of the store management process, but it should not be read in isolation.

It should be remembered that the crop in the store came from a field where there was opportunity to influence many attributes that affect how the crop performs in store, from simple decisions, including choice of variety, to more complex issues, such as the impact of chronological age on dormancy break and the need for sprout suppression. Another major factor in storage success is whether the crop has an adequately 'set' skin, as, without this, storage of potatoes is seldom straightforward.

It is also intended that this third edition of the guide be used in conjunction with new decision support tools that AHDB plans to develop in the near future. Keep up to date with the ever-changing range of online assistance tools by visiting the AHDB website at **ahdb.org.uk**

The team at Sutton Bridge Crop Storage Research is there for all AHDB levy payers to consult for store management advice on the Storage Advice Line. Call free of charge on 0800 02 82 111. There is also a range of assessments and evaluations that can be offered, to assess whether your storage is performing well enough to deliver for your business.

Storage buildings

A well-sealed and insulated potato store will allow the crop to be kept at a stable temperature largely unaffected by diurnal (daily) variation in ambient conditions (Figure 1). It will help maintain a relative humidity of 90–100% to minimise tuber weight loss; it will also allow crops to be stored free from condensation in changeable weather conditions. Storage is usually undertaken in bulk or in boxes.

The capital cost of a bulk store with load-bearing, insulated retaining walls is higher than for a box store. But when the capital cost of boxes is added, box storage is more expensive overall. Deep bulk piles benefit from positive ventilation but can lead to pressure-bruising problems if the crop is stored more than 4 m deep or is excessively ventilated. Box storage is more complex to ventilate uniformly. However, box stores help with separation of different stocks and provide more flexibility for crop movement and marketing. Depending on their size, age and quality, boxes can be stacked up to eight high.

Ventilation

Controlled ventilation allows crop respiration heat to be removed and a crop to be dried and cooled. Fans are best positioned to create a flow of air through the crop (positive ventilation, bulk or box) or, less efficiently, to form a rolling mass of air that flows over the stack of boxes and through the pallet slots (space ventilation).

Cooling can be achieved using ambient air and/or mechanical cooling (refrigeration). Internal recirculation of air (without cooling) can be used to eliminate temperature variation or to distribute chemicals for sprout suppression or disease control.

Airflow should be as uniform as possible throughout the store, to give even drying and stable crop temperatures. A well-designed store will have been balanced to achieve uniformity of airflow at its typical operating condition. This might include features such as tapered air ducts or graduated lateral outlets to deliver similar quantities of air across the whole store.

Computer-aided (CFD) modelling (Figure 2) is being developed to optimise ventilation design for new and retrofit installations.

Insulation

The quality of the insulation will determine to a large extent how well a potato store performs. Insulation is a key factor for a potato store, much more so than it is for general-purpose buildings.

Maintaining temperatures above freezing point is seldom a problem, given the quantity of heat produced in a large store. However, any heat that leaks into a store has to be removed by ventilation or refrigeration, which adds to the cost of electricity.

In addition to implications on cost, the avoidable operation of environmental control equipment will always increase water loss from the crop. It is, therefore, as worthwhile to use insulation to limit heat ingress into the store as it is to minimise the effects of cold weather. A light-coloured, reflective, external surface will reduce unwanted solar radiation gains.

Nearly all insulation materials have their performance reduced significantly by small increases in their moisture content. The use of vapour barriers to protect insulation is only effective in the high humidity conditions found in potato stores where composite metal/polyisocyanurate (PIR) sandwich panels are used. These are commonly used for newly built stores at thicknesses of up to 120 mm.

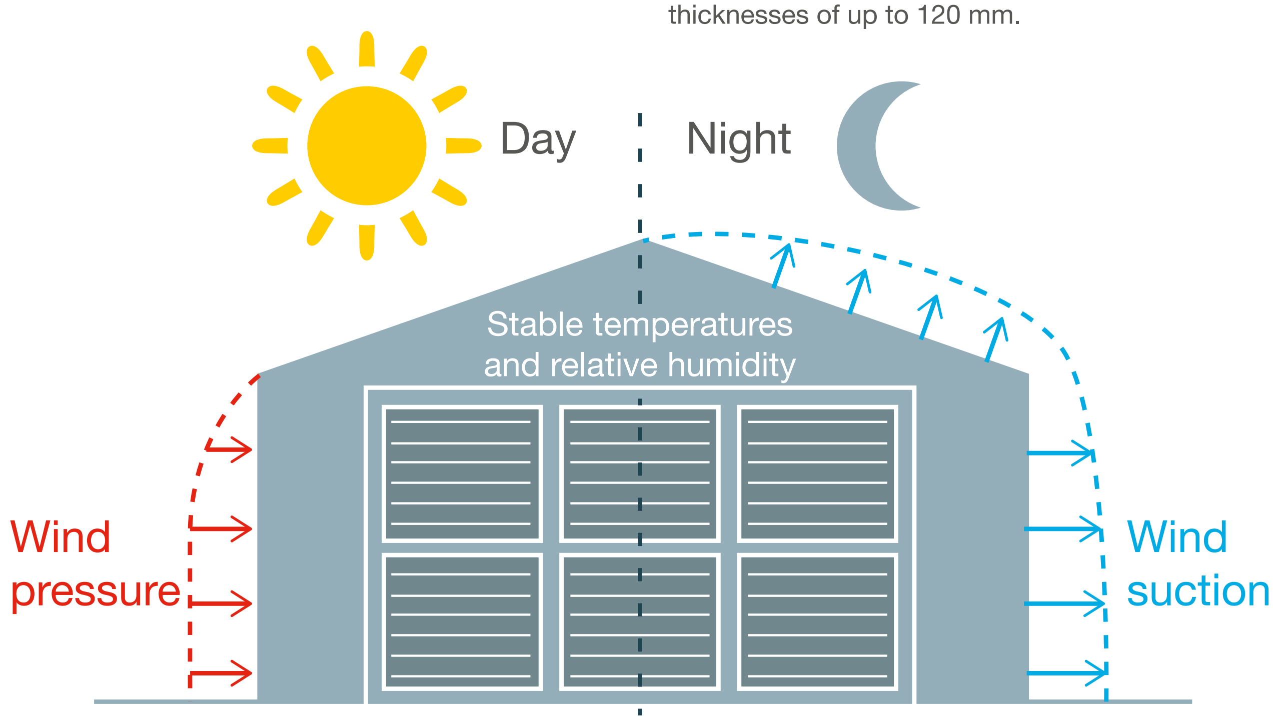


Figure 1. The building envelope has to minimise the impact of external climate on the stored crop

Other systems for upgrades offer, at best, little more than a vapour check. This tends to limit the choice of insulation to either spray or board polyurethane or, occasionally, EEP board (e.g. Styrofoam). If moisture 'drive' across insulation cannot be prevented, or if the insulation is inadequate, condensation will form within or on the structure, reducing its effectiveness and risking moisture deposition on the crop.

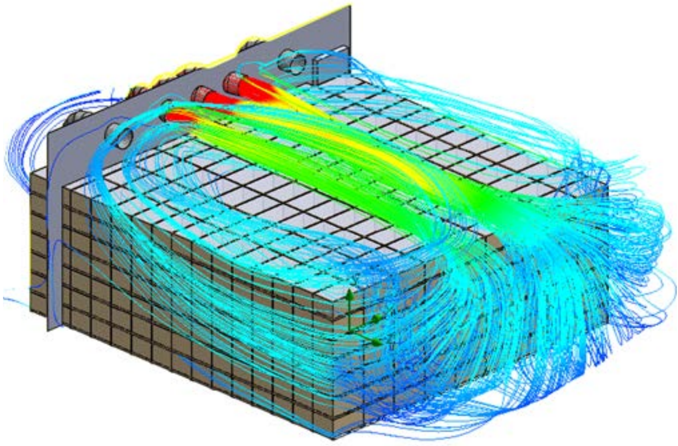


Figure 2. Computer simulation has increased understanding of air movement in stores

Courtesy of Crop Systems/TRC/Innovate UK

Air leakage

Fabric or door leakage to wind-induced ventilation reduces the effectiveness of the store, as it is likely to lead to loss of environmental control. Crop weight loss and possible condensation on the crop will result as ventilation or refrigeration running hours will increase in order to cool the crop warmed by the leaking air.

A specific air leakage test for stores has been developed to assess buildings' relative performance. This uses a fan system (Figure 3) to generate an AP50 value for each store. This is a measurement of the leakage when the building envelope is subjected to a differential pressure of 50 pascals. An AP50 of ≤ 3 m^3/h.m^2 is regarded as an acceptable standard for new buildings. Existing buildings, even good ones, may not achieve this; a threshold of ≤ 10 m^3/h.m^2 is more realistic.

It is strongly recommended that specialist advice be sought for all aspects of storage building design.

Checklist

Store assessment

✔ Consider an air leakage AP50 analysis

✔ Self-check a store easily: check how lightproof it is

Airflow uniformity is key

✔ Balanced, positive air system required

✔ CFD model may help to optimise airflow

Insulate well

✔ Reduce impact of climate

✔ Keep store condition stable

✔ Minimise condensation

Figure 3. Air leakage assessed by forced introduction of air and monitoring pressure change

Respiration

Potato tubers are living organisms and, in store, continue to respire and respond to their environment. They do so by using sugars, from starch, in respiration. This process consumes oxygen and releases carbon dioxide and some heat energy, which impacts on storage systems.

Respiration is highest after harvest and falls rapidly to a basal level in the first weeks of storage (Figure 4). Respiration is greater in early-lifted, immature crops than in late-lifted, mature crops.

Although basal respiration rate depends predominantly on storage temperature in the period after harvest, new AHDB work at SBCSR has shown that temperature has a less significant effect later in storage (Figure 5).

Evaporation

Although some moisture is lost in the process of respiration, most is simply lost by evaporation from the tuber surface. Effective wound healing and sprout control are important in limiting water loss from tubers.

All other things being equal, moisture loss is a function of store humidity and airflow rate, although this process is regulated by the permeability of the skin of the potato.

Over time, well-sealed potato stores will equilibrate to approximately 95–98% relative humidity, although, in the absence of humidification to add moisture to the store air, this will be derived from evaporation. Leaky stores may never achieve this, but, in lower humidity air, weight loss will be higher.

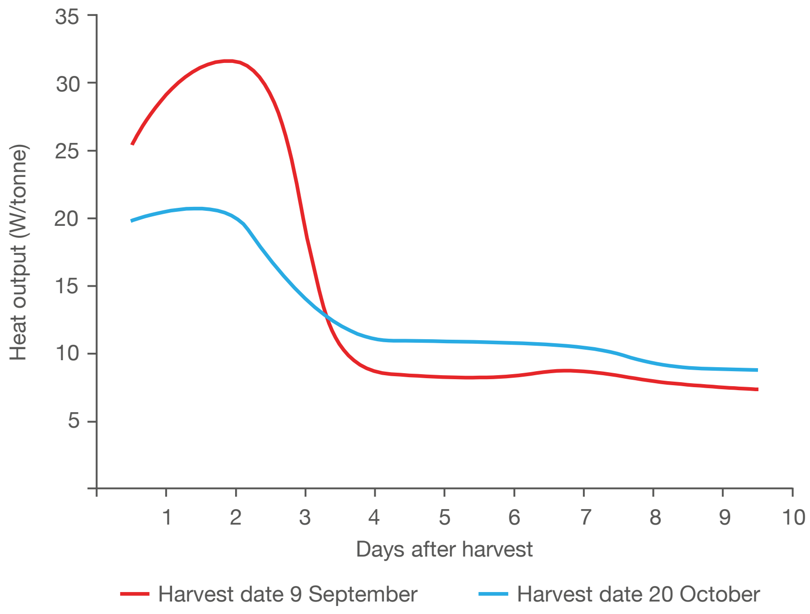


Figure 4. Respiration after lifting – early harvest

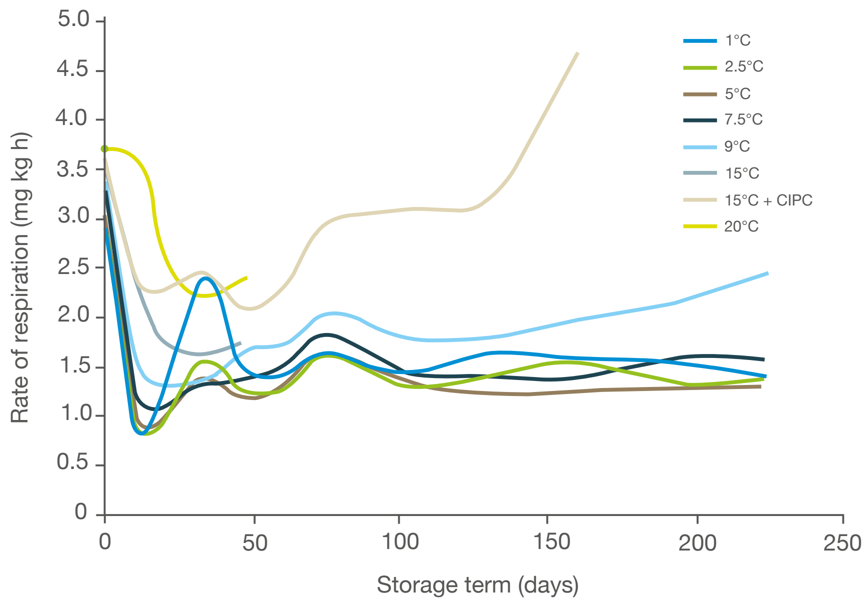


Figure 5. Respiration in relation to storage temperature

Dormancy

Freshly harvested tubers usually do not sprout, even when conditions are optimal for sprout growth. The period over which sprout growth is inhibited by the tuber's physiology, rather than the environment, is termed the dormant period or simply 'dormancy'. Large differences in dormancy occur between varieties.

Warm storage temperatures have a dormancy-breaking effect. Selection of varieties with longer dormancy can be useful for minimising sprout suppressant input.

Dormancy break is taken as the point where 50% of tubers have sprouts of 3 mm or more in length. Warm, dry summers tend to reduce dormancy (in extreme cases leading to sprout growth in the field before harvest), while cool growing conditions will generally prolong it. Waterlogging breaks dormancy.

Wound healing

Where tubers have been subjected to wounding (e.g. by handling during harvest), the tuber will attempt to heal the wound – this involves both suberisation (which forms an impermeable barrier to moisture loss) and cell division. The speed of this process (curing), which is also important for preventing disease ingress, is affected by factors such as storage temperature and humidity, with warmer temperatures and higher humidity generally reducing the time required for wound healing.

The need for specific action is often greatest in crops harvested late, in wet or cold conditions, when some supplementary heating may be required to achieve effective curing.

Sugars and conditioning

Potatoes contain three main sugars: glucose and fructose (monosaccharides/reducing sugars) and sucrose (a disaccharide). All three are sweet and important flavour components in ware potatoes. Where potatoes are destined for frying, quality is determined by the reducing sugars as these react on cooking to produce browning (fry colour). Trends in sucrose levels can help identify when reducing sugars are low during storage.

Variety, growth stage and storage temperature are important in determining tuber sugar content. Potatoes exhibit low temperature sweetening, where sugars accumulate within the tuber as temperature is reduced. During storage for processing, temperature should, therefore, be maintained at the lowest level that safely maintains acceptable fry colour.

For processing crops, excess low temperature sweetening (and hence dark fry colour) may be reversed using reconditioning (warming prior to unloading). This is not the case for senescent sweetening, which results in a sugar increase when tubers age.

Checklist

Respiration

✔ Ventilate well to remove heat

✔ Early-lifted/immature crops respire most

Evaporation

✔ Seal stores to limit weight loss

Dormancy

✔ Use dormant varieties to limit need for chemicals

Sugars

✔ Avoid low temperatures

✔ Manage acrylamide risk

A by-product of the frying process is acrylamide, regarded as a food safety hazard. Legislation (EU 2017/2158) introduced in 2018 describes practical measures, based upon guidance developed by the food industry, to mitigate acrylamide formation in a range of foods.

Greening and glycoalkaloids

Tubers exposed to light turn green, due to the synthesis of chlorophyll pigment. Chlorophyll is harmless, but green tubers are generally rejected because they have elevated levels of glycoalkaloids, a group of natural toxins present in potatoes.

To prevent greening in storage, exposure to light must be minimised, although the need to inspect the crop, health and safety access requirements, etc. will override this during loading and subsequent short periods when stores are accessed for monitoring or sampling.

Disease control

Controlling disease is a fundamental component of storage management. Few diseases originate in store. They mostly come from two primary sources: the seed or the soil. However, many of the disease problems affecting the premium markets can develop to some degree in store and, if not controlled, the consequences can be catastrophic, either in terms of physical breakdown of the crop or in loss of market value.

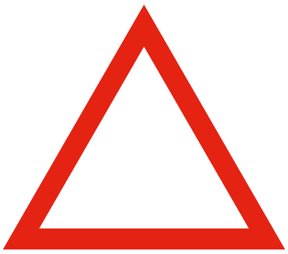


Figure 6. Disease triangle: if all three factors are satisfied, disease will result

Whether disease will develop in store or not depends on three key factors which all need to be present (Figure 6):

- The amount of disease inoculum, usually spores or bacteria, present on the tubers
- Whether moisture, nutrients and temperature are suitable for the disease to develop (microclimate)
- The natural resistance of the tuber to the disease organism. This includes having a robust set skin, so effective defoliation is important for disease control

Store management influences this interactive relationship, particularly in regard to the microclimate around the tuber, in order to control diseases during storage (Table 1 and 2).

Notifiable diseases

Some diseases are not indigenous in Britain and their establishment would affect the long-term viability of the potato industry. If symptoms of either **brown rot** or **ring rot** are suspected, then immediate contact with local Defra offices or the Plant Health & Seeds Inspectorate is necessary. Visit **gov.uk** and search plant health controls to report suspected cases in England and Wales. In Scotland, visit **gov.scot/planthealth**

Preventative measures exist; to learn more about the national schemes that protect seed and ware crop health, go to **potatoes.ahdb.org.uk/safehaven**

Ring rot (left) and brown rot (right).

Table 1. Pre-storage control

	Silver scurf 	Black dot 	Skin spot 	Dry rot 	Gangrene 	Pink rot/ watery wound rot 	Soft rot 
Healthy seed	✔	✔	✔	✔	✔	✔	✔
Long rotation	✔	✔	✔			✔	
Short growing season	✔	✔			✔		✔
Early harvest	✔	✔	✔		✔	✔	✔
Variety susceptibility			✔	✔	✔	✔	✔
Minimise damage			✔	✔	✔	✔	✔
Dry harvest	✔	✔	✔	✔	✔	✔ but cool	✔

Best practice

There are seldom many storage scenarios where there aren't potential disease hosts, even with the use of clean seed and resistant varieties. Good skin set is crucial, as disease inoculum is often present and control of the microclimate is essential for management of disease risk.

Reducing the chances of disease development can be achieved through best practice measures, which include:

- Timely burn down to ensure robust set skins for storage
- Efficient harvest, allowing store to be closed quickly
- Optimised airflow for effective drying and cooling
- Avoidance of condensation
- Good store and grader hygiene

Checklist

Low disease risk

✔ Minimise host susceptibility

✔ Remove inoculum

✔ Manage store environment

Disease control for all storage

✔ Early defoliation

✔ Robust skin 'set'

✔ Minimise damage

✔ Efficient loading to allow store to be closed

✔ Dry to reduce disease risk

Blemish disease control for fresh market

✔ Prioritise fast pull-down to cool storage

Table 2. Control during storage

	Silver scurf 	Black dot 	Skin spot 	Dry rot 	Gangrene 	Pink rot/ watery wound rot 	Soft rot 
Curing			✔	✔	✔		
Immediate pull-down	✔	✔				✔	✔
Fast pull-down	✔	✔				✔	✔
Low holding temperature	✔	✔		✔		✔	✔
Minimise damage				✔	✔	✔	✔
Store hygiene	✔		✔	✔			
Box and grader hygiene	✔		✔	✔		✔	✔

Store preparation and hygiene

An annual inspection of buildings and hardware is an important step in store preparation. It can be carried out at the same time as store cleaning a few weeks before loading; don't leave it until the last minute. Look for signs of fabric damage and take action to seal any gaps and repair any defective equipment.

Spore dispersal and removal

Cleaning stores annually will minimise disease risk. Ventilation and convection currents, caused by respiration heat from the crop, will circulate dust containing disease spores throughout the store. Cross-contamination of spores between potato stocks is inevitable. Major dust movement and dispersal also occurs when store activity, e.g. forklift truck movement, stirs up dust on the floor. The resultant dust cloud will settle on top of the crop, where the risk of condensation needed for spore germination is greatest.

Sweeping with a brush moves the heavier dust particles along the floor, while creating a cloud of lighter particles, which includes the majority of spores. Vacuuming (Figure 7) loosens and removes all fractions of dust and, if fitted with a fine filter, will remove most harmful spores from the store. Vacuuming is, therefore, much preferred to sweeping.

Figure 7. Vacuuming is best for removing dust

Hygiene and disinfection

Clearing dust and stray tubers from storage areas and ducts will normally remove the majority of disease inoculum present. This is usually adequate for most ware crops. However, if wet rots have been a problem in the previous season, then steam-cleaning of the boxes and affected areas of the store is recommended.

If total removal of viable spores is required, for high-health crops, disinfectant can be used. This is particularly relevant in stores where bacterial soft rotting or damage-related fungal diseases such as dry rot have occurred. Most disinfectants will not work without prior cleaning and removal of dust and debris (Figure 8) as they are deactivated by organic matter. Make sure any disinfectant used on parts of the store that are in contact with crops are food-safe and acceptable to your intended market.

Removing chemical residue

As part of due diligence and to ensure compliance with maximum residue levels, it is important to follow best practice for cleaning stores subjected to previous chemical treatments that may leave a residue in the store for years to come, such as CIPC.

These measures will include hygiene steps described above to clean the building and ventilation infrastructure; exposing boxes to UV and outside air to maximise chemical breakdown, plus any product-specific guidance published by the approval holders.

Boxes

Leaving boxes outside will allow light to kill viable spores. Empty boxes should not be stacked more than four boxes high for safety and, if stacked in pairs, a small gap between rows will help natural (UV) light to reach every box. However, outside stacking can reduce box life by up to 40%.

Many box stocks now require annual replenishment to replace boxes at the end of their useful life. Ensure that an inspection of box condition is undertaken annually to identify those that are in need of repair or replacement. Do not take risks with boxes in marginal condition as, if a stack collapses in store, the consequences can be significant for operator safety, store integrity or crop ventilation.

Servicing

Maintaining fans, ventilation and refrigeration coils in a clean condition will help prolong their life and improve their working efficiency. Routine servicing by specialists of refrigeration, cooling and monitoring systems will ensure reliable and efficient store operation during the winter and prolong equipment life. Refrigeration equipment, in particular, is too complex to be serviced by non-specialist personnel.

New regulations require some refrigerants to be replaced and leakage to be monitored, to minimise ozone depletion in the upper atmosphere, so it is important to ensure systems are legally compliant.

Store sensors

Good store management should ensure crop temperatures are as uniform as possible to minimise the risk of condensation. Sensors, therefore, need to be sufficiently accurate to measure differences as small as 0.5°C. Regular verification against a calibrated, precision thermometer at ambient temperature and in melting ice at 0°C should be carried out to ensure any differentials measured are real and not due to sensor inaccuracy. Always replace sensors that show any sign of damage to either the cable or probe. This includes stretched or compressed cables as, while these may give a reading, the electrical resistance of the cable may have changed as a result of it being damaged.

In both box and bulk stores, sensors should be preferably located in the top and bottom of the stack, with most located in the top of the crop and some at the base. Alkathene tube, e.g. water pipe, makes a good sleeve in which to fit sensors at low level in a bulk store; fit it on the face of the stack, rather than vertically.

Figure 8. Remove all debris before loading

Checklist

Store inspection

✔ Test store fans/controls

✔ Get specialist kit serviced

✔ Ensure fridges are F-gas compliant

Store hygiene

✔ Remove all dust and debris before use

✔ Vacuum dust – don't sweep

✔ Disinfect only after cleaning

Sensors

✔ Calibrate annually

✔ Repair broken or stretched cables

✔ Measure gradients

Loading the store

Loading

Loading the store should be an activity that is planned well in advance of harvest. It is important to match crops, in terms of their quality, likely storage periods and market expectations, to the storage available so management is effective and returns are maximised.

Harvesting

Crops should be harvested as free as possible from damage, soil, stones and haulm. Within an hour or two of entering store, the crop should be ventilated to remove surface moisture from tubers and from any remaining soil. If positive ventilation is available, as in bulk stores or letterbox stores, ventilation will prevent condensation forming on tubers in crops lifted in dry conditions. The airflow removes the warm air produced by the rapidly respiring crop and will reduce the likelihood of the warm up-current condensing on the cooler potatoes above.

Speed of loading

Try to load stores within a week and absolute maximum of 14 days. This ensures potatoes can be brought under optimal control and reduces the need to compromise on store management and, ultimately, crop quality. If loading within this timeframe is not normally achievable, you may benefit from dividing your store into two smaller sections. Temporary curtains can be used as a cost-effective option for this.

Crop condition

Field sampling will identify rots, blemish disease or slug damage, while warm storage (>20°C) of samples before harvest can identify potential rotting prior to loading. Crops with rots, or loads which have been rained on, should be kept out of the bulk stack to prevent contamination. Crops with 1–2% rots should be set aside, ideally in boxes, and positively ventilated continuously for 4–6 weeks until any rots are mummified. Crops with over 2% rots should not be stored.

During store loading (Figure 9), the temperature of the crop already in store should, ideally, track the daytime average temperature of the crop in the ground, usually between 20°C down to 10°C, over the harvesting period. The store should be ventilated whenever the outside air is within ±4°C of the crop temperature to ensure all surface moisture is removed and condensation is not caused.

If dew-point temperature sensing is available, it can be used instead of temperature to prevent condensation when ventilating with air warmer than the crop. Crops should be quickly blown dry to prevent disease development, which will be encouraged by the relatively warm temperatures during this period, if crops are moist.

Damage prevention

As at harvest, mechanical damage when loading should be kept to an absolute minimum. Rots and blemish diseases invade through wounds and broken skin, while bruising causes rejection from premium markets. Testing for damage should be routine so increased damage can be quickly identified. Standard methods of damage assessment are available; hot-boxing samples overnight will help to show any bruising.

An automated swinging-head elevator is best for systematic loading of bulk stores (Figure 10) and avoids the formation of soil ‘cones’, while most automatic box fillers are designed to minimise drops into boxes.

Figure 9. Store loading: boxes

Figure 10. Store loading: bulk

Box stacking

The stacking arrangement is crucial to achieving uniform air distribution and crop temperatures in box stores.

Stacking for positively ventilated systems is usually predetermined by the design, although may require the fitment of covers or bungs to work correctly.

In space-ventilated, 'overhead throw' systems, the rolling air mass created by the ventilation system always takes the path of least resistance. Pallet openings should be aligned with this airflow to force ventilating air within 400 mm of the centre of every box, to ensure drying and temperature control are achieved. Poor air distribution often occurs in the back corners of the store, especially where there is a biased flow towards a centrally positioned fan. Additionally, short-circuiting of air back to the main fan around the store perimeter can compromise the effectiveness of the cooling and ventilation system.

Separation of delivery and return air using an air curtain (Figure 11) or plenum around the fan is recommended to optimise airflow. Recent work on airflow modelling suggests this can at least double the quantity of air reaching the far end of the store. The deposition of thermal fog sprout suppressant is similarly reliant on effective and uniform air distribution and can also be improved by such measures.

In long buildings, overhead distribution fans, which assist the roll of air within store, can help to even crop temperature and minimise potential condensation.

Checklist

Planning

✔ Plan loading well before harvest

✔ Match best storage to best crops

✔ Try not to compromise good crops by sharing stores

Crop condition

✔ Ensure crops are in good condition with set skins if storing

Box stacking

✔ Prevent short circuiting for best drying and lower energy costs

✔ Don't block pallet slots by overfilling

Figure 11. An air separator curtain boosts ventilation efficiency significantly by preventing short circuiting

Ventilation

Ventilation is a critical process in storage, as the movement of air through the potatoes is the primary means of regulating the crop condition by drying, cooling, heating, humidifying or adding chemical treatments. Specific strategies are needed for key processes, such as drying and initial pull-down, to holding temperature and for the use of refrigeration, which are discussed in the following sections. Many potato stores, however, still employ ambient air cooling, which uses external (ambient) air, when suitable, to cool the crop. Because ambient air does not need to be mechanically cooled, running costs are about a quarter of those of refrigerated cooling.

Air mixing

If a mixing system is fitted (Figure 12), a minimum-desired duct air temperature can be regulated in relation to the crop temperature. Indeed, some more modern storage systems use this as their primary control parameter. On an ambient mixing system, in spells of cold weather, the inlet flap or louvre will be partially shut and the recirculation flap/louvre will partially open, causing the incoming air to blend with the warmer air coming back from the crop. This produces ventilation air that will not reduce the temperature too much (e.g. in a processing store) nor create too large a differential (typically <4°C) across the crop.

Ventilation rates

Bulk stores

In bulk stores, virtually all the air that leaves the fan will pass through the crop. Traditionally, the recommended ventilation rate for bulk stores in Great Britain has been 0.02 $m^3/s/t$, but, with quality parameters increasingly dependent on efficient drying, there has been a move over to systems with higher rates of up to 0.04 $m^3/s/t$, where the airflow removes heat more rapidly, with less weight loss.

The introduction of affordable inverters (also known as variable-frequency drives or variable-speed drives) in the early 2000s enabled fan speeds to be adjusted and offered scope to lower rates once drying and/or pull-down is complete. This can provide significant savings in running costs; for example, reducing a fan to 80% of its full speed reduces the energy consumption by around 50%. It is also an effective way to circulate CIPC sprout suppressant (at, typically, 20–30% of full speed, around 0.003–0.006 $m^3/s/t$) and has been universally adopted by the GB industry through stewardship of the product.

However, reducing airspeeds too much can be detrimental since there is a corresponding loss of pressure and this can adversely affect distribution if a system has been sized for a higher airflow, unless adjustments are made to rebalance the ductwork (this is what is done for slow-speed CIPC application). Fan running times and dehydration will also be increased and response times reduced at low speed.

Box stores

Airflow rates for box stores are, typically, designed to be 0.02 $m^3/s/t$, although a similar trend towards higher volumes has been observed in the past decade. In space-ventilated ‘overhead throw’ stores, this airflow provides air movement around the boxes to dry and cool the crop. However, since the air is not forced through the boxes, heat transfer is partly by natural convection between boxes and the surrounding air and partly by the turbulent airflow created by the cool air jets passing over the top of the boxes and through their pallet apertures. This rate of airflow is primarily to aid distribution, rather than that required to remove the transferred heat, but overall efficiency of these stores is poor.

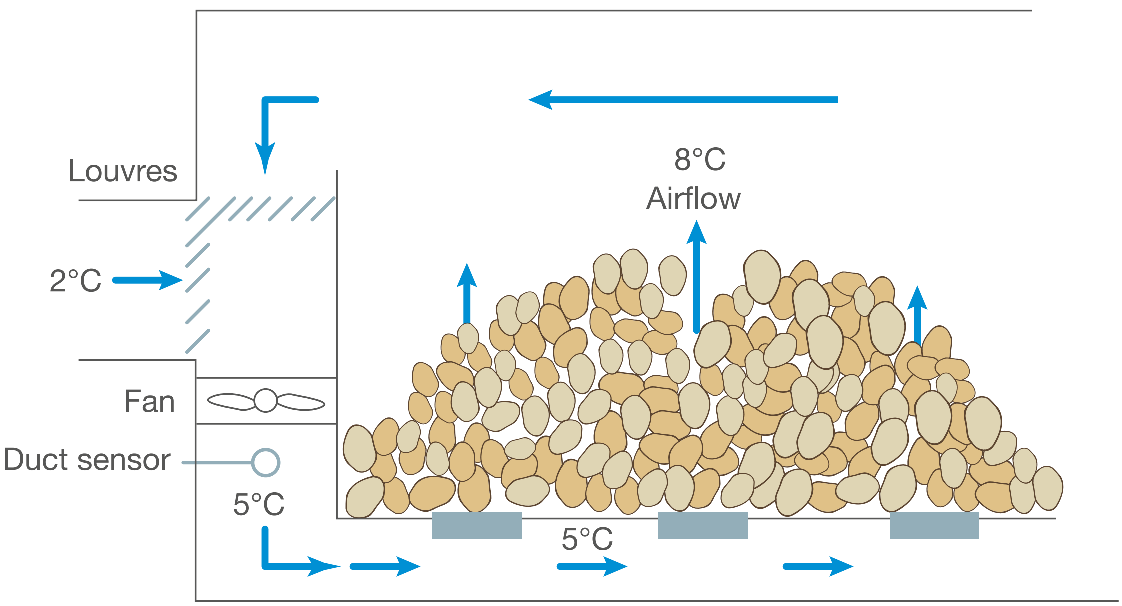


Figure 12. Air mixing, regulated by duct temperature, to permit use of very cold air for cooling

Positive ventilation

To achieve more rapid drying and cooling, systems of positive ventilation may be used that drive air through the potatoes. These are especially suited to densely packed, soil-contaminated potatoes and crops that are warm, wet or affected by disease. Positive ventilation is also a valuable tool for maintaining close temperature control (thereby limiting condensation risk) and application of CIPC.

New storage systems are increasingly featuring positive ventilation systems, including those with greater capacity than conventional letterbox layouts, which are limited to a maximum of around 8–10 boxes from the duct. The lateral suction store layout (Figure 13) is one such system and this is now available with automated sheeting rollers to eliminate safety concerns with their fitment.

Cooling in 'overhead throw' stores

Since cooling in space-ventilated 'overhead throw' stores is from above the box and below, with the greatest airflow being over the top of the upper layer of boxes, space ventilation encourages an undesirable temperature profile within the box – cool at the surface and warm in the centre – which is liable to result in surface condensation when ventilation stops.

The reason this form of ventilation is so popular is that it is low in cost and utilises the otherwise unusable store headspace as a distribution 'duct'. The system works adequately but inefficiently. In principle, when cooling, the store becomes flooded with cool air. The air within the boxes is then warmer than the surrounding air, so the rate of convective ventilation increases. However, this process is much slower than in positive ventilation systems, so cooling takes longer.

Checklist

Ventilation rates

✔ Ensure there is enough air to dry crop

✔ Target: 0.03 m^3/s/t against 375 Pa back pressure for bulk and 250 Pa for box

Positive is best

✔ Systems which force air through the crop perform best

Passive systems can be improved

✔ Work with your supplier to optimise airflow

✔ Make sure air circulates around the whole store

For the system to work best, air distribution should be as uniform as possible over the whole area of the stack of boxes, but recent research has highlighted this is the primary deficiency of such stores, with as little as 15% of the air discharged from the fans reaching the far end of the store. A large component of the airflow short-circuits back to the fans through the sides and top of the boxes.

Figure 13. Lateral suction is a positive ventilation option for box storage

Drying

Drying is a critical phase of potato store management. Successful storage is so often dependent on ensuring the crop is dried before it is able to deteriorate and that it is then kept dry to maintain the crop in its best possible condition.

Free moisture

When a crop is brought into store, moisture in the adhering soil comes with it. Air surrounding a free water surface has a relative humidity (RH) of 100%. This free moisture must be evaporated off if the RH of the air is to reduce to the level associated with dry potatoes – about 96%. While this difference in RH would appear small, it is the key to having a dry, fresh-smelling store where every tuber has a dry skin, rather than a dank one dripping with moisture.

Immature crops, harvested from dry soils, will become wet through condensation if there is insufficient rate of positive ventilation to remove the high respiration produced by heat. Drying will then be necessary to remove this condensed moisture.

Water-holding capacity of air

Warm air can hold more moisture than cold air. A cubic metre of air can hold 17.5 g of water at 20°C, but only 9.5 g at 10°C and just 6.4 g at 4°C. The drying of crops in warm weather, in September or early October, is, therefore, much quicker than if attempting to dry crops in cold weather in late November. The high heat output from the crop over the first few days after harvest will also further warm the airflow, making drying even faster during this period.

Rate of drying

If a box or pile of potatoes is positively ventilated from bottom to top, the base layer dries first. A ‘drying front’ forms, a few centimetres deep, over which the air becomes saturated, which means it cannot take up any more moisture. This front then progresses very slowly up through the crop and, depending on the airflow rate, may take several days to travel through the potatoes. Below the front, the crop is dry; above, it is still wet. The saturated air leaving the front passes up through the wet potatoes higher up, doing very little drying as it rises, so most effective drying actually occurs in this narrow drying front.

The rate of drying is dependent on:

- Airflow rate, which in turn depends on fan output and air leakage from the system
- Temperature of the air, which affects its water-holding capability
- Relative humidity of the air, which dictates the amount of water the air can take up
- Amount of moisture present on the potatoes and in the adhering soil

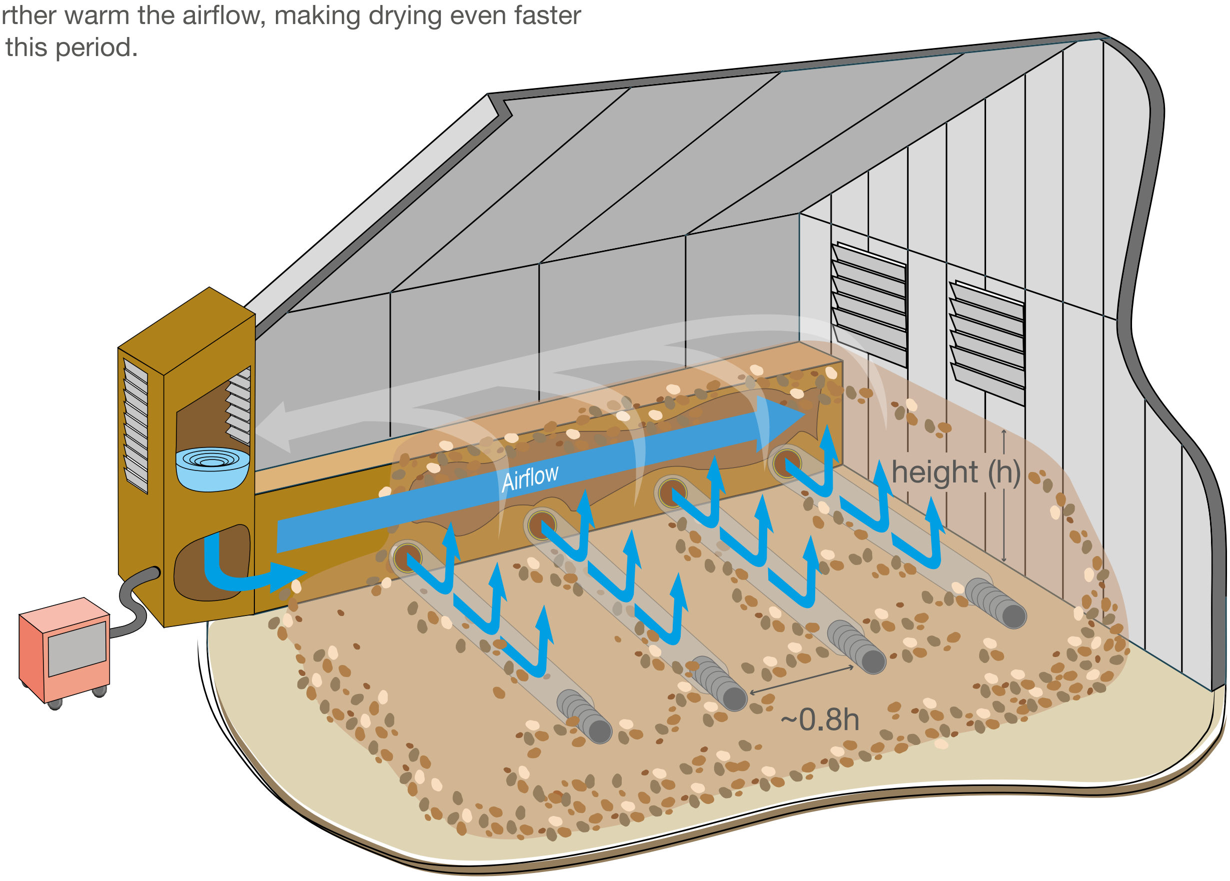


Figure 14. Ventilation through lateral ducts in a bulk store

Positive ventilation

Drying is most effective if ventilation is positive – where the air delivered has to travel through the box or pile of potatoes.

In bulk stores, virtually all of the air flows through the crop (Figure 14), whereas in positively ventilated box-storage systems, at least 50% of the air typically escapes through gaps between the boxes. Letterbox systems are limited to 8–10 boxes deep for effective drying. Lateral suction or suction wall systems (e.g. open suction – Figure 15) are more suited to stores with more than 10 boxes per row.

Airflow rates for effective drying

Always use the highest airflow rate available for drying. Batch systems are very well suited to drying, as air can be concentrated on a small tonnage at a time. Bulk stores require a minimum of 0.02 m^3/s/t, rising to 0.04 m^3/s/t for early-lifted crop. Box stores need up to 0.08 m^3/s/t to allow for air leakage.

Figure 15. Open suction is a non-positive drying solution

Checklist

Don’t hold back on drying!

✔ Wet crop needs 100% airflow

✔ Rapid drying is crucial to reduce risk

✔ Positive ventilation gives best results

Use inverters for holding period

✔ Once dry, reduce fan speed to save

✔ 80% fan costs half to run versus full speed

Dry only until surface moisture is removed

✔ Over-drying will add to weight loss

Wound healing and pull-down

Curing requirement

Wound healing ('curing') is a required element of modern potato production. Automated processes for harvesting and handling inevitably result in some level of mechanical damage and/or bruising and this needs to be cured to prevent long-term impact on storage quality, notably from weight loss and disease.

Where the skin is severed, the wounds allow fungi and bacteria to develop in the flesh of the tuber. The potato has a natural defence mechanism to cure these wounds. This leads to suberin formation between and below damaged surface cells and provides an initial barrier to disease entry, and new cells form soon after into a more impenetrable barrier. Rate of wound healing is primarily influenced by temperature (Table 3) and is faster in recently harvested crops, compared with physiologically old crops, such as those graded after a long storage period in the spring. Humidity plays little part in speeding up wound healing.

The rate of moisture loss from fresh damage is in the order of 100 times that of undamaged skin, so weight loss over the first few days is inevitable. The faster the wounds heal, the less this weight loss will be.

Decisions on whether to cure crops or not will depend on the desired market and the potential for disease development. For example, a long duration at a relatively high temperature will be required for varieties and conditions where skin spot or gangrene development is likely (e.g. late-harvested, mechanically damaged King Edward), whereas a specific curing period could be omitted where markets demand low levels of silver scurf or black dot.

Figure 16 illustrates that development of 'low temperature' diseases like skin spot is more likely where curing is omitted. Those diseases that favour higher temperatures, like silver scurf and black dot, can take advantage of conditions associated with traditional curing regimes and the initial effect can persist into long-term storage.

Table 3. Wound healing rate in relation to tuber temperature

Tuber temperature (°C)	Initial suberisation (days)	Periderm complete (days)
<5	7–14	21–42
10	4	7–14
20	1–2	3–6

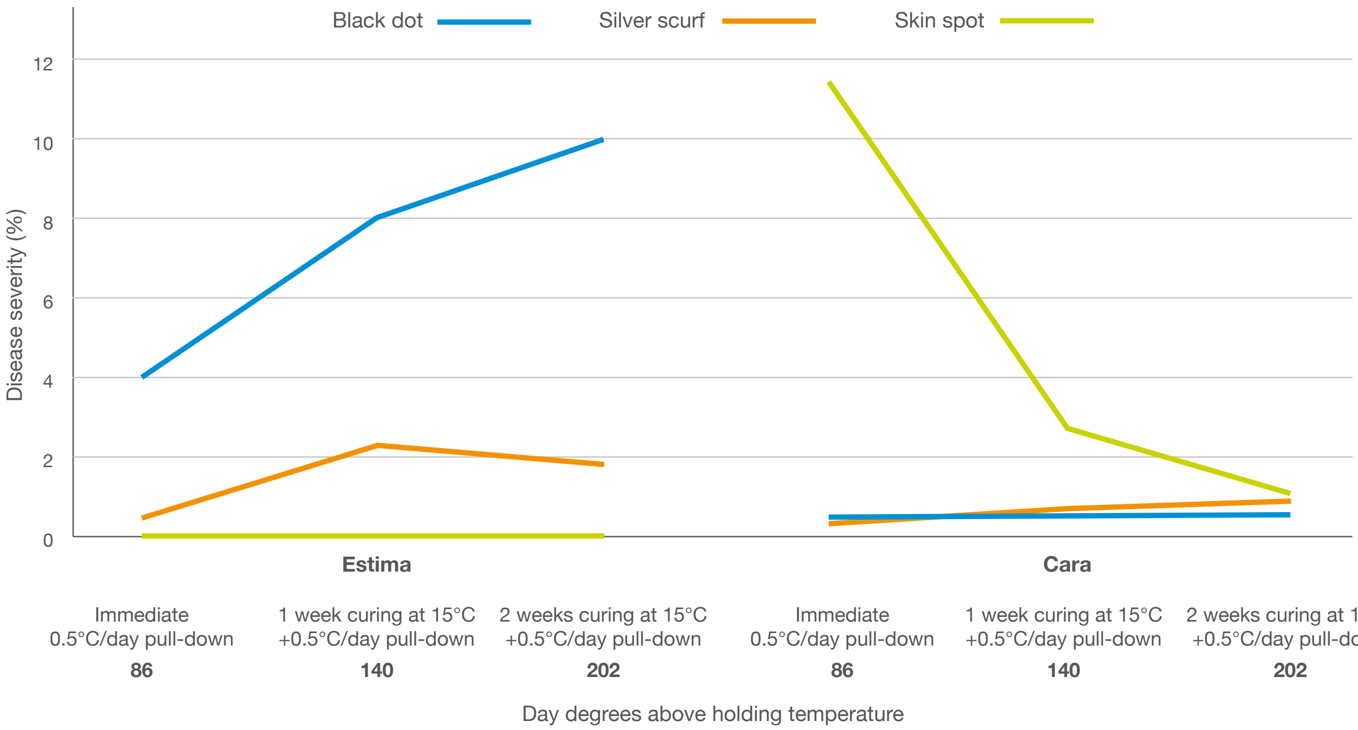


Figure 16. Effect of variety (Estima, second early vs. Cara, late maincrop) in combination with curing strategy (day degrees above holding temperature) on development of different diseases

Dry curing

Dry curing, where crops are ventilated with suitable ambient air immediately on entering store, allows drying, heat removal and wound healing to occur simultaneously. Studies have shown disease development to be markedly slowed by dry-curing techniques compared with leaving the crop to ventilate naturally. As cooling is not desired during wound healing, ventilation control is normally set to manual. On manual, the automatic control box is switched out of circuit, and only the frost thermostat, if wired correctly, will stop ventilation, should ambient temperature fall below its set point.

The aim of ventilation when dry curing is to remove all moisture from the crop and then to keep it dry. Selection of suitable quality air is essential and even short condensation events can undo the benefit from dry curing, as re-wetting can initiate diseases like silver scurf.

Ventilation and recirculation

If conditions are not suitable for dry curing with ambient air, it is important to maintain air movement in the store to avoid temperature gradients becoming established. This can be achieved by regular recirculation (using auto-recirculation control, if required), especially at night when the store is closed and there is less risk of drawing in unsuitable external air.

Pull-down

As soon as wound healing of the last crop loaded is complete, the crop should be brought down to its recommended holding temperature. Earlier commencement of pull-down is likely to be appropriate for some markets, e.g. for black dot control – Figure 17.

While a relatively small differential may reduce the cooling rate, a larger one can cause excessive temperature differences within boxes. This can result in condensation when warm humid air within the centre of the box rises and condenses on the cooled surface tubers, unless positive ventilation is used.

To avoid re-wetting, the temperature of the cooling air should be kept in a band between 1–4°C below the crop temperature, no cooler. Pull-down rates should average out at about 0.5°C/day in space-ventilated fridge stores.

Checklist

Wound healing

✔ Need time and temperature combination for layer of suberin to form over wounds

Integrated management

✔ Usual to cure during pull-down

✔ Wounds heal quickly if warm and humid, but be wary of condensation!

Higher risks if…

✔ Late harvest

✔ Cold ambient temperatures

✔ Skin-spot-susceptible varieties

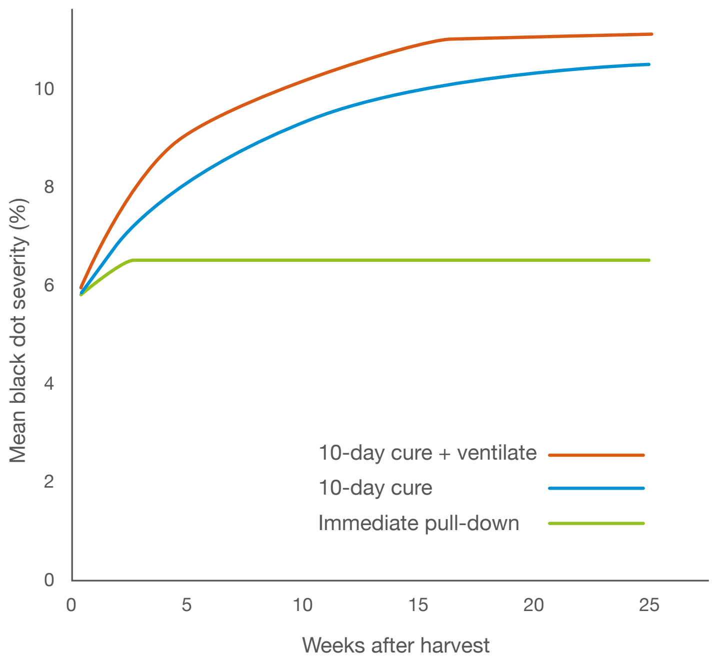


Figure 17. Effect of curing strategy on subsequent development of black dot

Condensation control

How condensation forms

Condensation is a major concern in potato storage. In a sealed store, over just a matter of hours, potatoes can naturally create an environment with a high relative humidity (RH) of 90% or higher. At such a high RH, condensation can occur on the crop (or the roof) if the surface is only marginally colder than the air. Condensed moisture is pure water, highly available to microorganisms residing on the tuber skin or in wounds, lenticels or sprout buds. A condensation period of just an hour can allow blemish disease development or rotting to begin.

Warm air can carry more moisture vapour than cool air. Relative humidity is a way of expressing the amount of moisture in a given volume of air in relation to its maximum moisture-carrying capability. So if 1 m^3 of air at 4°C is at 50% RH, it contains 3.2 g of the maximum 6.4 g/m^3 that the air can hold.

Air temperature and relative humidity are related. If the temperature of air rises, the moisture-carrying capacity increases and the RH will drop. Conversely, if the temperature of air falls, the RH will increase until it reaches a point where it cannot hold any more moisture. This point is known as the dew-point.

Condensation will occur when warm, moisture-laden air comes into contact with cold surfaces and the dew-point is reached. Cool air coming into contact with warmer potatoes is not a condensation risk.

Condensation on the crop can occur in a number of situations but will only do so directly, if:

- Air surrounding the potatoes is warmer than the potatoes
- Potatoes' surface temperature is below the dew-point temperature of the air

As a general rule, a temperature difference of 4°C or more between the warm air and the cooler crop will cause condensation. But, in some situations (e.g. at cold temperatures), this difference might only need to be as little as 1°C for condensation to occur.

Condensation control

Control condensation by minimising temperature differentials. At harvest, do this wherever possible by keeping the store temperature at that of the potatoes being loaded into store.

Be particularly careful if the store fans are off; this is when there is greatest risk of differentials building up, due to convection and condensation forming as a result.

In bulk stores, place sensors 100 mm and 300 mm down in the pile. The top surface (100 mm) sensor should be no more than 0.5°C cooler than the sensor 300 mm down. Use roof-space heating to manage the temperature if this cannot be maintained.

Only ventilate with air warmer than the crop if the crop temperature is above the air's dew-point temperature. Dew-point can be calculated using the table on page 44.

Prevent condensation from warm air leaking into the headspace by sealing gaps in the structure and keeping store doors closed, especially in warm, humid weather.

Structural condensation

Condensation forming on the structure will often lead to problems in the crop. On the roof, it forms on the underside, runs down to the purlins and then drips, in lines, onto the potatoes below. The wet potatoes can start rotting or skin-surface disease may develop.

Condensation on walls is only a risk in bulk stores, where the moisture can run down through the crop or pool under the stack.

Structural condensation may occur due to one, or more, of the reasons below:

- The store's insulation is inadequate or has failed because it is wet
- Air movement across the roof's internal structure is insufficient, allowing localised pockets of high humidity at the roof surface

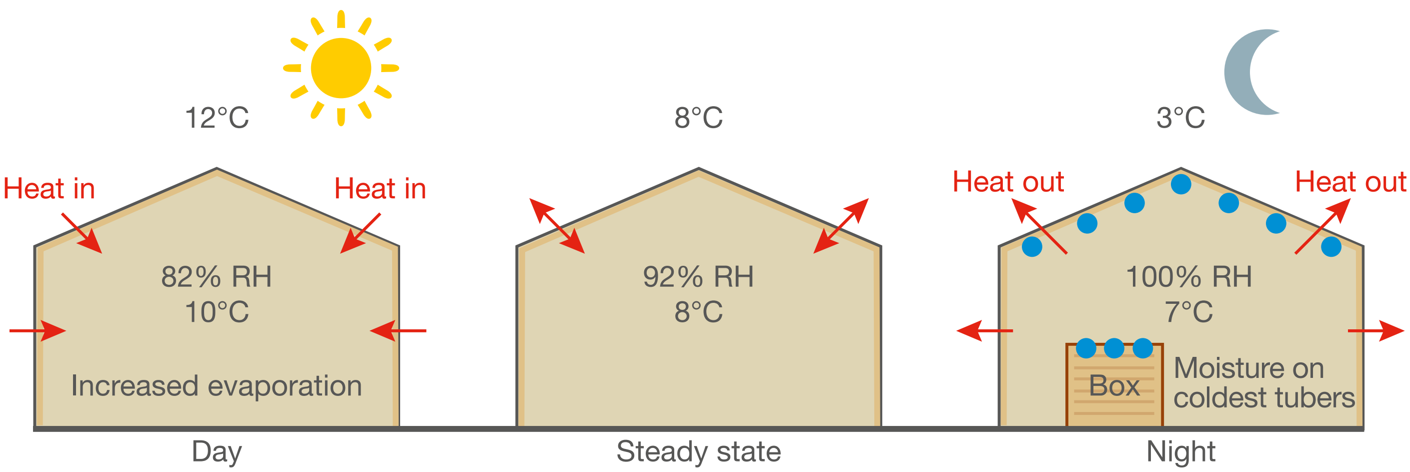


Figure 18. Diurnal temperature variation can result in condensation

- A cold spell of weather or diurnal (day/night) temperature variation (Figure 18) causes heat, but not water vapour, to escape from the store
- Internal store atmosphere is at or very near 100% RH

During cold weather (>6°C below the store temperature), look carefully for signs of structural condensation, for example on the underside of the roof. Check also for signs of dripping from insulation joints or sagging roof insulation caused by interstitial condensation within the roof structure. Seek specialist assistance to rectify any problems.

The roof insulation should be at least 75 mm thick for refrigerated stores and 50 mm for ambient cooled stores. Where it is less, consider increasing its thickness. Always replace damaged insulation.

Better insulation, and air movement in the roof void, will reduce structural condensation, but roof-space heating is the best way to prevent it. Fit roof-space heating (Figure 19) in stores that are prone to structural condensation during cold weather, especially those held at higher storage temperatures for processing. Automate control to heat when the headspace air temperature falls *c.*1°C below crop (surface) temperature.

Checklist

Condensation wrecks a crop quickly

✔ A short period of condensation is enough for disease to strike

✔ Keep tight temperature control to avoid wetting

✔ Inspect stores in periods of cold weather

✔ Use roof-space heating to control structural condensation

✔ Keep store doors closed: warm air blowing on to cooler potatoes risks making the crop wet

Figure 19. Roof-space heating in a bulk store

Refrigeration

Refrigerated storage using mechanical cooling offers the scope for close environmental control, largely irrespective of the ambient condition. In stores where this control is paramount, refrigeration is, therefore, becoming an essential part of the storage toolkit.

Even where there isn't a need for constant optimal control, a combination of ambient air cooling and refrigeration can reduce the energy required for drying and cooling when ambient conditions allow, while retaining the ability to control temperatures in store when warm temperatures prevail outside the store.

With long-term storage accounting for up to 100 kWh of energy use per tonne, ensuring that systems work efficiently (whether they use refrigeration exclusively or partially) will not only preserve crop quality but also help manage energy costs.

A refrigeration system consists of two heat exchangers: the evaporator or cooling coils inside the building and the condenser outside. These are connected by a circuit containing a liquid/gas refrigerant. Air that picks up heat within the store passes over the evaporator and is cooled according to the size of the compressor. This cooled air is blown out of the fridge to recirculate around the store. The temperature difference between the air going into the fridge (the air-on) and the cooled air coming out (air-off) reduces as the store temperature falls (Table 4) but should not exceed 2.5–3°C.

Table 4. Typical air-on/off values for refrigeration (°C)

Air from crop (air-on)	Air from outlet duct (air-off)	Air-on/air-off temp. difference
12.0	9.0	3.0
8.0	5.5	2.5
3.5	1.5	2.0

Heat is pumped out of the store in the refrigerant to the condenser outside by a compressor. Older condensers often have banks of multiple fans fitted for dissipation of heat, which switch on sequentially according to demand. Fitting inverters on fans can be a good way to reduce energy consumption on these condensers. Modern condensers have continuously variable EC fans for efficient dissipation of heat.

Refrigeration is increasingly an area for which there is compliance legislation, which needs to be adhered to, particularly in relation to the choice of refrigerant. Older systems installed in the 1980s and 90s (or earlier) are likely to have used refrigerants that are no longer permitted or that can no longer be replaced (Figure 20). If these systems contain HCFC refrigerants with a high global-warming potential (GWP), such as R22 (banned from use in 2015) or R404A (scheduled for phase-out from 2020), they will need to be replaced by a modern, more environmentally friendly refrigerant with a lower GWP. Where these are used for retrospective replacement, they are referred to as drop-in refrigerants. Examples include the blends R407F, R407A, R448A, R449A and R452A. It is recommended to consult a professional refrigeration advisor regarding the choice of drop-in.

Refrigeration systems are complex and should be serviced annually by the supplier. However, operators can help ensure the equipment runs efficiently by carrying out the following simple checks before use:

- Compressor crankcase oil heater is switched on 24 hours before starting
- Condenser coils outside are free from leaves and dirt
- Refrigerant is dry and clear of air bubbles (use the sight glass or other monitoring device)
- Compressor is operating when the recirculation fans are operating
- Check the calibration of temperature and humidity sensors

Regular checks of the high and low refrigerant pressure switches need to be made during operation as these can trip out the compressor. The fans may still operate even if no cooling is taking place.

Figure 20. Floor-mounted fridge unit typical of older installations

Control of refrigerated storage

In cooling mode, simple control systems will tend to favour the use of refrigeration over ambient air cooling. Indeed, the sole use of refrigeration to achieve a controlled pull-down is increasingly common in storage for fresh markets. More sophisticated control systems allow delays to be installed for fridge operation, which either allow cooling to wait until night-time low temperatures are available or enable lower-cost energy tariffs to be used if fridge use is necessary.

Defrost

The temperature of the evaporator (cooling coils) is *c.*6°C lower than the crop temperature. The air flowing through the evaporator is cooled to a level between the air-on temperature and the evaporator temperature. At low storage temperatures (<2.5°C), condensate is, therefore, likely to freeze on the evaporator coils, which will require periodic defrosting (Figure 21). Defrost is often only available as off-cycle (i.e. the system shuts down), but it is more efficient if defrost can be carried out 'on demand' (i.e. if defrost is actually required), avoiding unnecessary downtime or heating of coils that have already been cleared of ice. Sensor systems, which can assess the need for defrosting, are increasingly prevalent on newer fridge systems for this reason.

Store integrity

Refrigeration costs can be minimised if stores are well sealed. Only one, preferably small, opening door should be required for winter access. Close off and seal any doors, flaps or louvres not required for access or ventilation. Use a controller with positive closing action so that any louvre that opens under wind pressure is detected and the motor acts quickly to reclose it.

Checklist

Refrigeration

✔ Valuable in mild autumns or to extend storage term

Compliance

✔ High-GWP refrigerants are to be banned from 2020

✔ Costs rising sharply

✔ Look to use new 'drop-ins' instead

Save energy

✔ Well-sealed stores

✔ Composite insulation

✔ Smart control

✔ Use defrost on demand

✔ Servicing is key for good performance

Figure 21. Ice must be regularly cleared from cooling coils

Humidity and moisture loss

Potatoes have a high water content (over 70%) and, in storage, lose moisture over time through evaporation to the environment around them. At 4°C, tubers reach equilibrium (i.e. they neither lose nor gain moisture) when the surrounding air is at 98% relative humidity (RH), very close to saturation. As the RH of air surrounding stored potatoes falls, water loss increases.

Ventilating a potato store will always, to some extent, dehydrate the crop. As air moves through the potatoes, it evaporates moisture on the skin and picks up heat that lowers its relative humidity, increasing its drying capacity. Where the skin of the tuber is not intact, either due to poor skin set or unhealed wounds, increased moisture loss will occur.

The risks of dehydration from ventilation can be minimised, by:

- **Harvesting with set skins –** this is a critical measure to minimise moisture loss from the tuber. Because the potato's skin acts as a regulator governing the rate of moisture from the tuber, the actual amount of moisture lost is proportional to the ventilation time during the holding period
- **Optimise the ventilation time by regulating the quantity and temperature of the air used to reach the required storage condition –** this is best done using an automatic ventilation controller, as this will bring on the fans only when ventilation is required and the air is suitable for use

The effects of dehydration can also be exacerbated by deep-pile storage (>4 m deep), where it is common to see some evidence of compression damage in crops removed from long-term storage. In severe cases, compression damage can be seen within boxes, where depths are seldom much more than 1 m.

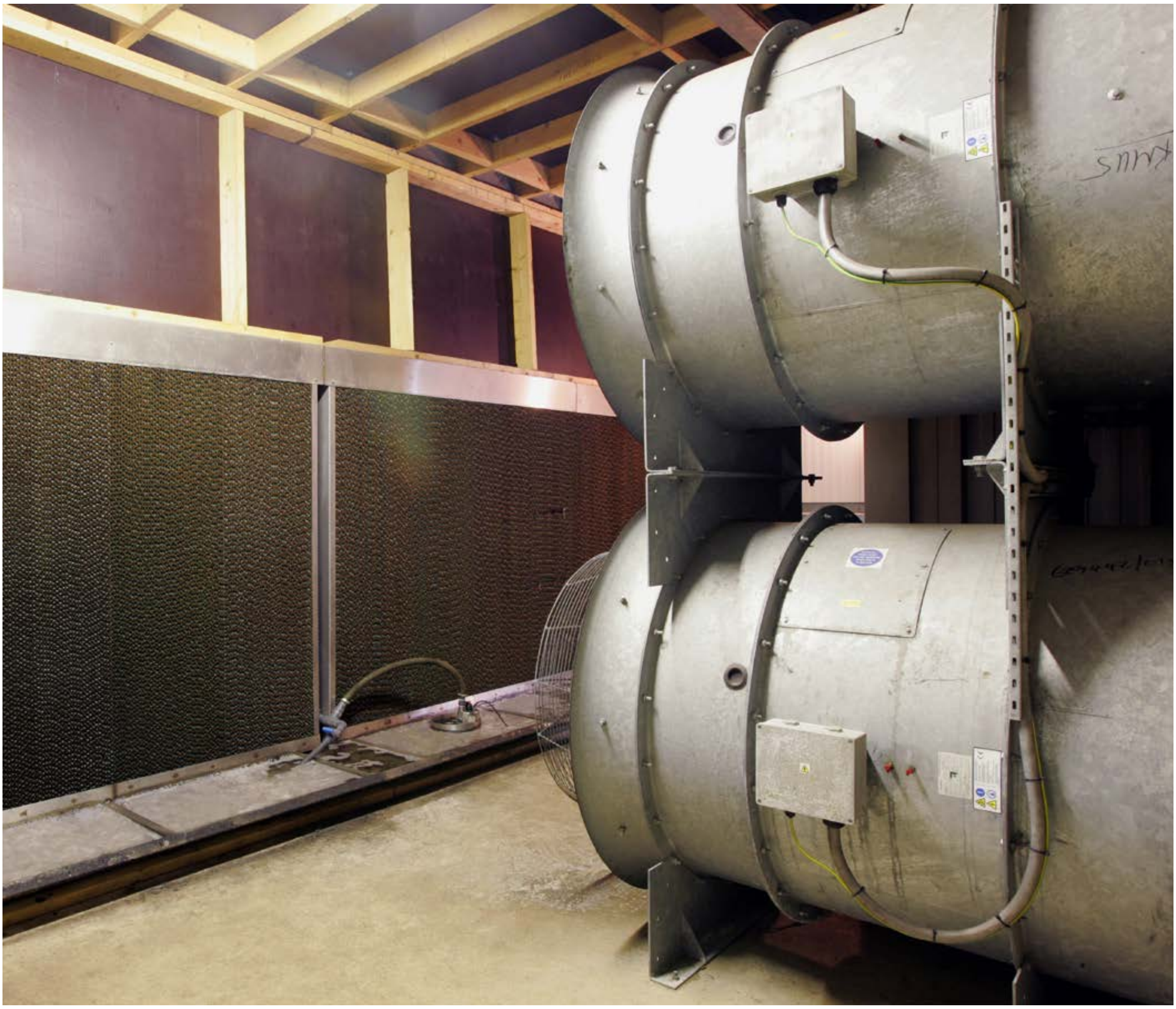


Figure 22. Cell humidifier for ambient air (and adiabatic cooling)

Humidification

By supplementing the moisture content of the air through humidification, there is scope to increase its RH and reduce moisture loss from the crop. A range of systems are available (Table 5). Humidification is most commonly used in ambient processing stores held at warm temperatures (>6°C).

A further benefit of humidifying is evaporative cooling. If moisture is evaporated during the ventilation process, it has the effect of cooling the air at the same time. This means systems using humidified air can operate at tighter air/crop differentials as the differential is widened as a result of water evaporation. This is known as adiabatic cooling.

Humidification systems should only be used in well-sealed buildings with a close level of temperature control (range <0.5°C). This is because as humidity increases towards saturation, the tolerance for temperature variation before condensation occurs is reduced. Note also that humidification cannot be expected to rectify major dehydration deficiencies caused by incorrect ventilation control or poorly specified refrigeration systems.

Checklist

Humidity

- ✔ Naturally high in most stores
- ✔ Crop adds moisture
- ✔ Key is to keep temperatures even to avoid condensation

Humidify if…

- ✔ Looking for weight loss reduction
- ✔ Need more ambient cooling hours

Table 5. Humidification systems

Type	Description	Benefits/disadvantages
Cell humidifiers	These systems (Figure 22) use a special perforated, treated paper membrane (cell) down which water is cascaded to humidify air blown through the membrane at right angles to the water flow. The cell has a very high surface area to optimise the uptake of moisture	Can be fitted retrospectively Do not require active control of humidification Can filter out some disease spores
Atomiser systems	Ultrasonic atomisers use compressed air to shatter the water into a very fine mist. Delivery of the water to the air is through nozzle(s), which are usually placed within the ventilation duct of the store	Can be fitted retrospectively Small risk of free water being carried into the crop, requiring close monitoring at all times Active or pulsed control of humidification is needed
Spinning discs	This method of humidification uses a high-speed rotary atomiser to break the water supplied to the disc into a fine mist that then enters the store through the ventilation system	

Energy monitoring

The biggest consumer of energy during storage, whether using ambient or refrigerated air, is for cooling the crop.

Monitoring consumption is a key factor in managing energy use successfully. It is a relatively cheap exercise to undertake and allows managers to identify high-energy-use equipment and times, spot where problems may be occurring and make rational investment decisions on energy-saving equipment.

Energy monitoring can range from the regular, organised reading and manual recording of utility meters on site, to the use of sophisticated data-logging equipment. It can be applied to whole sites or, by submetering, to individual buildings and pieces of equipment. Store-specific metering is recommended (Figure 23).

Figure 23. Store-specific smart meter

If metering each store separately is not practical, energy use per store can be estimated from fan and fridge hours' runtime. For each store, total the power rating in kW or HP stamped on the electric motors that run when the ambient air cooling is operating and when the refrigeration is running. Comparing the cost of current electricity suppliers with other suppliers, contracts or changing tariffs may be a way of saving money. Specialist energy brokers can assist with this process.

Building improvements

Leakage of warm ambient air into stores, through gaps in the structure, joints and doors is a primary cause of condensation. It also leads to excessive cooling-fan or refrigeration running costs. Major air-leakage points are obvious, as daylight can be seen through the gaps from inside a dark store (Figure 24). Other leaks, such as gaps between composite panels, may only be identified by detecting draughts on a windy day or by use of equipment such as a thermal-imaging camera (Figure 25). Simple solutions can often help minimise air leakage and, consequently, reduce energy use.

Figure 24. While this store looks well constructed, major air-leakage points can be seen inside when dark

Figure 25. Thermal-imaging camera

Use of inverters (VFDs) on fans and pumps

Inverters can improve the energy efficiency of fans and fridge components, such as condensers, fans and compressors, by moving away from a one-size-fits-all approach. Instead, they match the performance of equipment to the store's needs.

Be aware that a fan will often consume energy equivalent to its capital cost within as little as one season. So, when upgrading equipment, the extra cost of new technology or a more efficient motor needs to be offset against the delivery of energy savings.

Good control is essential in providing optimal storage conditions at the lowest energy cost. Compared with many capital investment options, control is generally quite cheap to integrate into an existing store. The ability to regulate refrigeration use to coincide with a cheaper night tariff can make significant cost savings.

Web-based forecasting systems are increasingly available on new store controllers to anticipate the weather and delay cooling until cool ambient air is available.

Record-keeping

It is key to maintain good records if there is a desire to improve storage efficiency. Without them, it is difficult to assess whether changes are real and worthwhile or simply a facet of the many variables that relate to storage use.

For example, a simple change in storage duration of a week between seasons could easily hide a 2% difference in energy consumption.

If major decisions around the use of a store are contemplated, consider engaging a specialist energy-auditing service, which will highlight where true energy savings can be made.

With ever-increasing energy costs, a higher profile for environmental issues and the carbon footprint of storage, understanding energy use and exploring energy-saving options such as solar panels (Figure 26) are now high priorities.

Checklist

Store efficiency

✔ Measure energy use

✔ Crucial to controlling costs

✔ Attention to detail is key

Air leakage

✔ Massive impact on energy bills

✔ Seal stores well

Technology pays

All of the following help to lower running costs and boost returns:

✔ Inverters

✔ EC condenser fans

✔ Defrost on demand

✔ Smart meters

Figure 26. Refrigerated potato stores can make good use of solar energy in summer months

Store atmosphere

Oxygen

Potatoes are living organisms, which require oxygen to metabolise their food reserves to maintain life.

Respiration rates (see page 6) are usually higher in processing stores compared with pre-pack stores due to their higher holding temperatures, although, at times during the storage period, respiration rate can increase if the holding temperature falls below 5°C.

A lack of oxygen in a potato store can lead to blackheart (Figure 27), where the central core of the potato is starved of oxygen and the tuber effectively suffocates from the inside out. The result is an odourless, blackened area in the central pith tissue. However, susceptibility to blackheart is a complex issue with multiple causes related to tuber stress, so it cannot be assumed to be linked to oxygen levels in all cases.

Carbon dioxide

The respiration process generates carbon dioxide (CO_2), which will accumulate in the store atmosphere. Carbon dioxide levels in potato stores are often in the region of 0.3–0.5% (3,000–5,000 parts per million), which is about 10 times the 0.04% level normally found in air.

Modern, highly sealed stores are more likely to have higher levels of carbon dioxide if the air within the store is not freshened daily. Carbon dioxide can accumulate to levels as high as 3% at times of high crop respiration. Crop respiration rates are higher immediately after harvest, following the thermal application of sprout suppressants and also when using ethylene in store.

Many storage control systems are now available with CO_2 sensors, allowing measurement and control of the store atmosphere automatically. Portable CO_2 sensors (Figure 28) can also be used to monitor levels at times of high crop respiration but are relatively expensive to buy. The main priority for the potato crop is to control excessive build-up, which may induce stress-related responses. As such, the most recent control systems are using CO_2 levels more as an indicator of crop stability and instigate 'flushing' or 'purging' regularly to maintain low levels of CO_2 at all times.

Otherwise, a simple timer control can automate this process without the need to measure the carbon dioxide level. This can be achieved most simply by running a small extractor fan continuously, fitted in the store wall, or by ventilating for a few minutes each day to let some ambient air into the store. Some controllers use the ambient mixing function to maintain temperature. Without this protection, be aware of the risk of potential problems, such as condensation or chilling when flushing stores with warmer or cooler ambient air, respectively.

Adherence to Health and Safety Executive recommendations for operator exposure limits (see page 36) ensures a safe working environment for those working within the store.

Ethylene

Ethylene, a plant growth hormone, can be a component of the store atmosphere where it is used as a sprout suppressant treatment. When used, ethylene can influence crop respiration rates, so interactions are likely with other atmospheric components, e.g. oxygen and carbon dioxide.

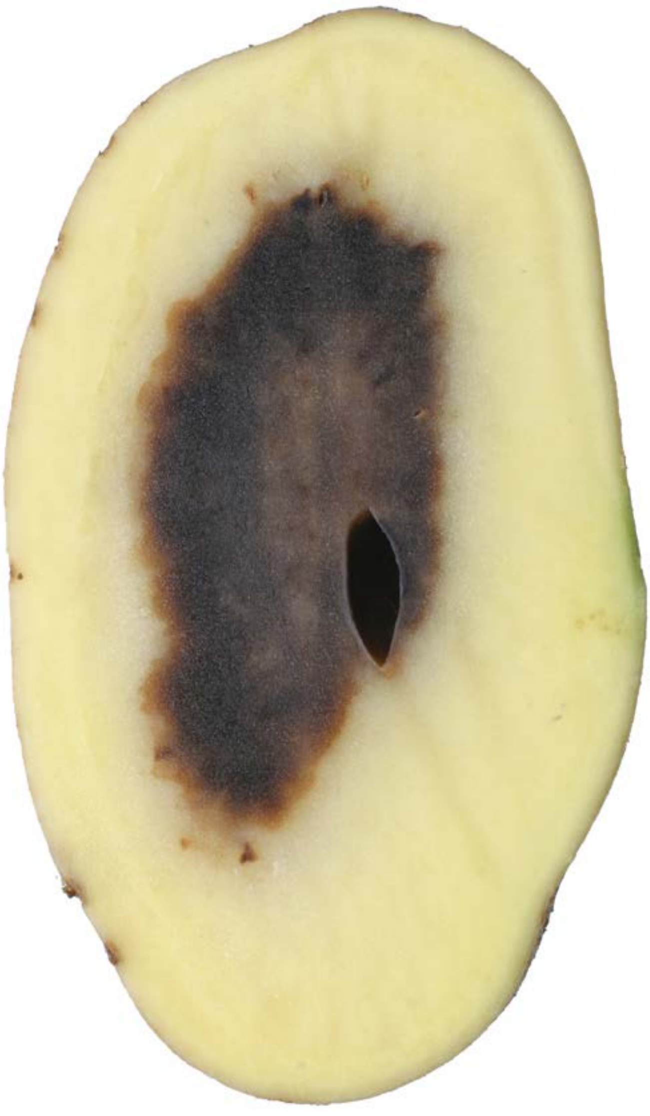


Figure 27. Blackheart

Other gaseous components

In addition to carbon dioxide, there are other gaseous components in the store atmosphere (volatile compounds) which are associated with potatoes and the development of some diseases. Some of these have been identified, but their influence on potato quality is still being investigated. However, it is known that volatile compounds (including ethylene) can be introduced to the store through processes such as thermal fog application and these may have a detrimental effect on crop quality if they are allowed to persist in the store.

The identity of other volatiles within a potato store remains largely unknown and their role is, therefore, not yet understood; research has been undertaken and it is hoped in future to be able to use measurement of these chemical compounds to develop systems for early detection of diseases such as soft rot.

Figure 28. Use a meter to measure carbon dioxide

Checklist

Oxygen

✔ Potatoes need oxygen to survive

Carbon dioxide

✔ Natural by-product of respiration

✔ Levels can rise markedly in store

✔ Control for benefit of crop and for safety of staff

✔ High CO_2 can be indicative of crop stress

✔ May lead to dark fry colour

Ethylene

✔ Plant hormone

✔ Affects rate of respiration

✔ May be released by hot-fogging processes

Sprout suppression

At harvest, potatoes are usually dormant and sprouting does not occur, even under conditions favourable for growth. The period of dormancy varies considerably by variety and season. After break of dormancy, sprouts grow at a rate primarily determined by temperature. Reducing storage temperature is, therefore, an effective way of controlling sprouting, by first prolonging dormancy and then limiting the rate of growth.
To avoid use of sprout suppressants entirely, storage temperatures need to be consistently below 3°C. However, potatoes held at such cold temperatures will be affected by low-temperature sweetening, which can adversely affect taste, texture and colour on roasting/frying. In potatoes stored for processing, where low-temperature storage is not an option (because of poor fry colour), the use of sprout suppressants will be necessary for all but the shortest storage durations.

At the time of publication, chemical treatments with chlorpropham (CIPC), ethylene, maleic hydrazide and spearmint oil are available for sprout suppression. The principal characteristics of these compounds are shown in Table 6. Some production protocols may restrict the use of certain active substances.

Minimisation strategies

Take steps to avoid unnecessary use of sprout suppressants. Plan control strategies, taking account of the following:

- Varieties with long dormancy and low-temperature tolerance reduce the need for suppression
- Segregate storage by dormancy – varieties with contrasting dormancy characteristics should be held in separate stores so only crops requiring suppressants are treated
- Requirements can be limited by judicious use of combination treatments, but always check market acceptability first

Chlorpropham (CIPC)

CIPC has been the main sprout suppressant used in Britain for over 50 years; virtually all has been applied as a hot fog. Its use in recent years has been subject to Stewardship but, from 8 January 2020, its approval is withdrawn so it cannot be used after the 2019/20 season.

Because CIPC leaves a residue over several years, it will be necessary to clean previously treated stores to ensure compliance with Maximum Residue Level legislation.

Ethylene

Ethylene is an effective sprout suppressant on some varieties. However, because it is a plant hormone, some varieties respond better to ethylene than others. If the variety responds to ethylene, it can be used successfully on low-temperature stored crops for fresh market and at higher temperatures on crops destined for processing. It is important to know the varietal suitability before treatment; consult your seed supplier or market for more information. In ambient stores, some form of automated

Table 6. Sprout suppression options in UK

Active substance	Application method	Notes	MRL*
Ethylene	Gas applied by direct release or generated in-store	Effective on varieties which respond to ethylene Can be unpredictable so check with seed supplier or market May affect fry colour Successfully trialled as a combination treatment	None
Maleic hydrazide (MH)	In-field foliar spray	Provides volunteer control Results from MH vary depending on weather and canopy condition at the time of application Can give up to 9 months sprout control; effective long-term in combination with in-store treatments	50 mg/kg
Spearmint oil	Hot-fog	Volatile chemical which is easily lost from store: manage outside air exchange carefully Seal stores after treatment: follow product best practice guidelines closely May be used in combination with other products	None
Chlorpropham (CIPC)	Hot-fog	Only approved for use until 2019/20, subject to stewardship – see **www.cipccompliant.co.uk** Residues will remain in treated stores and boxes Cleaning will be needed to meet new lower MRL	10 mg/kg whilst approved; will reduce on loss of approval

*Maximum residue level permitted in potatoes for sale control is likely to be needed, to stop the ethylene generator during periods of external ventilation.

The use of ethylene is not controlled by an MRL, so its residue-free status is favoured by some markets. However, ethylene has little residual effect on sprout growth, which will resume soon after removal of crops from store and can therefore limit shelf life.

Ethylene is a plant hormone which has the potential to markedly increase tuber respiration rate and, as a consequence, increase store CO_2 levels. It is important to manage the interaction of ethylene with high levels of CO_2. For this reason, guidelines require ethylene concentration to be increased very gradually up to the 10 ppm (parts per million) holding concentration to limit respiratory response. Ethylene has a varietal interaction, so store managers must follow suppliers' guidelines closely.

Maleic hydrazide (MH)

Maleic hydrazide is applied to the growing crop in the field, primarily for groundkeeper control. Canopy condition and weather conditions at the time of application are important factors governing uptake and, therefore, its successful use. MH can also control sprouting but can be used as a stand-alone sprout suppressant only in situations where storage is short-term and sprouting risk is relatively low. Nevertheless, it can give useful early control prior to application of other treatments.

Spearmint oil

Spearmint is an essential oil that can be applied as a hot fog to remove sprout growth. It is a volatile product, so care is required in the management of the store to prevent loss of chemical and to manage sprout control costs. Keep stores closed immediately after application; refer to best practice guidance for use of the product. Minimise exchange of external air for cooling and, especially, for store flushing where possible. Multiple applications may be required as part of a treatment programme. Consider use of a residual product such as MH before spearmint is applied as combination treatments have performed better (and synergistically) in AHDB trials.

Volatile products

Management of the new generation of volatile chemicals like ethylene and spearmint oil, which are easily lost from the store, requires a different emphasis on potato store management. Stores will need to be kept closed for longer after application to allow products to distribute. Excess use of outside air for ventilation or flushing will increase costs and reduce efficacy. If ambient air is a significant component of the ventilation regime, or would be needed to control rots, ensure a non-volatile product such as maleic hydrazide is included in the sprout control plan.

Checklist

Chemical options

✔ CIPC no longer available from 2020 harvest

✔ New products are volatile; seal stores well

✔ Minimise unnecessary air exchange

Low temperature

✔ Offers sprout control for fresh market

✔ Ensures airflow is optimised

✔ Keeps gradients to a minimum

Integrated sprout control

✔ Essential for affordable suppression

✔ Consider more dormant varieties

✔ Possible synergies

Other alternatives

Several other active ingredients are in use elsewhere in Europe and North America. These may become available in the UK in the future, subject to meeting requirements for approval. These include 1,4-dimethylnaphthalene (DMN sold as 1,4 Sight®), orange oil (Argos®), 3-decen-2-one (SmartBlock®) and clove oil.

Figure 29. Hot fog application of sprout suppressant using an electrical fogger

Heating

Heat may be used in a potato store for two primary purposes. The first is to increase the drying capability of ambient air. The second is to warm crops to enable them to be handled mechanically.

Heat to enhance drying

This is a relatively new technique where gas heaters (Figure 30) are fitted to ambient stores to provide drying capability within stores for use in cold and wet conditions. Adding controlled heat to the drying air increases the moisture-carrying capacity of the air, enabling the wet crop to be dried much more quickly than would otherwise be possible.

Figure 30. Gas heater

Courtesy of Pellcroft Engineering Ltd

The technique requires careful use to ensure that combustion by-products are flushed from the store.

Warming to reduce the risk of damage

Potatoes graded below 8°C are susceptible to impact damage, splitting or bruising. Any wounds that result will heal slowly at cooler temperatures and may make a crop unsuitable for market. To minimise tuber damage and speed up wound healing, particularly for disease control, it is recommended that crops below 6°C are warmed before grading.

To warm potatoes to 10°C, the warming air should also be at 10°C. The rate of warming is dependent on the flow of air between the tubers. If boxes of potatoes at 3°C are placed in a grading area at 10°C, natural, convective ventilation will warm them up in about four days. However, if air is forced through the boxes, the rate of warming will increase with the rate of airflow. At a delivered airflow rate of 0.8 $m^3/s/t$ (around 0.4 $m^3/s/t$ through the potatoes, after leakage is taken into account), warming a crop by 6°C will take 10–12 hours. But if the crop temperature is below the dew-point of the warming air, the whole process is extended. This is because water vapour in the air will condense on the crop. This moisture will then need to be dried, cooling the potatoes by evaporation, before the crop starts to rewarm. Warming occurs progressively in each box, like a drying front, with the warming front moving vertically in letterbox warming systems and from side to side in suction wall systems.

Warming systems

Heated air can be delivered either by forced delivery (blowing) or extraction (suction). In blowing systems, heat can be fed into the fan to bring the temperature of the warming air up to 8–10°C. Warming can be done within the cold store or in a non-heated building. In suction systems (Figure 31), the air being sucked into the crop needs to be warmed to 8–10°C, which means the atmosphere surrounding the crop being warmed must be kept at this temperature.

Allowing boxes to warm naturally over four days in a building kept at 8–10°C is the simplest way of warming, but this requires a buffer storage area four times the daily grading rate. If the crop is below the ambient air dew-point temperature, condensation may form on the crop, extending the warming time and exposing the damp potatoes to infection by disease. Forced warming systems such as the letterbox, suction wall or drying tent, which take a night to warm and 24 hours to recover skin moisture, require a warming area twice the daily rate of grading.

Figure 31. Suction warming system

Thumbnail cracking

When ventilating the crop with warm air, tuber skins lose moisture. This makes the skins inelastic and more liable to tearing when rehandled, giving rise to thumbnail cracking damage (Figure 32). In rapid-warming systems, skins should be given 24 hours to recover and rehydrate, prior to grading.

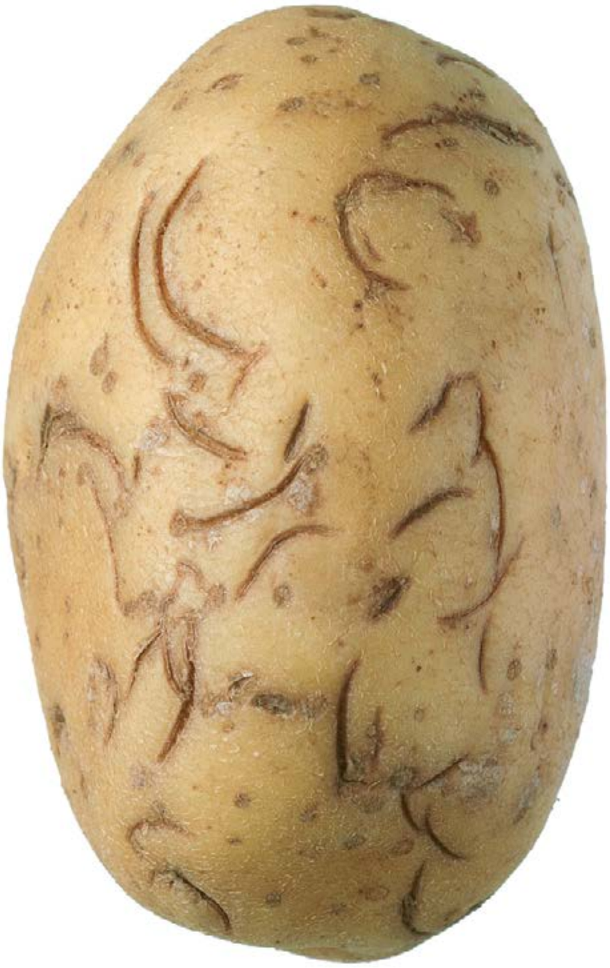


Figure 32. Thumbnail cracking

Checklist

Enhanced drying

✔ Adding heat can improve ambient drying capability

✔ Use in cold, wet seasons

✔ Requires care

Warming

✔ Reduces handling damage

✔ Don't overheat!

✔ Skin recovery key to avoid 'thumbnail' cracking

Store monitoring and quality assurance

Store diary

It is important to keep a store diary to record general store management information related to all the stocks held within the store. This will include major events such as loading or a chemical application and regular store inspections for condensation, dehydration, rots or blemish diseases. Where detailed individual stock records are kept, it is unlikely that they and the store diary will come together, unless there is some system set up to link the two. This can be resolved by keeping a detailed record or plan showing where each stock is located in the store. Inspection information can then be linked to stocks located in the problem areas.

New systems are becoming available to help the store manager to keep records more easily and for these to be available for quality assurance and traceability purposes at a later date.

Store monitoring

Store temperatures and controls should be checked daily. Temperature information is the most critical and a simple log of key probe readings can be kept manually or printed off daily. It is also useful to know how long the hardware has actually been running. Hour meters can be easily fitted to most equipment to provide this information. Stocks of potatoes should be checked weekly.

Many store-control systems now offer facilities to log information electronically. Computer-based control is also commonplace. Ensure the output is in a clear, easy-to-interpret format for the operator to use and understand, so errors are avoided. Make good use of user-friendly features such as touchscreen operation, graphical-user interfaces, web-based data portals and text alerts.

In addition to routine monitoring, there should also be procedures in place to assess the crop regularly and in relation to the specific requirements for the intended market.

Within the limitations of access to the crop in store, try to take adequate samples to ensure they are representative of the crop. If sampling from the top of the store is required, permanent ladders and walkways should be fitted to allow this to be done in safety.

Quality assurance

Potato production and storage is increasingly subject to quality assurance procedures, such as Red Tractor Farm Assurance, which include traceability, care for the environment and minimisation of risk to the consumer. Good record-keeping is also a benefit to management, as it can quickly identify weak points in a production system. Recording systems should be designed so that all of the information on a batch of potatoes is consolidated, enabling the reasons for any problem to be more rapidly identified. All actions taken should also be recorded on the log for that batch.

Checklist

Traceability

✔ Keep a diary of key events for each stock

✔ Record daily temperatures and fan use

✔ Chemical application

✔ Store servicing

Seed passports

✔ Record key information

✔ Disease levels pre-grading

✔ Fungicide use

Seed passports

Since many diseases on crops can have origins in the seed used, seed passports are increasingly being recommended. While husbandry factors such as date of planting and lifting are useful, a disease assessment of stock before grading is essential.

- Provide all seed with seed passports, including key agronomic dates, plus variety, grade and size
- Record disease levels before grading
- Record seed treatment (if any)
- Record temperature on dispatch
- Send leaflet with load, detailing action to be taken by grower on receipt

Servicing of store equipment

Regular servicing of store equipment reduces the risk of breakdowns, which can seriously compromise quality if they occur. It is recommended to ensure that all key equipment is serviced and checked annually. If manufacturer servicing is not possible, verify temperature-recording equipment against a reliable handheld reference thermometer.

Keep service records safely as it is important to be able to demonstrate due diligence in the management of the store, especially if there is a need to demonstrate legal compliance or if there is a contractual problem affecting the quality of the crop.

There are a significant number of regulations that cover health and safety, which are likely to apply in and around the potato store. Store owners, operators and employees working in potato stores must do everything possible to ensure their own safety and the safety of others. The easiest way to do this is to complete a risk assessment.

Risks in stores

Specialist help is available to advise on the risk assessment process in detail, but further guidance can be obtained, in the first instance, at **hse.gov.uk/risk**

When assessing risk, it is best to keep matters simple wherever possible, to ensure any measures to improve safety are followed. So, the questions used to identify the risks – and what steps are being taken to minimise those risks – should be straightforward. If measures are inadequate, additional controls may be required. Remember: not implementing preventive measures simply to save time or expense is not acceptable in a situation where safety is compromised.

Risk assessment is a statutory requirement as part of health and safety legislation. It is relatively straightforward to make and record an assessment of risks in each store. Risks that commonly occur in a potato store include:

- Working at height
- Slips and trips
- Lone working
- Carbon dioxide accumulation
- Chemical use, including pest control
- Electric shock
- Lighting
- Vehicle movement
- Box stacking
- Dust exposure

An important aspect of the risk management process is the feedback it provides, so if a particular risk is measured and continues to present problems, it can be re-evaluated and further measures taken to minimise it (Figure 33).

Working at height

A significant piece of legislation to impact potato storage practice was the Work at Height Regulations 2005. Potato storage is not deemed to be a short-term activity, so one of the main changes resulting from these regulations was the ban placed on the use of long ladders in stores. While a ladder can still be used for temporary access, such as changing a light bulb, using a ladder for regular access to the top of a store over two metres high is not legal. If access to the top of the potatoes is required, an alternative means of access must be provided (e.g. stepped ladders as in Figure 34). Once on top of the stack, it is also necessary to provide a physical barrier to alert someone to any gaps between boxes or proximity to the edge.

Figure 33. PDCA management cycle

Lone working

Irrespective of the measures taken to address health and safety, accidents can still happen and this can be a significant risk in potato stores, where there is a high degree of lone working.

Remember that mobile phones seldom work well inside stores, so, if working alone, consider one of the following alternatives:

- Tell someone where you are going and how long you will be
- Place signs on doors to alert others that someone is in the store
- Use a tag system or tracking device

Carbon dioxide accumulation

Potatoes are living organisms and, as such, respire, consuming oxygen and producing CO_2. Be aware that in well-sealed stores, CO_2 can accumulate to dangerous levels, as high as 3%, if measures are not in place to flush regularly with fresh air. Watch for signs of high CO_2, such as breathlessness and dizziness, when in the store. The exposure limits are shown in Table 7.

Table 7. Working exposure limits

CO_2	8-hour day	15 minutes acute
%	0.5	1.5
ppm	5,000	15,000

Figure 34. Working at height on stepped ladders in a box store

Checklist

Actively address all key risks

✔ Plan, Do, Check, Act

✔ Keep good records

✔ Get help from **hse.gov.uk**

✔ Keep staff safe and healthy at work

Be aware of the main safety issues

✔ Lone working

✔ CO_2 build-up

✔ Working at height

✔ Food safety

✔ Electricity in damp stores

✔ Vehicle movement

Pest control

It is important where storing food products to have a robust system of pest control in place. Seal buildings to prevent rodent and bird ingress. Eliminate any sites of potential harbourage for rats and mice. If using rodenticides, follow the Campaign for Responsible Rodenticide Use (CRRU) Code of Best Practice. Further information can also be found in the **AHDB Rodent control on farms guide**.

The UK Rodenticide Stewardship Regime was developed by the Campaign for Responsible Rodenticide Use to meet the Government's high-level principles defined by the Health and Safety Executive.


AFI

Storage costs

For potato storage management, as with any business undertaking, it is important to understand the true costs involved. Some costs of storage are quite obvious, but others less so. Storage should always be undertaken for a specific target market, with a known expectation of the specification to which the crop is to be delivered.

During the storage period, take steps to verify routinely that this specification can still be achieved through regular sampling and quality assessment; this helps to avoid uncertainty or any unwanted surprises if the crop's condition changes in store.

Fixed and variable costs

Costs can be categorised generally into fixed and variable costs. Fixed costs may be thought of as costs which are incurred because the store exists, whereas variable costs are incurred by using the store (running costs).

Examples of fixed costs are:

- Depreciation to cover capital costs, including:
  - Storage building
  - Associated concrete to service the store
  - Dedicated power supplies
  - Ventilation/fridge equipment
  - Boxes
- Finance costs to cover borrowing (or loss of interest) on the money used for capital
- Building maintenance and repairs
- Building insurance

Typical depreciation periods would be 20–30 years for buildings; 10–15 years for fans and refrigeration systems and 8–10 years for wooden boxes.

Examples of variable costs are:

- Electricity
- Loading and unloading
- Store cleaning/hygiene
- Chemical treatments
- Equipment maintenance and repairs
- Crop insurance
- Crop monitoring and management
- Storage losses, e.g. weight loss; deterioration of quality in store
- Opportunity cost for delayed payment (i.e. payment after storage, compared with at harvest)

Checklist

Cost awareness

✔ Successful storage depends on it

✔ Measure key variable costs, e.g. electricity

✔ Don't exclude finance and opportunity costs

Use AHDB support tools

✔ Farmbench

✔ Storage Cost Calculator

AHDB analysis of energy consumption revealed a wide range of electricity usage across stores, with as much as 300% variation between stores of the same type (range 0.09 kWh/tonne/day to 0.27 kWh/t/d). Therefore, to obtain accurate running costs, it is important to have store-specific metering in place. Inexpensive metering can be installed using current transformer (CT) links onto most supplies.

AHDB has devised a **Storage Cost Calculator** which can be used to assist with storage analysis. Contact Sutton Bridge CSR on **0800 02 82 111** for further information.

FARMBENCH

Farmbench is a cross-sector enterprise benching scheme available for its levy payers to use for cost analysis. Further information is available at **farmbench.ahdb.org.uk**

	Processing
Market demands	Uniform and acceptable fry colour Low levels of rot and skin spot (peeling waste) Freedom from sprouting Dry matter appropriate for market Controlled use of sprout suppression
Management principles in-field	Plan to harvest mature crops before soil temperatures dip below 8°C Agronomy (e.g. canopy management, seed selection, planting density and nutrition) to contribute to achieving size and maturity that permits long-term storage
Store management: pre-holding	Maintain warm temperature at 10–15°C after harvest to ensure any damage is fully cured Only lower temperature very gradually (max 0.3°C/day) once curing is complete In crops at high risk of sweetening, keep temperatures high (10–13°C) for first weeks of storage (pre-conditioning), where disease levels and sprouting permit Monitor fry colours and sprouting regularly
Store management: holding	Holding temperature (range 6–11°C) depends on use, variety and storage duration. The lower end of the scale is appropriate for 6–9 month storage; the higher end should be used for shorter durations Daily, controlled flushing with fresh air required to prevent build-up of CO_2 It is imperative that sprouting is avoided (in preparation for sprouting, tubers will convert starch to sugars and fry colour will be adversely affected) and application of sprout suppressant (e.g. CIPC) will be necessary for long-term storage Following best practice guidance is essential to avoid exceeding maximum residue levels. Holding temperatures which are lower than recommended, often as a result of prolonged periods of low ambient temperature, can result in cold-temperature sweetening, which will affect fry colour
Unloading	Poor fry colour at this stage is usually the result of one of two things: • Low-temperature sweetening – this may be alleviated by reconditioning (storing at *c.* 15°C prior to unloading to increase respiration and 'burn off' sugars), although this is very variable and further advice should be sought on a case-by-case basis • Senescent (old-age) sweetening – this is largely irreversible

	Fresh/Pre-pack	Seed
	Bright, shiny skins Low levels of scuffing/damage Low levels of blemish disease Freedom from sprouting Minimal residues	Specific size requirements Low levels of disease Freedom from sprouting
	Plan to minimise time crop is in field to avoid disease development Bearing above in mind, agronomy to focus on achieving size and skin set that allows lifting to minimise damage Harvest when dry Minimise damage and bruising	Plan to harvest crops with minimal damage and follow procedures to keep crops dry Fungicide application (for control of disease in the daughter crop) can take place either at loading or unloading
	Curing and pull-down strategy depends on final market and likelihood of disease development In general, curing will be required for damaged crops or skin-spot-susceptible varieties, whereas it can be omitted if preventing development of silver scurf and black dot is essential Aim to pull down temperatures at *c.*0.5°C per day. Prevention of condensation is important	Seed crops will generally require dry curing Protracted loading period and multiple stocks/varieties in different physiological states mean condensation risk is high (high temperature differentials between stocks are common). Risks reduced by regular positive ventilation As access to stocks is often required throughout storage, individual letterbox 'lanes' that can be switched on and off are preferred
	Holding temperatures vary from 2–5°C, depending on variety, market, storage duration and fridge capabilities A sprout suppressant will be required in warmer-temperature stores Ethylene is an option for fresh market: introduce treatment gradually to minimise any stress on the crop. Consult with your ethylene specialist prior to use	Prevention of sprout growth is important and requires the use of refrigeration, especially for storage after Christmas A holding temperature of 3°C is often used to hold crops through to when seed is removed from store in the spring Airflows may differ from fresh storage because seed is generally small and packs together more tightly within a box As grading takes place, ensure main doors within refrigerated holding store stay closed whenever possible to reduce the risk of condensation
	Aim to warm crop (>8°C) before unloading to reduce damage Warmed crops should be stood to equilibrate for a day; this allows skins to become more elastic and reduces 'thumbnail' cracking	Aim to warm crop (>8°C) before unloading to reduce damage Warmed crops should be stood to equilibrate for a day; this allows skins to become more elastic and reduces 'thumbnail' cracking

Diseases and defects


Silver scurf


Black dot


Skin spot


Common scab


Powdery scab


Black scurf


Bacterial soft rot (right, rinsed)

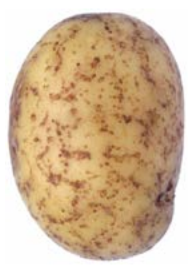

Dry rot


Gangrene


Growth cracks


Blackheart

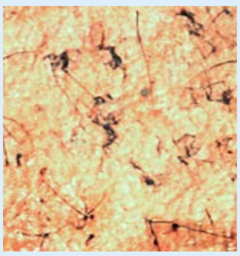

Anthocyanin


Potato cyst nematode (PCN)


Bruising


Stem end discolouration

Silver scurf or black dot?

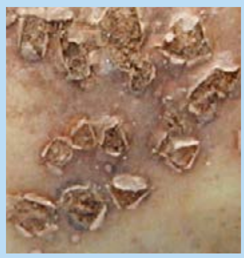


Identifying **silver scurf** by its silvery sheen is not reliable. At 10x magnification, with a hand lens, seeing short black thread-like structures definitely is. However, they do wash off very easily.

At the same magnification **black dot** appears as small, dispersed, black dots, sometimes as small as a skin cell. They are never dislodged by washing.

Common or powdery scab?

Common scab shapes vary widely and can both protrude from or crater the surface. They frequently coalesce into giant scabs. Angular edges and star-like cracking can sometimes be seen.



Powdery scab lesions are more uniform in shape and are generally small, round eruptions through the skin, which mostly remain discrete. A shallow depression forms in the flesh.

Rhizoctonia distortion

Violet root rot

PVY^{NTN}

Pit rot

Spraing

Late blight

Pink rot

Pythium

Internal sprouting

Hollow heart

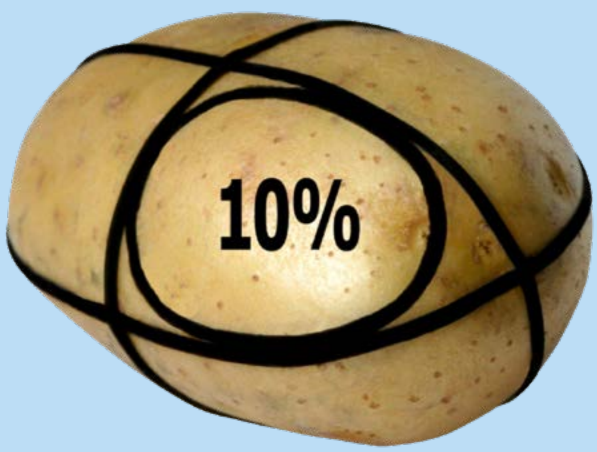
Internal browning

Mechanical damage

Slug damage

Surface area

To assess blemishing, it is useful to visualise what 10% of a tuber's surface area looks like.
Take a marker pen and draw three opposing equators on a potato, dividing it into eight triangles. A large circle drawn inside the triangle is about 10%.



Sampling

To choose an appropriate sample size, it is useful to set a threshold incidence, above which a load would be rejected. In the table, the minimum number of tubers required to detect an unacceptable tuber (95% of the time) is shown for a range of thresholds. Accurate estimation of the level of disease or defect requires sampling **three times** as many tubers at the chosen threshold. Samples must be representative of the whole crop.

Table 8. Sample sizes for 95% confident defect detection

Maximum permitted defect threshold %	Minimum sample to detect defect
20	15 tubers
10	30 tubers
5	60 tubers
2	150 tubers
1	300 tubers

Dew-point chart

The dew-point temperature of air, based on its temperature and relative humidity. Use this dew-point table to determine condensation risk.

Temperature* (°C)	Relative humidity (%)													
	60	62	64	66	68	70	72	76	80	84	88	92	96	100
20	12.1	12.6	13.1	13.6	14.0	14.5	14.9	15.7	16.5	17.3	18.0	18.7	19.4	20.0
19	11.2	11.7	12.2	12.6	13.1	13.5	13.9	14.8	15.5	16.3	17.0	17.7	18.4	19.0
18	10.3	10.7	11.2	11.7	12.1	12.5	13.0	13.8	14.6	15.3	16.0	16.7	17.4	18.0
17	9.3	9.8	10.3	10.7	11.2	11.6	12.0	12.8	13.6	14.3	15.0	15.7	16.4	17.0
16	8.4	8.8	9.3	9.7	10.2	10.6	11.0	11.8	12.6	13.3	14.0	14.7	15.4	16.0
15	7.4	7.9	8.3	8.8	9.2	9.7	10.1	10.9	11.6	12.4	13.1	13.7	14.4	15.0
14	6.5	6.9	7.4	7.8	8.3	8.7	9.1	9.9	10.7	11.4	12.1	12.7	13.4	14.0
13	5.5	6.0	6.4	6.9	7.3	7.7	8.1	8.9	9.7	10.4	11.1	11.7	12.4	13.0
12	4.6	5.0	5.5	5.9	6.3	6.8	7.2	8.0	8.7	9.4	10.1	10.8	11.4	12.0
11	3.6	4.1	4.5	5.0	5.4	5.8	6.2	7.0	7.7	8.4	9.1	9.8	10.4	11.0
10	2.7	3.1	3.6	4.0	4.4	4.8	5.2	6.0	6.7	7.5	8.1	8.8	9.4	10.0
9	1.7	2.2	2.6	3.0	3.5	3.9	4.3	5.0	5.8	6.5	7.1	7.8	8.4	9.0
8	0.8	1.2	1.7	2.1	2.5	2.9	3.3	4.1	4.8	5.5	6.2	6.8	7.4	8.0
7	-0.1	0.3	0.7	1.1	1.5	2.0	2.3	3.1	3.8	4.5	5.2	5.8	6.4	7.0
6	-1.0	-0.6	-0.2	0.2	0.6	1.0	1.4	2.1	2.8	3.5	4.2	4.8	5.4	6.0
5	-1.8	-1.4	-1.0	-0.7	-0.3	0.0	0.4	1.2	1.9	2.5	3.2	3.8	4.4	5.0
4	-2.7	-2.3	-1.9	-1.5	-1.2	-0.8	-0.5	0.2	0.9	1.6	2.2	2.8	3.4	4.0
3	-3.5	-3.1	-2.7	-2.4	-2.0	-1.7	-1.3	-0.7	-0.1	0.6	1.2	1.8	2.4	3.0
2	-4.3	-4.0	-3.6	-3.2	-2.9	-2.5	-2.2	-1.5	-0.9	-0.3	0.2	0.8	1.4	2.0
1	-5.2	-4.8	-4.4	-4.1	-3.7	-3.4	-3.0	-2.4	-1.8	-1.2	-0.7	-0.1	0.4	1.0

*Dry bulb temperature

Source: CIBSE

Example 1:

If air (dry bulb) temperature is 15°C and its relative humidity is 70%, the dew-point temperature of that air is 9.7°C

Example 2:

To determine condensation risk, for example:

> If external air at 8°C and 84% RH enters a store, will it condense on potatoes with a temperature of 5°C?
>
> Check dew-point of air at 8°C at 84% RH. It is 5.5°C
>
> Therefore, the air will condense on any surface with a temperature below 5.5°C and so condensation on the crop will occur.

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Glossary

Air mixing/blending Mixing or blending of recirculated and ambient air controlled by regulation of the duct temperature

Air-on/air-off TD Temperature difference (TD) between air coming on and off a fridge coil

Ambient air Air external to the building structure

Anaerobic conditions Where no oxygen is present

Blemish diseases Diseases which cause unsightly marks on the skin of the tuber

Bloom Reflective shine on tubers

Composite panel Factory-made insulation panel with a core made of polyisocyanurate (PIR) injected between two metal skins

Crop set-point Target or desired crop temperature

Curing period See wound-healing period

Dead band Tolerance either side of a crop set-point

Dew-point Temperature at which water vapour in air will start to condense

Differential Difference in temperature between one area in a store and another, e.g. crop/ambient air differential would be the difference between the temperature of the crop and air drawn from outside

Disease expression Display of visible disease symptoms

Disease infection Entry into the flesh of the tuber by bacteria or fungus

Dormancy Period between tuber initiation in the soil and growth of sprouts

Dormancy break When 50% or more of tubers have sprouts of 3 mm or more in length

Duct lower limit Minimum allowable temperature of air in main duct

Fridge TD Temperature difference (TD) between air coming onto coil and evaporating gas temperature within the fridge coil

Hot box Insulated cabinet warmed to 32–36°C, and humidified with water, used for samples of potatoes to speed expression of bruising or to accelerate rotting

Inoculum Infective agents of disease, e.g. fungal spores, bacteria, etc.

Interstitial condensation Condensation forming within the building structure

Latent heat of evaporation (Hidden) heat required to change water from liquid phase to vapour phase with no increase in its temperature (2.4 MJ/kg). Half of cooling of potatoes with cool air results from heat removed by evaporation

Lateral (duct) Secondary delivery duct off main air duct, usually beneath a bulk pile

Mummify The process of drying a rotten tuber to a dry shrivelled mass

Periderm Corky outer skin layer of potato

Relative humidity (RH) Mass of water vapour in air at a defined temperature, compared with the maximum vapour it can hold at that temperature, expressed as a percentage

Saturation	Point where air contains the maximum mass of water vapour which can be held per unit mass of air at any given temperature (=100% RH)
Soft rots	Bacterial wet rots
Split-grading	Separating tubers into two or more size fractions, usually at harvest
Stack condensation	Condensation forming within the crop
Structural condensation	Condensation forming on the building structure
Suberisation	Laying down of the chemical suberin between damaged surface cells of tuber as first part of periderm formation in the natural wound healing process
U-Value	Heat conductivity of a building material (W/m^2.°C). The lower the value, the better the insulation
Wet rots	Tubers where the flesh has been invaded by disease organisms to form a liquid mass with little structural strength. The wet mass collapses on unaffected neighbouring tubers, providing inoculum and anaerobic conditions, which can lead to further rotting
Wound-healing period	Period for wounds on crop to heal, to form a barrier against disease ingress to the flesh of the tuber

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