

Seed storage guide



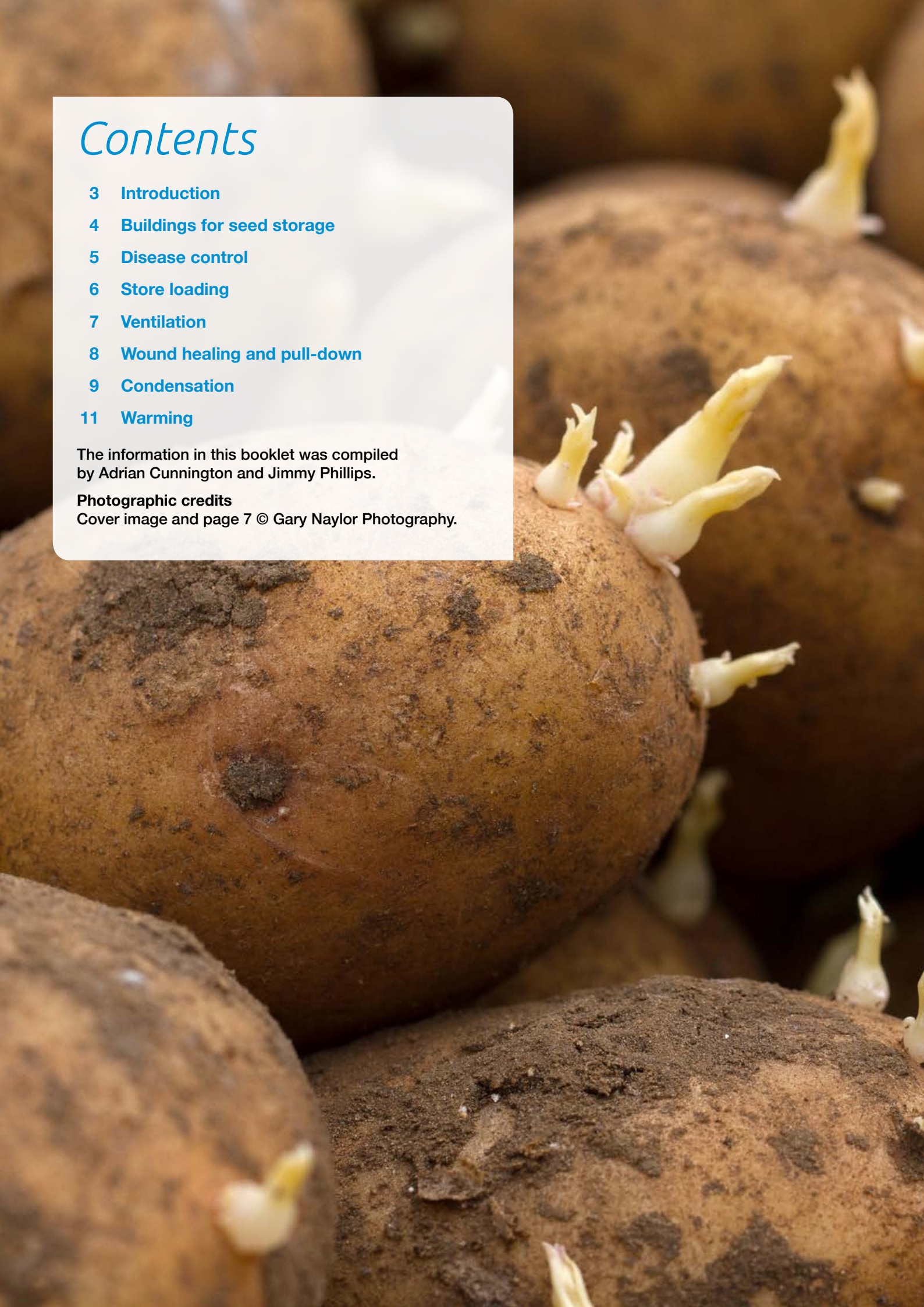
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The information in this booklet was compiled by Adrian Cunnington and Jimmy Phillips.

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Introduction

Seed storage is a key element of modern-day potato production, aiming to produce high-quality, clean seed 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 is delivered the quality for which they are prepared to pay for the crop in question.

This guide seeks to steer the store manager through the various steps of seed store management but it should not be read in isolation. It should be remembered that the crop in the store comes 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 seed age on dormancy break and crop emergence. Another major factor in storage success is whether the crop has an adequately 'set' skin, as, without this, storage of potatoes is seldom straightforward.



Adrian Cunnington
Head of Crop Storage Research

Buildings for seed storage

A well-sealed and insulated seed potato store will allow the crop to be kept at a stable temperature largely unaffected by diurnal (daily) variation in ambient conditions. It will help maintain a relative humidity of 80–95% to minimise tuber weight loss; it will also allow crops to be stored free from condensation in changeable weather conditions. Seed storage is usually undertaken in boxes, although bulk bags are suitable for short-term storage and for transport.

Passively ventilated box storage is often difficult to ventilate uniformly; this is much less of a problem where a positive ventilation system is fitted. For seed production, box storage means it is relatively easy to separate different stocks and provides more flexibility for crop movement and marketing. Depending on their size, age and quality, boxes can be stacked up to 8 high.

Buildings need to be fitted with controlled ventilation to allow crop respiration heat to be removed and a crop to be dried and cooled. Fans are best positioned to drive a flow of air through the crop (positive ventilation) 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, which is important to manage condensation risk. Airflow should be as uniform as possible throughout the store, to give even drying and maintain 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 graduated outlets or suction slots to ensure similar airflow across the whole store.

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, more so than it is for general purpose buildings. Maintaining temperature 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 from outside has to be removed by ventilation or refrigeration, which adds to weight loss and running costs.

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 commonplace. These are used for newly built stores at thicknesses of up to 120 mm. A light-coloured, reflective, external surface will reduce unwanted solar radiation gains.

Fabric or door leakage to wind-induced ventilation reduces the effectiveness of the store. A specific air leakage test for stores has been developed to assess buildings' relative performance. This uses a fan system (pictured) 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 (Pa). An AP50 of $\leq 3\text{m}^3/\text{h.m}^2$ is regarded as an acceptable standard for new buildings. Existing buildings, even good ones, may not achieve this; for these, a threshold of $\leq 10\text{m}^3/\text{h.m}^2$ is more realistic.

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



Figure 1. Air leakage assessed by forced introduction of air and monitoring pressure change

Disease control

Controlling disease is a fundamental component of seed storage management. Few diseases originate in store; there are two primary sources, seed or soil. However, many of the disease problems affecting seed 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 health status and market value.

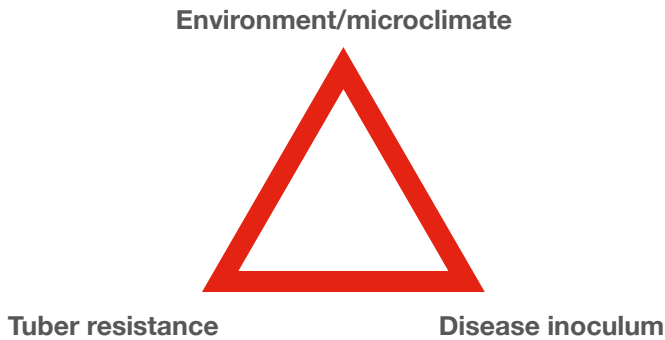


Figure 2. Disease triangle: if all three factors are satisfied, disease will result

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

- The amount of disease inoculum, usually fungal 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 desiccation is an important aspect of disease control

Store management influences this interactive relationship, particularly in relation to the microclimate around the tuber, to control diseases during storage.

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 so 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 haulm removal/desiccation 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

If total removal of viable spores is required, e.g. for high health crops, a combination of vacuuming and disinfectant can be used, especially 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, as they are deactivated by organic matter. Otherwise, clearing dust and rogue tubers will normally remove the majority of disease inoculum present. Leaving boxes outside will allow light to kill any remaining viable spores. However, if wet rots have been a problem in the previous season, steam cleaning of the boxes and any badly affected areas of the store is highly recommended.

Notifiable diseases

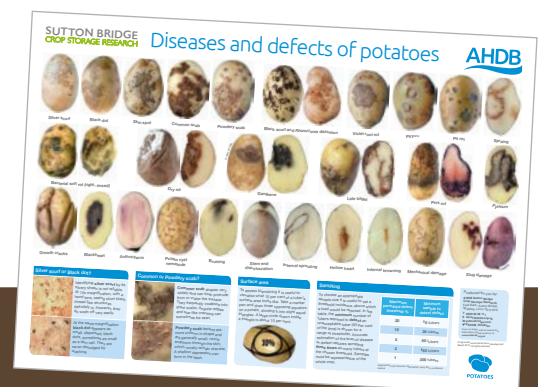
Some diseases are not indigenous in Britain and their establishment would affect the long-term viability of the potato industry. If symptoms of either **brown rot** (*Ralstonia*) or **ring rot** (*Clavibacter*) are suspected, immediate contact with local Government offices or the Plant Health & Seed 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



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



Preventative measures exist through the AFS **Safe Haven** certification scheme; to learn more about this, go to potatoes.ahdb.org.uk/safehaven



Order a poster at:
ahdb.org.uk/knowledge-library/diseases-and-defects-of-potatoes-poster

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 health status/quality, likely storage periods and market expectations, to the storage available, to make management as effective as possible and maximise returns.

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.

Try to load stores within a week and an 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, there can be benefit from dividing a store into two smaller sections. Temporary curtains can be used as a cost-effective option for this.



Figure 3. An air separator curtain boosts ventilation efficiency significantly by preventing short circuiting

Field sampling will identify stocks with rots (e.g. blackleg or blight), blemish disease, or slug damage, while warm storage (>20°C) of subsamples before harvest can help to identify any borderline rotting prior to loading. If crops have been rained on during harvest, these should be stored separately to prevent any risk of contamination. Crops with 1–2% rots should also be set aside. Affected material should be positively ventilated continuously for 4–6 weeks until any rots are mummified. Crops with over 2% rot should not be stored.

During store loading, temperatures 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 $\pm 4^\circ\text{C}$ 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, if 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.

The store's box stacking arrangement is crucial to achieving optimum air distribution and uniform crop temperatures. Stacking for positively ventilated systems is usually predetermined by the design, although may require the fitment of covers or bungs to work correctly. Lateral suction (e.g. 'Aspire') systems are effective systems for crop drying and even pull-down.

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/fridge. 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 or plenum (pictured) around the fan discharge is recommended to optimise airflow. Recent research using airflow modelling suggests this can at least double the quantity of air reaching the far end of the store. In long buildings, overhead distribution fans, which assist the roll of air within store, can help to even crop temperature and minimise potential condensation.

If it is considered preferable to leave longitudinal gaps between columns of boxes to facilitate flexible unloading, make sure these gaps are no wider than the size of a pallet slot (typically 100 mm) to prevent them becoming short circuits for the airflow.

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.

If an air mixing or blending system is fitted, a minimum desired duct air temperature can be set 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 nor create too large a differential (typically $<4^{\circ}\text{C}$) across the crop.

Airflow rates for box stores are, typically, designed to be about $0.015\text{--}0.02\text{ m}^3/\text{s}/\text{t}$, although a trend towards use of higher volumes, as much as $0.04\text{ m}^3/\text{s}/\text{t}$, has been observed in the past decade, especially for drying. This has been supported by the availability of inverters to regulate fan speeds so a higher rate can be

used for initial drying and then a more modest rate (with lower running costs), once the store has been stabilised for holding.

In space-ventilated 'overhead throw' stores, the 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. The airflow stated above is, therefore, primarily to aid distribution, rather than that required to remove the transferred heat, but, nevertheless, overall efficiency of these stores is poor.

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.

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 about 8–10 boxes from the duct. The lateral suction system (pictured) is one such solution and this is now available with automated sheeting rollers to eliminate safety concerns with their fitment.



Figure 4. Lateral suction is a positive ventilation option for box storage

Wound healing and pull-down

Wound healing (sometimes called ‘curing’) is a required element of modern seed potato production, even when harvesting directly into boxes. The 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 and it is only when ambient temperatures fall below 5°C that the time required for curing will normally be a concern. When crops are harvested cold,

wound healing can take as much as two weeks to complete initial suberisation, leaving the crop exposed to the risk of wound pathogens such as skin spot (*Polyscytalum*) and gangrene. Under most other circumstances, wound healing will happen by default during the normal pull-down period.

When reducing the store temperature, a relatively small differential may reduce the cooling rate, but a larger differential 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.



Figure 5. Handle seed carefully to prevent tuber and sprout damage

Condensation

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 and severely jeopardise the quality of a seed lot.

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. For example, if 1 m³ of air at 4°C is at 50% RH, it contains 3.2 g of the maximum 6.4 g/m³ 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 exceeded. Cool air coming into contact with warmer potatoes is not a condensation risk.

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.

Only ventilate with air warmer than the crop if the crop temperature is above the air's dew point temperature. Dew point risk can be calculated using the table at the end of this section.

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. Good insulation and maintaining air movement in the roof space will reduce the risk of structural condensation.



Figure 6. Failure to allow through-airflow under and around bags can increase the risk of condensation

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.

Warming

Warming is important, prior to handling, to minimise the risk of damage to seed. Note the requirements for avoiding condensation (page 9), but aim to warm crops to at least 8°C before handling operations commence.

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. Using suction, the air being pulled 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 that will hold four times the daily grading tonnage. If the crop is below the ambient air dew point, condensation may form on the crop, extending the warming time and exposing any damp potatoes to infection by disease. Forced warming using letterbox, lateral flow or drying tent systems, which take a night to warm and 24 hours to recover skin moisture, requires a warming area roughly twice the daily rate of grading.

Note that, 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. In rapid warming systems, skins should be given 24 hours to recover and rehydrate, prior to grading.

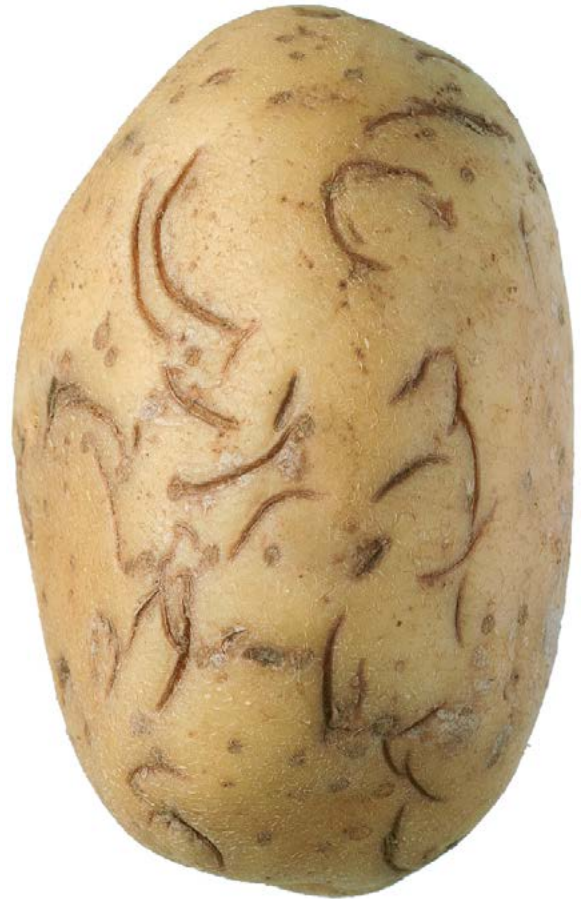


Figure 7. Thumbnail cracking

SUTTON BRIDGE

CROP STORAGE RESEARCH

AHDB

Sutton Bridge Crop Storage Research

East Bank
Sutton Bridge
Spalding
Lincolnshire
PE12 9YD

Freephone: 0800 02 82 111

E sbcsr@ahdb.org.uk

W suttonbridge.com

Produced for you by:

AHDB Potatoes

Stoneleigh Park
Kenilworth
Warwickshire
CV8 2TL

T 024 7669 2051

E comms@ahdb.org.uk

W ahdb.org.uk

 [@AHDB_Potatoes](https://twitter.com/AHDB_Potatoes)

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