Know-how for Horticulture™

Seed potato handling and storage - implementing best practice

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Serve-Ag Research Pty Ltd

Project Number: PT01030

PT01030

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Know-how for Horticulture™

PT01030: Potato Seed Handling and Storage – Implementing Best Practice

FINAL REPORT

and

DRAFT MANUAL

SEED POTATOES

BEST PRACTICE HANDLING AND STORAGE

Prepared for

Horticulture Australia

By

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13 December 2004

PT01030: Potato Seed Handling and Storage – Implementing Best Practice

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Disclaimers

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Media Summary

A survey of current Australian practices and a review of international information have resulted in a manual for potato seed handling and storage management, which includes handling, hygiene and disease prevention information. The aim of preparing this manual was to:

- Compile available information on potato seed handling and storage into one easy to use document;
- Improve the understanding of seed potato handling and storage requirements within the industry, and instigate improvements based on an awareness of the most important factors affecting seed performance;
- Provide some practical, ready to use guidelines.

The project team surveyed seed potato storage operations and persons associated with the seed potato industry (processing and ware potato growers, consultants, IDO's, processors) in Victoria, Tasmania, New South Wales, South Australia and Western Australia. Store visits and numerous discussions with a wide range of people provided a good understanding of the variability of seed potato handling chains from seed potato paddock, over several handling, transport and storage steps to the next seed or commercial paddock.

The manual focuses on the subject areas mentioned below to give guidance on the major issues identified during industry consultation.

- What can go wrong - risks associated with different activities;
- How to prevent problems, risk management – how to prioritise and focus on issues that potentially cause the biggest losses/problems;
- What to monitor to identify and prevent problems;
- Specifications - the optimum storage and handling conditions to aim for, and how to go about it;
- How to get as close to specifications as possible under given operational circumstances.

The manual was designed to include relevant, understandable information for each operator, which is easy to locate. A major consideration in preparing a user-friendly manual was that different types of operators in the seed potato handling chain might perform the same activity, depending on how a seed production area has developed. The idea was that all operators could use the manual as a look-up guide for certain steps without the need to read the entire publication.

The guidelines and references cover the following operational steps: harvest, holding in the paddock, transport and intake, curing, storage, grading, cutting, and seed transport from store to commercial or seed grower.

The above operations are summarised in brief checklists to highlight the most important considerations for each step and operator. Self-assessment tables for different operators involved in seed potato handling and storage are included to allow them to prioritise areas of improvement in their part of the chain. Optimum conditions and potential risks for each operational step are listed in an easy to follow table format. Further references, diagrams, photos and assessment sheets are available in separate sections of the manual in support of the specifications and descriptions in the operational tables. A glossary, a troubleshooting guide and a list of reading material are included to complete the information.

Technical Summary

Seed potato handling and storage requirements have been researched extensively, especially in Europe and the USA. Research findings have been published in scientific, technical and grower journals. Most publications take for granted a high level of knowledge of plant physiology, technological awareness and easy access to state of the art technology. The amount of time it would take for single operators to gather and evaluate existing information form all its sources and adopt or adapt it to a specific operation is generally prohibitive.

A survey of current Australian practices and a review of international information have resulted in a manual for potato seed handling and storage management. It includes handling, hygiene and disease prevention information. It is designed so that it can be easily updated or extended. An emphasis has been placed on operational planning, documentation of desirable standards and technologies, record keeping, preventive /corrective actions, and the understanding of potential risks.

Relevant technological specifics described by different information sources have been included. They may not always be completely transferable to each different handling and storage chain component; however, the principle requirements of seed potatoes remain the same, and most technologies are adaptable to a wide range of situations. For this to occur, an effort has been made to present relevant information in a way that makes it easy to find and use for individual operators.

One of the prerequisites for this manual was to re-define “Seed Storage”. It was felt that industry and research focus mainly on crop production issues and the in-store period. Other seed life stages and issues receive less attention, even though they can have a significant influence on outcomes of handling and storage. We came to the conclusion that seed storage management starts at harvest and ends at planting. It includes planning, documentation and communication.

General industry concerns/requirements that have been addressed in the manual are summarised in the following points:

- The need for smaller seed tubers and more uniformity in tuber size and quality;
- Better storage practices needed by some operators;
- Better hygiene needed in some cutting operations;
- Effective disease management throughout the chain;
- Injury prevention (bruising, cuts, etc.);
- Greater understanding and control of physiological age (P-age) required;
- Better lines of communication needed between buyer and seller (eg. bin labels, ‘seed history record’);
- Timely information provided from commercial growers to seed growers/storers about requirements;
- Better traceability and information about seed history needed throughout the chain;
- Store operators need a better understanding of curing, store capacity, ventilation/airflow temperature and humidity effects on seed;
- Better transport conditions or control of conditions (temperature, condensation control) required.

The importance of seed curing was stressed in Holland and the US, although it was rarely mentioned as an issue of concern by the Australian industry. Little attention is paid to optimum curing conditions by most operators due to a lack of understanding of the importance of this phase and how to best provide a suitable curing environment.

There is a general need to better understand the accumulative loss of production potential caused by getting some important steps in the storage and handling process “not quite right”. The more important a factor, the greater the losses caused by errors. The earlier in the seed storage period the error occurs, the greater its effect.

The manual has been designed considering the above industry requirements and major operational steps in the seed potato handling and storage chain. It can be used as a look up guide for certain steps without the need to read the entire publication. The guidelines and references cover the following operational steps:

- Harvest, holding in the paddock, transport and intake;
- Curing, storage, grading, cutting; and
- Seed transport from store to commercial or seed grower.

The above operations are summarised in brief checklists to highlight the most important considerations for each step and operator. Self-assessment tables for different operators are included to enable them to prioritise areas of improvement in their part of the chain. Optimum conditions and potential risks for each operational step are listed in an easy to follow table format ('operations’ tables), outlining the following points for each step:

- Specifications, required standards / preventive action
- Potential risks / corrective action (if possible)

Further references, diagrams, photos and assessment sheets are available in separate sections of the manual in support of the information in the operational tables. A glossary, a troubleshooting guide, and a list of further reading material have been added to provide additional details on important specifications listed in the operations tables.

Introduction

This report contains the draft seed potato handling and storage manual, which we believe will provide useful guidance to operators in the seed potato handling chain. The chosen format should enable quick reference by various operators on selected issues; however, we believe that the draft should be reviewed by a number of people associated with the seed potato industry prior to final publication.

The current draft lends itself to both electronic and hardcopy publishing. In an electronic version, hyperlinks to References, Troubleshooting Guide, and Glossary, etc. in the 'Operations' tables will be useful for easy navigation. In a hardcopy, colour coding and or symbols, eg. for certain operators and / or steps, could be helpful. Terminology explained in the Glossary could be marked with a superscript G, eg. respiration[g] and physiological age[g], etc. Symbols would be explained in the Introduction, under 'How to use the manual'.

Some of the information, eg. the troubleshooting guide, could be translated into further tables and expanded on. The glossary could be extended to include other expressions used in the manual that not all operators would be familiar with. Some of the diagrams should be re-drawn to make them of a better, more uniform standard.

Although more photographs were taken during the industry survey, they were not considered suitable to illustrate the requirements for the manual now that the contents have been clearly defined. It will now be possible to target certain topic for photos and have them taken by a professional photographer.

Some of the contents of the Materials and Methods section of this report may be suitable to use in the introduction to the report.

Aims

- To compile available information on potato seed handling and storage into one easy to use document;
- To improve the understanding of seed potato requirements and instigate improvements based on an awareness of the most important factors affecting seed performance in different operations and production/handling chains;
- To provide some practical, ready to use guides.

This project does not aim to replace quality management systems or be a guideline for the development of a quality assurance scheme. However, the manual will include information that could prove useful for operators embarking on quality assurance accreditation.

Materials and Methods

How the manual contents were researched

Industry Survey

Seed potato operators in all states were asked a range of questions in semi-structured interviews to develop an understanding of current procedures and issues with current systems. The main topics addressed during visits to cool store operations are listed below under 'example of industry comments.

Information survey

Most of the information on best practices for seed potato storage and handling systems was sourced mainly from Holland, USA and Scotland. The publication 'Seed Potato Technology'[1], (Struik and Wiersema, 1999) deals with some pre-and post-store handling aspects, relevant to this project.

Discussions with seed potato store operators in New South Wales, Victoria, Western Australia and Tasmania, and the review of literature, resulted in a revision of the meaning of 'seed potato storage'. We believe that ***seed storage management*** *starts at harvest and ends when the seed is planted*. Therefore, we define the ***storage period*** as commencing with vine death and finishing at planting. The actual time in a cool store is only part of the storage period. The importance of pre- and post-store factors was highlighted in most publications and stressed by seed growers/storers.

Example from literature[2]: Yields of seed lots stored under a wide range of different conditions at the Potato Storage Research facility, Kimberly Research and Extension Center, University of Idaho, were generally not significantly different in any of three years of trials. Researchers concluded that differences in yield observed by commercial growers are often due to factors other than the storage environment. Previous work conducted at the Center had shown that the majority of the yield differences observed between seed lots was due to seed piece size at planting, and to bruising during improper handling of the seed lot when not in store.

Example of industry comments: Seed industry members believe that seed producers who store their own seed are able to create the correct storage environment. They mentioned issues such as supply chain management and communication (seed & ware potato producers), on-farm storage (by ware potato producers), seed grading, cutting and disease management, as having a major influence on seed performance in addition to in-store management.

The importance of curing conditions was stressed in Holland and the US, although it was rarely mentioned as an issue of concern by the Australian industry. It seemed that little attention was paid to optimum curing conditions by most operators due to a lack of understanding of the importance of this phase, and how to best provide a suitable curing environment.

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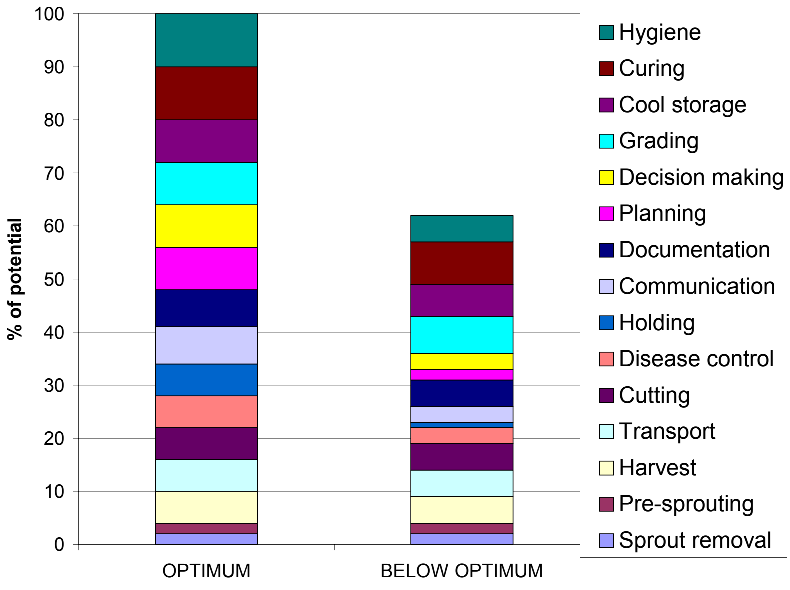
[1] Struik P.C., S.G. Wiersema, 1999; Seed potato technology. Wageningen Pers, Wageningen, The Netherlands

2 Kimberly Research and Extension Center, Kimberly

General industry concerns/requirements are summarised in the following points:

- Smaller seed tubers and more uniformity cut pieces (the larger the tubers the more cuts— the lower the yield potential)
- Seed of a higher, uniform quality required (need to define / measure internal quality)
- Better storage practices by some operators
- Better hygiene in some cutting operations (dust, spread of diseases)
- Effective disease management
- Injury prevention (bruising, cuts, etc)
- Greater understanding and control of P-age
- Better lines of communication and information flow between buyer and seller (e.g. bin labels, 'seed history record')
- Timely information provided from ware potato growers to seed growers/storers about requirements
- More information provided about seed to ware potato growers (traceability)
- Accountability and reliability throughout the production chain
- Need to better understand store capacity, ventilation/airflow/air exchange
- Need to separate intake, curing, grading and dispatch
- Need for good store stacking plans
- Better transport conditions (temperature, condensation control)

Generally, there needs to be a better understanding of the potential for accumulative loss of production caused by getting some important factors "not quite right" (refer to below graph illustrating the accumulative effect of mistakes). The more important a factor, the greater the losses cause by errors. The earlier in the seed storage period the error occurs, the greater its effect.



How the manual format was chosen

A lot of thought was given to the manual's design. Information has to be relevant to each operator in the chain, and be easy to understand and to locate within the manual. When consulting potential users of the final document, they liked the idea of:

- The inclusion of self-assessment and troubleshooting/hazard warning sections that allow operators to prioritise activities and improvements that will have the greatest effect on seed performance while it is in their care;
- The inclusion of preventative, corrective or alternative actions for times when the 'best practice' has not been or could not be followed;
- Colour coding or the use of symbols for different operators and activities;
- The use of tables, diagrams and photos;
- The inclusion of checklists, work instructions and record sheets that can be either copied or even removed, for display in the relevant area of the operation;
- The option of using the manual as a basis for developing or improving HACCP based QA systems;
- Explanations of essential physiological processes and diseases/disease prevention in an easy to understand format.

The manual deals with the following topics

- What can go wrong - risks associated with issues listed;
- How to prevent problems, risk management – how to prioritise & focus on issues that potentially cause the biggest losses/problems;
- What to monitor to identify and prevent problems;
- Specifications (which conditions to aim for and how to go about it);
- How to improve on priority issues and get as close to specifications as possible under given conditions (pick and choose options for existing storage/handling operations).

Appendices

Appendix 1 - Semi structured interview contents

1. Harvesting

a) What percentage of the incoming material is graded on the harvester?
b) Are any of the potatoes sprayed with fungicide on the harvester?
c) What percentages are bin loaded and bulk loaded?
d) What types of bins are used ½ tonne plastic, ½ tonne wooden, 1 tonne wooden, 5/7/8 tonne steel bins, 20-25 tonne bulk trucks?
e) Are the bins or bulk containers generally sterilised on the farm prior to dispatch?
f) Are the loads covered for transport?
g) Over what period does the harvest take place (for all farms serviced by the grading shed)?
h) What is the usual period of skin set?

2. Delivery

a) What level of information on the field stage of the crop is provided by the grower – ie. disease incidence, skin set period, problem areas in the field, etc?
b) What is the maximum period the potatoes stay in the bulk containers?
c) Is a consistent period of time allowed for wound healing after harvest?
d) Are the bins stored in a cool and well-ventilated area after delivery and before grading?
e) Is here any provision available for tuber drying should they be delivered wet?
f) From a hygiene perspective, how do you deal with material coming from a range of farms across the state?
g) Do you have a clean-down procedure in the delivery area?
h) Do you monitor temperature in the pre-grading storage area?
i) Are the bins protected from the rain in the pre-grading storage area?
j) Are the forklifts gas, diesel or petrol powered?
k) Are the bins covered while in the pre-grading store?
l) Is the pre-grading store concrete floored?

3. Grading - General

a) How many growers are serviced by this grading operation?
b) Over what geographical spread does the material come from?
c) How many graders are used?
d) How many staff does the entire operation employ?
e) Does the operation handle seed only or some commercial?

Appendix 1 - Semi structured interview contents (cont.)

3.1 Grading - Machinery

a) What material is the floor of the grading area made from?
b) What type of grader is used?
c) How old is the machine?
d) Does the grader use sizing belts, expanding rollers or other sizing equipment?
e) How are the potatoes loaded onto the grader, eg. creep belt hopper, bin tipper, direct from the truck, etc?
f) Are bin fillers with magic eyes used?
g) Are tuber counters used?
h) Does the grader brush the tubers?
i) What type of spray unit (for fungicide application) is used?
j) What are the major damage areas on the grader?
k) Are there any falls greater than 300 mm?
l) What types of rollers are used and what material are they made from?
m) Is there a particular area on the grader where the seed regularly becomes trapped?
n) How many people usually work on the grader?
o) What facilities are available for air extraction in and around the grading area?
p) How is staff protected from the fungicide spray?
q) Are the tubers dry prior to loading into bins?
r) Are the tubers sprayed on a belt or a roller table?

3.2 Grading - Protocols

a) Is a core temperature taken prior to grading?
b) Can the grower recommend / suggest a particular spray dependant on the conditions in the growing crop?
c) Worker safety – what protocols are in place – alarms, etc?
d) What are the resultant size grades and how does this equate to the cut grades?
e) What are the clean-down procedures (including timing) for the grader and the grading area?
f) What type of sterilant is used to clean the grader?
g) Are vacuums or brushes used to clean the floor?
h) Are pressure washes, hot water washers, or steam cleaners used?
i) After clean-down, what is the time delay before grading can be re-started?
j) What are the spuds graded into – grower's own bins, store's bins – and generally what type of bin?
k) Is any bin cleaning and / or sterilisation carried out at the grading facility?
l) Which chemicals are applied?

4. Curing

a) Is there a physical barrier between the grading area and the curing area?
b) What is the hygiene protocol for this area?
c) For how long and under what conditions (temperature, humidity, ventilation, etc.) are the tubers cured after grading prior to cold storage?
d) Is there a restricted access policy in this area?
e) Is the area positively pressured?
f) Are forklift wheel baths and personnel footbaths used?

Appendix 1 - Semi structured interview contents (cont.)

5. Cool storage

a) Who supplied the refrigeration units?
b) How is the cool store loaded – loaded then switched on, or switched on then loaded?
c) What is the pull down rate of cooling?
d) At what temperature is the cool store set?
e) What is the relative humidity in the cool store after pull down?
f) Is any form of humidification used?
g) Are any gases or tuber treatments, etc. (eg. Pirigene) used within the store?
h) What is the overall airflow per tonne of tubers?
i) How is the cool store vented?
j) What level of air exchange is achieved throughout the store (particularly at the back of the store)?
k) What monitoring apparatus is available within the store?
l) Is monitoring continuous or intermittent?
m) Can this information be downloaded to PC?
n) What alarms are in place?
o) Does the cold store have an automatic defrost cycle?
p) Do the cooler units drip water – how do you deal with this problem?
q) What are the size dimensions of the store?
r) How thick is the wall insulation and what is it made of?
s) How high are the bins stacked?
t) What gap is allowed between the bin rows?
u) What is the gap from the top box to the ceiling?
v) Is there any gas concentration data available for this cool store – O_2, CO_2, Ethylene, etc?
w) Are tuber core temperatures taken regularly?
x) How are different seed lots kept separate in the store – store floor plan?

6. Unloading the store

a) What is the procedure for unloading the store?
b) How do you deal with tuber condensation – what facilities are available?
c) What warm up program is followed – degrees per day, etc?
d) Who or what determines the order in which the store is unloaded?
e) Are seed lots mixed or kept separate throughout the entire process?

7. Cutting

a) When, in the storage period, do you cut the seed?
b) How do you treat seed prior to and after cutting?
c) Do you hand cut or machine cut?
d) What are your hygiene procedures?
e) What seed piece size you are aiming for?
f) What do you use as a seed treatment after cutting?

8. Dispatch and transport

a) How do you pack seed for transport?
b) How long does the seed stay in that bin/bag prior to and after transport?
c) Do you keep a sample back from each load?
d) What kind of documentation goes with the seed?

Appendix 2 - Draft Manual

DRAFT MANUAL

SEED POTATOES

BEST PRACTICE HANDLING AND STORAGE

Prepared by:

Doris Blaesing
Serve-Ag Pty Ltd

Table of Contents

Foreword

Why a seed handling and storage reference manual?

The Seed Potato Industry's Strategic Plan highlights that Australian seed potato handling and storage practices do not always result in seed that is performing to its potential.

Seed potato handling and storage requirements have been researched extensively, especially in Europe and the USA. Research findings have been published in scientific, technical and grower journals. Still, it is not always easy for seed producers and storage operators to access, evaluate and adapt this information from a wide range of sources.

The impact of a deviation from optimum handling and storage practices is often not fully appreciated. An understanding of 'deviation risks', i.e. the extent of potential losses due unsuitable practices and technologies, can help to prioritise improvements, especially if technical or budgetary constraints exist.

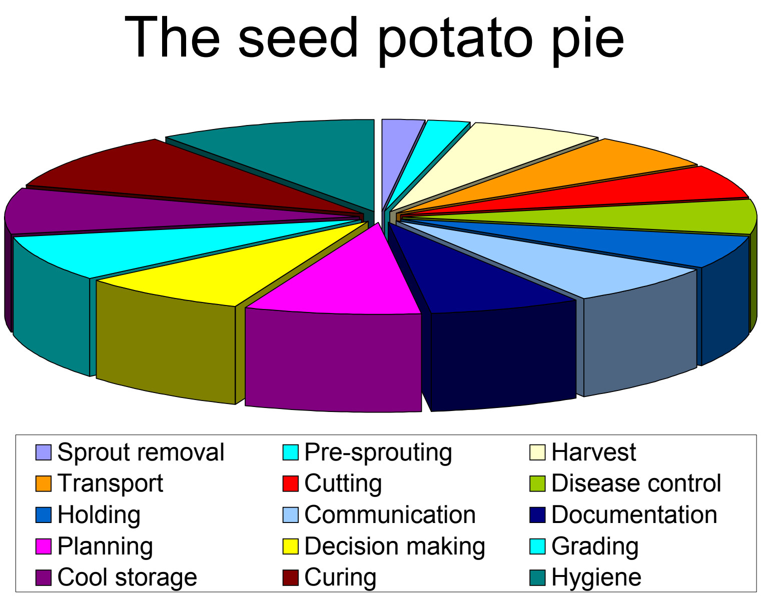
There is no shortage of information regarding the principles of handling, curing and storage of seed potatoes. However, most publications take for granted a high level of knowledge of plant physiology, technological awareness and easy access to state of the art technology. The amount of time it would take for single operators to gather and evaluate existing information from all sources, and adopt or adapt it to a specific operation, is considered prohibitive. The simple acquisition of state of the art facilities is not an option for most operators. It is therefore important to be able to improve on existing facilities, systems and procedures based on the understanding of 'what a seed potato needs' and how these need could be met.

While technological specifics described by different information sources may not be applicable to each handling and storage system, the basic principles remain the same and should be adaptable to a wide range of situations. For this to occur, relevant information has to be presented in a way that makes it easy to find and apply, providing assistance in prioritising technologies and actions for individual operations.

A survey of current Australian practices, and a review of international information, has resulted in the development of a draft manual for potato seed handling and storage management. It includes handling, hygiene and disease prevention information. It is designed so that it can be easily updated or extended. An emphasis has been placed on operational planning, documentation of desirable standards and technologies, record keeping and preventive actions. Basic technical information from literature sources on important aspects of seed potato handling and storage has been included as part of the manual. It details techniques or technologies that can be implemented in different situations to improve handling and storage outcomes.

Seed storage definition

One of the first initiatives was to redefine “Seed Storage” for the purpose of this manual. It was felt that industry and research should focus on crop production issues and the in-store time. Other ‘seed life stages and issues’, as detailed in the seed potato pie below, received less attention, even though they can have a significant influence on outcomes of handling and storage. We came to the conclusion that seed storage management starts at harvest of the seed crop and ends at planting the next generation or commercial crop. It includes the steps of planning, documentation and communication.



Acknowledgments

We gratefully acknowledge the help of all seed store operators who showed us their operation and discussed ideas with us, and representatives from processing companies who discussed seed handling and storage with us.

Special thanks to Tony Pitt who initiated contacts, supplied us with 'historic' and new information and assisted in technology transfer during the project, and to Leigh Walters for his valuable input towards the development of the guide.

Horticulture Australia Limited supported this work with funding from potato industry levies and the Australian Government.

How to use the manual

The manual is constructed based on a 'seed summary' of steps in the seed potato handling and storage cycle. The seed summary also contains a checklist for activities associated with major steps. It identifies which operators in the handling chain should be concerned with which step. Following the summary tables are self-assessment checklists to assist different operators in prioritising issues.

The body of manual includes a set of tables relating to the different operations during handling and storage, including the most important steps, specifications, risks and preventive / corrective actions. These tables contain references to more detailed guides included at the back of the manual. Literature references, a glossary of terms, a trouble-shooting guide and conversion tables can also be found at the back of the manual.

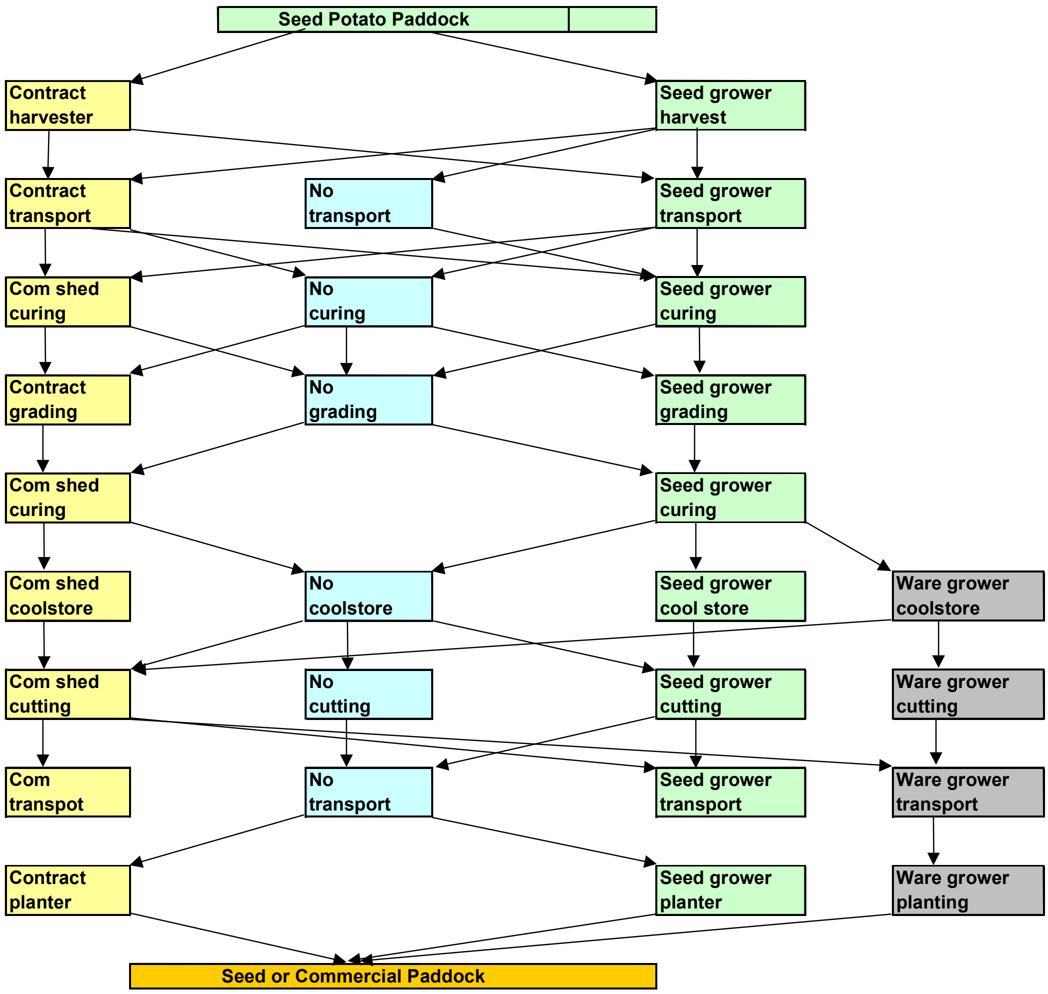
Activities and Operators

ACTIVITY	For further information go to[1]	OPERATOR[2]
Plan and prepare for harvest		Seed grower, Harvest contractor or Transport contractor
Harvest		
Holding seed in paddock prior to transport		
Transport to seed or commercial grower for curing, grading or storage		
Management of seed on receipt		Seed grower, Commercial grower or Contracted cool store operator
Plan and prepare for curing		
Curing (before or after grading)		
Prepare for grading		
Grading		
Waste management		
Plan and prepare for storage		
Holding prior to storage		
Chemical treatment prior to storage		
Ambient storage		
Cool storage		
Warming up ex cool store		
Chemical breaking of dormancy		Seed grower or Commercial grower
Sprout removal		
Pre-sprouting		
Grading after storage		
Waste management		
Seed cutting		Seed grower, Commercial grower or Seed cutting contractor
Pre-plant seed treatment		
Holding of cut and treated seed (planting delay)		

[1] In final manual version: Page number for hard copy, hyperlink to activities in back for electronic version.
[2] In final manual version: Symbols or color codes for operators that can be used right through the manual

Activities and Operators (cont.)

Flowchart showing activities in the seed handling and storage chain, and the range of different operators that conduct the same operation, depending on regional systems



Com = commercial

Critical actions checklist [1]

<table>
<tr><th rowspan="2">ACTIVITY</th><th colspan="5">CRITICAL ACTION</th></tr>
<tr><th>Equipment / Process</th><th>Supplies</th><th>Checks</th><th>Documentation and communication</th><th>Labour</th></tr>
<tr><td rowspan="4">HARVEST</td><td>Timely harvester maintenance</td><td>Spare parts, etc</td><td>Harvester set up (depth, drops speed, etc)
Harvester hygiene between crops</td><td></td><td>Harvester staff
OH&S
Training</td></tr>
<tr><td>Bin maintenance and labelling</td><td>New bins / bulk bags
Disinfectant for old bins
Bin labels (printed)</td><td>Bin availability
Bin hygiene/ cleaning</td><td>Bin cleanliness certificate (e.g. available from VicSpa)</td><td></td></tr>
<tr><td></td><td></td><td>Timing in relation to:
Soil moisture
Haulm kill
Soil temperature</td><td>Records of dates and soil moisture assessments and temperatures</td><td></td></tr>
<tr><td></td><td>Tarps</td><td>Tubers do not sunburn or get wet prior to transport to store</td><td></td><td></td></tr>
<tr><td>TRANSPORT TO STORE</td><td></td><td>Tarps</td><td>Tubers do not heat up, get wet (sweating) or wind burned</td><td>Documentation for store operator re seed management on receipt (delivery docket</td><td></td></tr>
<tr><td>INTAKE</td><td></td><td></td><td>Holding area for incoming seed separated from dispatch area</td><td>Job or lot numbers</td><td></td></tr>
</table>

[1] In final manual version: Hyperlinks to relevant information in the manual or page numbers in hard copy for major actions

Critical actions checklist (cont.)

STEP	CRITICAL ACTION				
	Equipment / Process	Supplies	Checks	Documentation and communication	Labour
GRADING	Timely grading line / maintenance capacity?	Spare parts	Hygiene procedures Drop heights Damage points		Staff selection, including QA[1] person Training OH&S
	Forklift – no gas or diesel in confined spaces		Electric fork available		Staff selection Training OH&S
	Fungicide applicator calibration	Protective clothing Fungicides tuber treatment	Chemical disposal system	For chemicals: Labels MSDS	OH&S Training
	Bin maintenance	New bins / bulk bags Bin labels (printed)	Bin availability Bin hygiene	Bin cleanliness certificate	
	Dust extractor	Disposal system (e.g. bags)	Waste removal organised		
				Recording sheets QA documents updated Filing system updated	
	Waste bins		Waste bin labels		

[1] QA = quality assurance

Critical actions checklist (cont.)

STEP	CRITICAL ACTION CHECKLIST				
	Equipment / Process	**Supplies**	**Checks**	**Documentation and communication**	**Labour**
CURING	Set up complete. Capacity matching intake of harvested seed?	Fans (for sufficient drying capacity), tarps to create airflow through bins[1]	Temperature, humidity, ventilation airflow, condensation control, temperature pull down capacity	Temperature and humidity, recording sheets	Training OH&S
			Hygiene (isolation of diseased batches)		
	Bins		Airflow through bins (under all weather conditions)		
STORAGE	Planning of layout and logistics	Aphid and rodent control products disinfectant	Capacity Temperature, humidity, air flow/tonne, ventilation, no condensation	Instructions regrading compatibility of varieties and isolation of diseased batches	
	Cooling systems, fans, Monitoring equipment etc. maintenance	Spare parts, monitoring equipment	Hygiene, fresh air supply		
CUTTING	Line or hand cutting facilities set up	Fungicides , treatment products (bark, cement etc) Protective clothing	Hygiene, blades sharp		Training OH&S
			Required seed piece size, eye number determined		
		Suberisation agent Fungicide	Curing after cutting, space & hygiene		

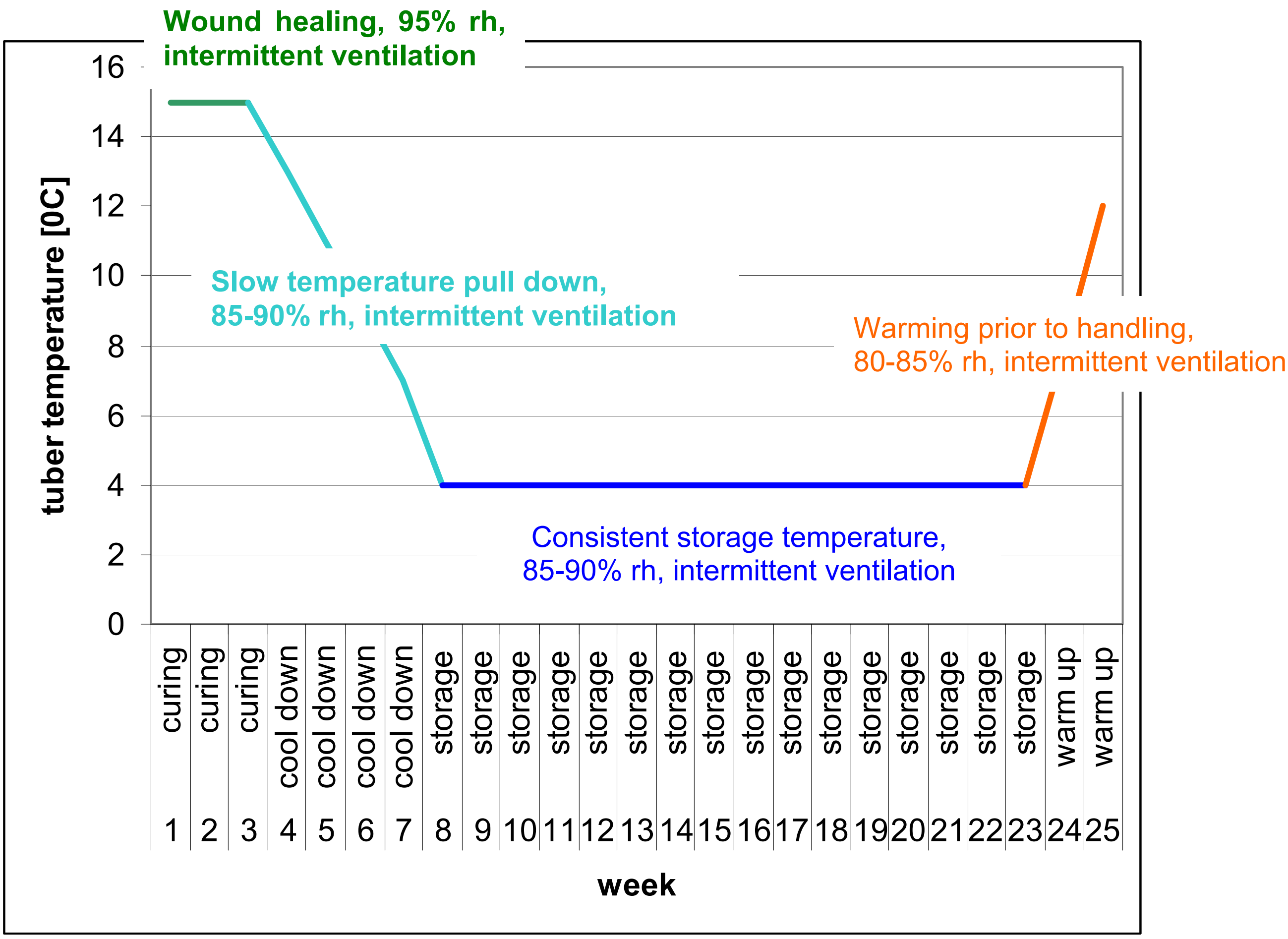
[1] Fans and tarps can be used to build simple curing systems for smaller lots, eg. for diseased lots.

Critical actions checklist (cont.)

STEP	CRITICAL ACTION CHECKLIST				
	Equipment / Process	**Supplies**	**Checks**	**Documentation and Communication**	**Labour**
STORAGE	Store maintenance and cleaning	Monitoring equipment	Monitoring equipment (temperature, humidity, CO_2) operational and calibrated	Recording sheets for storage conditions, if not kept electronically via loggers	Operator training
			Space between wall and bins, rows of bins and headspace sufficient for good airflow	Bin location plan	Operator training
			Controlled step by step temperature pull down possible, airflow , ventilation		
			Pre-storage holding space away from intake available	Identification & traceability documents	
	Electric fork lift		No ethylene in store from exhausts of forklifts or fruit storage		
SEED TRANSPORT	Suitable containers for sea freight, suitable trucks	Temperature data loggers for long distance transport	Sweating, airflow on long trips avoidable	Seed history for buyer/user	Training

The below graph presents a summary of ideal conditions for the 'in store period'. These will be discussed in more detail in the following chapters of this manual.

Temperature profile of seed potato tubers during the storage period and standard conditions (these need adjustment for diseased or wet seed)



Identification of priority improvement areas

Seed grower

ACTIVITY	ENTER OWN PERFORMACE RATING 1-5[1]	FURTHER INFORMATION[2]
Plan and prepare for harvest		
Harvest		
Holding seed in paddock prior to transport		
Transport to seed or commercial grower for curing, grading or storage		
Management of seed on receipt		
Plan and prepare for curing		
Curing (at any stage)		
Prepare for grading		
Grading		
Waste management		
Plan and prepare for storage		
Holding prior to storage		
Chemical treatment prior to storage		
Ambient storage		
Cool storage		
Warming up ex cool store		
Chemical breaking of dormancy		
Sprout removal		
Pre-sprouting		
Grading after storage		
Seed cutting		
Pre-plant seed treatment		
Holding of cut and treated seed (planting delay)		
Transport to paddock		
Communication and documentation		

[1] 1 = very good, 2 = good, 3 = satisfactory, 4 = less than satisfactory, 5 = poor
[2] In final copy: Page number for hard copy, hyperlink to activities in back for electronic version

Identification of priority improvement areas (cont)]

Contractors from transport, seed cutting or storage

TYPE	ACTIVITY	ENTER OWN PERFORMACE RATING 1-5[1]	FURTHER INFORMATION[2]
Transport	Holding seed in paddock prior to transport		
	Transport between seed and commercial grower for curing, grading or storage		
	Communication and documentation		
Cutting	Seed cutting		
	Pre-plant seed treatment		
	Warming and cooling pre and post cutting		
	Curing (after cutting)		
	Holding of cut and treated seed (planting delay)		
	Waste management		
	Communication and documentation		
Cool store operation	Seed management on receipt		
	Plan and prepare for curing		
	Curing (before or after storage/cutting)		
	Controlled temperature pull down		
	Isolation of varieties and diseased batches		
	Plan and prepare for storage		
	Holding prior to storage		
	Chemical treatment prior to storage or after		
	Cool store operation (airflow, ventilation, temperature, humidity, atmosphere control)		
	Warming up ex cool store		
	Communication and documentation		

[1] 1 = very good, 2 = good, 3 = satisfactory, 4 = less than satisfactory, 5 = poor
[2] Page number for hard copy, hyperlink to activities in back for electronic version

Identification of priority improvement areas (cont.)

Commercial Growers (ware and processing)

ACTIVITY	ENTER OWN PERFORMACE RATING 1-5[1]	FURTHER INFORMATION[2]
Management of seed on receipt		
Plan and prepare for curing		
Curing (before or after grading)		
Prepare for grading		
Grading		
Waste management		
Plan and prepare for storage		
Holding prior to storage		
Chemical treatment prior to storage		
Controlled temperature pull down		
Cool store operation (airflow, ventilation, temperature, humidity, atmosphere control)		
Isolation of varieties and diseased lots		
Warming up ex cool store		
Chemical breaking of dormancy		
Sprout removal		
Pre-sprouting		
Grading after storage		
Waste management		
Seed cutting		
Pre-plant seed treatment		
Holding of cut and treated seed (planting delay)		
Transport to paddock		
Communication and documentation		

[1] 1 = very good, 2 = good, 3 = satisfactory, 4 = less than satisfactory, 5 = poor
[2] Page number for hard copy, hyperlink to activities in back for electronic version

General Considerations

Responsibility allocation

A job/task description should be prepared for each operator/staff member in charge of specific activities, to ensure that all tasks are allocated and operators/staff know what is expected from them, and who to ask for advice/assistance. The job/tasks lists may be made up from the critical action checklist included under "Seed Summary". Preparing the job descriptions will also highlight OH&S requirements and training needs (eg. equipment operation, forklift usage in poorly ventilated areas and stores, bruise prevention, monitoring).

Planning of operations: What has to be organised and completed by whom, and by when?

It is important to produce an overall management plan for optimal pre-grading, grading, curing and storage management. The plan could be compiled in the form of a Gantt chart[1].

Critical control point: What has to be checked?

It is important to identify which important checks have to be performed during the different handling and storage stages. The staff in charge of a specific check have to understand the what, why and how of checks and their importance / priority.

Monitoring procedure and frequency: How, and how often, is the check done?

A description (work instruction) of how to go about checking important parameters may be required to ensure the necessary information is captured in the correct way, eg. where and how to place temperature loggers.

Specifications: Which is the acceptable range?

Staff / operators responsible for monitoring have to clearly understand what the required parameters are, eg. when the temperature or humidity is out of range, when the cut seed pieces are out of size, etc.

Preventive/corrective action: Risk assessment & prevention, and addressing problems as they occur.

It is important that operators and their staff know how to identify and avoid risks and prevent problems by being proactive. If problems occur, they need to know how they can be fixed. Staff training is essential for best results. It is dangerous if only one operator knows everything about a certain process or procedure.

References: Where to find further information.

Easy to follow references should be accessible to key staff so that they can check work instructions or specifications in case they are unsure of the correct parameters.

Records – What to document and where to keep records?

It is essential to keep records on monitoring results in an easy to review filing system. This will help with troubleshooting and inform people in the supply chain that the correct procedures have been followed. Continuous improvement will be easer if good records are kept.

[1] A Gantt chart is a graphical representation of the duration of tasks against the progression of time. http://www.ganttchart.com

General Considerations (cont.)

Review: How did we go against plan; where and how can we improve next time?

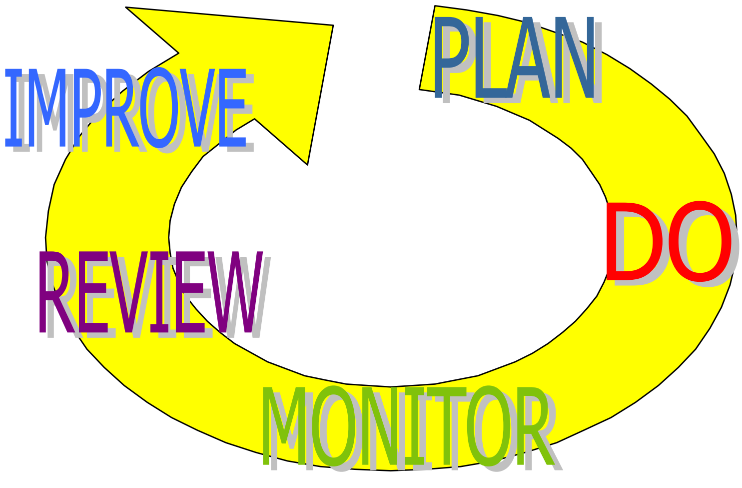
It is important to review records and outcomes, especially if problems have occurred. Staff involvement can help to encourage useful suggestions on improvements in their work area.

Reminder

Handling and storage can never improve the quality of the seed harvested but much can be done to maintain quality and minimise loss of tubers and overall quality.

Summarising the most important steps:

1. Handle seed with care at all times – no bruising, no contamination;
2. Know what you are putting into the ***clean*** store (paddock history, health);
3. Cure until tubers are completely suberised (all wounds healed);
4. Gradually lower the tuber temperature down to holding temperature after curing;
5. Constantly monitor store systems operation;
6. Monitor and record storage temperatures, humidity, air composition and ventilation;
7. Check the tubers frequently, more often if conditions during production and or harvest were not ideal.



The ABCD for seed potato storage and handling in Australia

The most important issues highlighted by industry can be summarised in a few points:

Airflow & ventilation – potato seeds are alive – they need fresh air to breathe

Bruising – potato seeds are alive – they hurt when they fall

Curing – potato seeds are alive – they need to have a special rest after stressful times

Documentation – potatoes are vain – they like their story told and to be treated with respect

Harvest

Critical Activity	Specification	Potential Risk – Preventive & Corrective Action
What has to be done?	**The required method or standard**	**What can go wrong?**
Harvester, tractor fork, truck (tarps) inspection / maintenance	Ready to go one week before predicted date. No drops above 15cm.	Harvester not ready in time.
Prediction of: **1. Harvest date** **2. Number of harvest days (start and finish)**	Physiological age and skin set finished. Ideal harvest soil temperatures.	Too early harvest leads to higher respiration rates = higher CO_2 production. Positive store ventilation for at least two days to avoid CO_2 damage. Monitor CO_2 levels in poorly ventilated areas of the store.
Vine (haulm) kill	Kill vines two or (preferably) three weeks before harvest.	Tubers from immature or recently killed vines are very susceptible to skinning and mechanical injury during harvest, resulting in storage decay problems. Such tubers also tend to have relatively low starch and high sugar concentrations compared to mature tubers.
Estimating the number of bins required **1. Per variety** **2. Per day**	CALCULATION SHEETS 1 and 2, or use an estimate of 100-150 bins per hectare; consider truck capacity.	Harvest delays, waste of time. Use of dirty bins or unsafe bins.
Bin maintenance and cleaning	Bins repaired, clean and dry (eg. hot, high pressure washed and sun **dried**) REFERENCE 1.	Contamination with storage pests and diseases.
Pre-printed waterproof bin labels to be used on both sides above tyne pockets (= 2 labels per bin) **Labels need to be attached securely to survive transport and moist conditions**	20 x 20 cm label to include: Grower, Grower code/ID Location Variety and generation No Certification No Harvest date Generation Minituber size (if applicable) Other, as required	Mix up of varieties. Waste of time. Wrong treatment in store or transit. Labels above both tyne pockets make handling bins easier. If one is lost, the bin ist still labelled.

Harvest (cont.)

Critical Activity	Specification – Preventive Action	Potential Risk – Corrective Action
What has to be done?	**The required method or standard**	**What can go wrong?**
Soil moisture check **Pre-harvest irrigation for softening soil, if required**	Soil moisture at harvest should be 50-75 % of field capacity; 50% for a well-structured clay loam soil and 75% for a course textured sand soil. Use soil moisture monitoring equipment readings or manual checks in the days before harvest. ASSESSMENT SHEET 1	If soil moisture is inadequate, tubers will be damaged or buried during harvest. If soil is too dry, soil clods can damage tuber skin, and if soil is too wet, the soil will not sieve well and will stick to the tubers.
Check and record soil temperatures in the time period between senescence and harvest **Checks in the week before harvest are most important**	Avoid harvesting tubers when it is colder than 5°C because then potatoes are very susceptible to shatter bruise. The ideal harvest temperature is between 12 and 15°C. The soil temperature should not be below 10 °C or above 18°C at 10 and 20 cm below the top of the mould, and very similar to tuber temperature. If the soil temperature is above 18°C, delay harvest or irrigate. Tubers at 18-20°C and under slight moisture stress are highly susceptible to black spot bruise. REFERENCE 2, ASSESSMENT SHEET 1	If soil temperature is much higher than tuber temperature, tubers will be susceptible to black spot bruise. If soil and tuber temperatures fall outside the ideal range, adjustments in curing/early storage settings may be necessary. Communicate any variations to personnel at the storage facility. SHEET 1, RECORD SHEET 2, REFERENCE 4
Harvesting performance check	Segregate tubers from low, wet, or diseased areas of the paddock if possible. Inspect tubers for damage, the paddock for tubers left behind, and bins for dirt. Watch chain speed; maintain and fix chains as required. If excess soil is present, either more agitation should be used on the harvester web, or the crop should be put over a continental web or soil extractor at the store.	Disease risk. Damaged tubers, losses through chains, storage rots. Increased respiration due to injury leading to additional heat and carbon dioxide production, which will retard the wound healing process.

Holding, transport and intake

Critical Activity	**Specification, Preventive Action**	**Potential Risk – Corrective Action**
What has to be done?	**The required method or standard**	**What can go wrong?**
Holding harvested tubers in paddock prior to transport	Boxes of harvested tubers must be stored out of the sun or under a tarp before loading onto a truck for transporting to the pre-grading / curing / storage area. If ambient temperatures rise above 25^0C, the boxes should be transported before 2 hours storage in the paddock. If temperatures are below 25^0C, the boxes should be transported before 4 hours storage in the paddock. The ambient air temperature and tuber temperature should be monitored to assure tubers are not heating up above 20^0C.	Dehydration and heating of tubers causing increased respiration and CO_2 production; faster ageing. Skinned or damaged tubers dehydrte quickly.
Transport	Boxes must be covered to avoid sunburn, wetting and loss of tubers. Condensation due to sweating under tarps must be avoided. Minimise storage under tarps on truck!	Damage to and loss of tubers. Damaged tubers are at risk of breakdown during storage or poor performance in the subsequent crop, if not graded out.
Holding harvested tubers after transport from the paddock prior to cleaning / curing	The environment in the pre-grading / pre-curing / storage area should be monitored. High humidity and fresh airflow are essential during holding, and a temperature of $10\text{-}15^oC$ is desirable but not essential.	Loss of quality and control over physiological ageing process if treatment of tubers changes between loads or over time. If harvest and grading speed / curing capacity do not match, quality is lost. SEE GLOSSARY AND REFERENCES 11 & 12
Holding harvested tubers after transport from the paddock, prior to grading (eg. splitting into ware and seed tubers) / storage	If split into ware and seed, T grade within 24 hours after harvesting, cured for up to 21 days after grading and cooled to 4^0C, or a temperature specified for the variety, in a controlled way[1].	
	If harvest capabilities exceed grading capabilities, limit harvesting hours per day, if possible. If grading capabilities limit filling storage area in excess of 14 days, increase hours of grading. CALCULATION SHEET 2	

[1] Hyperlink or page reference

Curing[1]

Critical Activity	Specification, Preventive Action	Potential Risk – Corrective Action
What has to be done?	**The required method or standard**	**What can go wrong?**
Design, arrange, maintain curing facility	The curing facility must provide the conditions listed below. It has to have sufficient capacity to keep up with incoming loads. DIAGRAMS 1-3, PHOTO 1	Loss of seed quality and performance because: • Set up does not allow airflow through bins. • Required temperature and humidity cannot be achieved. • Incoming bin numbers are in excess of what the facility can handle.
Separating ware and seed tubers before or after curing, before final storage	Treat seed with chemicals without the ware being affected; remove soil in the separation process.	Tubers are very susceptible to damage and skinning before curing. If tubers are wet, smearing can result. Separation is an extra operation at a busy time and can slow down loading into store. Ware potatoes have differtn storage requirements to seed tubers.
Store loading for curing (also refer to 'storage' section)	If excess soil is present, the crop should be put over a web, pintle rollers or a soil extractor at the store. Leave space for air ventilation around bins , especially near walls (min. 30 cm) and easy inspection of seed in bins..	Excess soil prevents good airflow and may prevent tubers from drying quickly; the curing result will be poor and the disease risk high.
Curing of seed prior to cool storage to allow suberisation of wounds and good skin finish	The curing process should take place ASAP after digging. To achieve satisfactory curing, the store or system should be filled to optimum capacity as soon as possible. DIAGRAMS 1-3, PHOTO 1	Tuber respiration uses oxygen (O_2), produces carbon dioxide (CO_2) and generates heat. Early harvested tubers usually have higher respiration rates than those harvested later. High carbon dioxide levels stress tubers, and speed up the ageing processes.

[1] Curing is considered by Dutch experts as the most critical operation of the seed handling and storage process.

Curing (cont.)

Critical Activity	Specification, Preventive Action	Potential Risk – Corrective Action
What has to be done?	**The required method or standard**	**What can go wrong?**
Curing of seed prior to cool storage to allow suberisation of wounds and good skin finish	Optimum curing is at 10-15^{0}C, 95% relative humidity (rh) for a minimum of 10-14 days and up to 3 weeks, but not longer than 4 weeks. If the seed requires increasing to the curing temperature of 15^{0}C, do so by increasing 0.5-1^{0}C per day, if possible. If cooling is required to bring tubers down to 15^{0}C, do so as rapidly as possible, but with air temperature just below tuber temperature. Adjust air temperature as tubers cool. If incoming tubers are very wet, ventilate continuously with humidifier off. Return to normal curing humidity (95% rh) when dried. REFERENCES 4 & 5, ASSESSMENT 5 Diseased tubers may benefit from dry curing at lower humidity (85% rh) until completely dry (1-2 days).	Poorly cured seed will have unhealed wounds und thus be more prone to breakdown, leading to uneven crop performance. Tuber temperatures may rise by self-generated heat (respiration) if not cooled rapidly and if airflow is poor. Suberisation is fastest at 20-25°C, which could shorten the curing period to 7-8 days, but these temperatures also promote the development of soft rot organisms. Low humidity will prevent suberisation, especially if temperatures are at the lower end of, or below, the curing temperature range.
Ventilation of store or area used for curing	Unless tubers are diseased or wet (see below), run humidifier and fans continuously while filling a store for curing. Once the store is filled, ventilate intermittently 2-6 hrs per day, 2 air changes per hour and twice a day, to get rid of carbon dioxide and introduce oxygen to the tubers. Ventilation of the dry tubers should be stopped and switched to internal re-circulation if the dew point temperature of the ventilating air exceeds the temperature of tubers. In general, the temperature of the ventilating air should not be more than 3-4^{0}C above tuber temperature. With good humidity control and capacity, more or less continuous ventilation is recommended. Always run the humidifier with outdoor air when ventilating, to reduce moisture and weight loss. REFERENCE 3	The higher the tuber temperature, the higher the rate of respiration and thus oxygen use and carbon dioxide production. High ventilation rates without humidification will lead to dehydration and weight loss. Ventilation air temperatures of more than 4^{0}C above tuber temperature will cause condensation on tubers. REFERENCE 3 If dry tubers are at, eg. 12^{0}C, the ventilating air is 20^{0}C and its dew point temperature is 16^{0}C (i.e. it is at 78%rh), the air will wet, rather than dry the tubers. If a curing store or system is not available, a well-ventilated open shed may be suitable for curing, if temperatures are not too high or low.

Curing (cont.)

Critical Activity	Specification, Preventive Action	Potential Risk – Corrective Action
What has to be done?	**The required method or standard**	**What can go wrong?**
Change pre-grading/ pre-curing (early curing) conditions according to harvest conditions	Obtain information on soil and tuber temperature and soil moisture at harvest. Change conditions accordingly. REFERENCE 5, ASSESSMENT SHEET 5	Poor storability and subsequent commercial crop performance.
Monitoring of curing conditions and management of curing problems	Inspect bins frequently, particularly if problem conditions or disease are detected, eg. in segregated lots. Check that bins are stacked to encourage airflow through the tubers. Monitor temperature and humidity of supply air and return air and tuber. The supply air humidity should be above 95%. Monitoring of tubers and wall for condensation is important. The supply air temperature should be a degree cooler than tuber pulp temperature until the tuber is cooled to the desired curing temperature. ASSESSMENT SHEET 2, REFERENCE 3 Use a ventilation meter[1] to assure curing conditions are correct in different part of the store.	Bins with inadequate ventilation gaps between boards do not allow sufficient airflow through seed for good curing and storage results. Poor suberisation, disease risk, poor storability, and commercial crop not reaching full potential, if curing (wound healing) is not complete before long term cool storage. Diseased lot may require special conditions to avoid disease spread (e.g. Silver Scurf) REFERENCES 4, 5, 7, 8
Temperature pull down for storage	1-2^{0}C every four to six days until the long-term storage temperature is reached, or proceed as described below. This may be started after a 2-week curing period.	If pull down is too slow or too fast yield potential is reduced.

[1] Hand held ventilation meters are available for measuring velocity, temperature, differential pressure, humidity, dew point, wet bulb temperature and heat flow.

Curing (cont.)

Critical Activity	Specification, Preventive Action	Potential Risk – Corrective Action
What has to be done?	**The required method or standard**	**What can go wrong?**
Monitoring of temperature pull down	The temperature and humidity of the supply and return air should be monitored. The supply air humidity should be above 95%. The pulp temperature of randomly selected tubers (bin centres) should also be monitored. Running the supply air at 1- 2^0C colder than the pulp temperature decreases it slowly until the desired temperature is reached. Once pulp temperature has reached set air supply temperature, it is reduced by a further 1- 2^0C, until the target storage temperature is reached. The return air temperature should be similar to the pulp temperature. If tuber temperature does not decrease to storage temperature over 10-12 days, airflow in the store is insufficient and should be improved. Careful monitoring of tubers and walls for condensation is important. If condensation occurs, humidity should be reduced for a while, and airflow should be increased until tubers are dry. REFERENCE 3	As above

Grading

Critical Activity	Specification, Preventive Action	Potential Risk – Corrective Action
What has to be done?	**The required method or standard**	**What can go wrong?**
Grading line inspection, cleaning and maintenance **Fungicide application equipment maintenance and calibration**	Functional, clean and easily cleanable at the end of the day and between varieties. A vacuum cleaner or wet cleaning must be used – no sweeping! Drop heights not above 15 cm. Sharp points, pinching and skinning conditions must be eliminated. Hoppers and line equipment should be fitted out with padding or deflectors where potatoes hit. ASSESSMENT 3 To avoid tubers falling into the bottom of empty bins, roll them into tilted bins. If the grading line is not set to tilt bins, bin inserts and/or padding should be used in empty bins to reduce drop height and speed.	Sweeping distributes fungal spores throughout the shed, increasing the disease risk for damaged or wet tubers. Bruising, open wounds, disease risk and / or cross contamination If fungicide application equipment is not calibrated and or nozzles are worn, actual fungicide levels on tubers may be too high, too low or coverage may not be sufficient, if droplets are too large.
Organise grading waste removal	Waste ½ tonne bins should be marked as such, and not used for graded tubers. Old bins can be used for waste.	Contaminated waste bins used for graded seed. Waste stored in vicinity of grading / storage facility.
Grading surroundings inspection and maintenance	Consider dust control for hygiene and OH&S. Cleaning to take place daily and/or between varieties Intake area for bins from the paddock must be separate from holding/dispatch area for graded seed. Consider space requirements and logistics of bins. A location plan for graded seed and signage and /or lines on the floor may be useful.	Disease spread. Poor OH&S, potential workers compensation claims. Low productivity / efficiency.
Estimating the number of clean bins required **1. Per variety** **2. Per day**	CALCULATION SHEET 1 and 2	Low productivity, waste of time. Use of dirty bins and disease risk.
Bin maintenance and cleaning	Bins repaired, clean and dry (eg. hot, high pressure washed and sun **dried**). A bin cleanliness certificate may be issued to confirm cleanliness. REFERENCE 1	Contamination with storage pests and diseases.

Grading (cont.)

Critical Activity	Specification, Preventive Action	Potential Risk – Corrective Action
What has to be done?	**The required method or standard**	**What can go wrong?**
Organise pre-printed waterproof bin labels to be used on both sides above tyne pockets (= 2 labels per bin) **Organise eed certificate labels (for one side per bin)**	20 x 20 cm label to include: Grower, Grower code/ID Location Variety and generation No Certification No Harvest date Generation Mini tuber size (if applicable only) Other as required	Mix up of varieties. Waste of time. Wrong treatment in store or transit. If seed certificate labels are used on one side of the bin, it will still be worthwhile labelling the other side for easy identifaction during bin handling.
Staff selection and training	As per employer, hygiene & OH&S requirements.	Poor work performance, poor seed quality, high cost, and injuries.
Waste management plan	Grading line waste has to be collated away from grading, storage and curing facilities and disposed of regularly.	Disease transfer to clean stock.
Cleaning schedule	Clear rules, posted on shed walls with checklist and record sheet to record cleaning dates/times.	Poor hygiene will lead to cross contamination between seed lots.
Electric forklift for confined areas	No ethylene and carbon monoxide (CO) accumulation from gas or diesel fumes.	Ageing of potatoes. Staff affected by carbon monoxide (headaches, nausea).
Grading of seed potatoes out of the cool store	Potato core temperature should be at least 7^0C before grading.	Bruising and breakdown.
Fungicide application	Product selection and availability, label information and MSDS available, protective clothing adequate, waste removal organised. REFERENCE 6	Insufficient protection of tubers. Contamination of staff.
Grade seed to the optimum size ranges	Seed tubers for cutting should not be above 300 - 350g. Depending on variety and buyer specification.	Seed lots that vary in size are difficult to cut uniformly and the resulting variation contributes to frequent planter errors such as doubles and misses. Seed lots that vary in size also produce plants that vary in productivity.

Storage

Critical Activity	Specification, Preventive Action	Potential Risk – Corrective Action
What has to be done?	**The required method or standard**	**What can go wrong?**
Planning of store capacity and logistics	Sufficient space for airflow in store roof area and between walls and bins, and rows of bins. Easy access to seed lots that have to be removed first or accessed (need for physiologically young seed or disease risk). DIAGRAMS 4-10, PHOTOS 2 & 3	Not enough oxygen (O_2), too much carbon dioxide (CO_2) leading to 'suffocation stress', physiological ageing and poor seed performance. SEE GLOSSARY AND REFERENCES 11 & 12 Unnecessary work in unloading and reloading seed lots.
Preparation, of storage facility well in advance of harvest **Cleaning and maintenance of cooling and monitoring equipment, fans, etc.** **Pest (insects, rodents) control plan**	Store is free of dirt and debris, cleaned with hot wash and disinfectant. REFERENCE 1 Ventilation ducts have to be cleaned and sanitised. All systems have been inspected and operation tested (cooling unit, insulation, vapour barrier, fans, humidifier, duct work, doors, monitoring equipment, etc.). Operate the entire system to humidify and pre-cool the storage to 15^{0}C a few days before potatoes are introduced.	Store is not clean, leading to infection of tubers and or pest damage.. Equipment does not work and temperatures, airflow, humidity and /or ventilation are incorrect for some time leading to faster ageing of tubers (early sprouting is a sign of ageing) and disease risk.
History of the storage facility	Which crops have been stored there previously? Are there any pathogens of previous crops that could infect seed potatoes? Is ethylene remaining in the store after fruit storage? Seed should not be stored in a storage facility that has been used for sprout inhibitor treatment or has held potatoes treated with inhibitor.	Disease transmission. Pest damage. Fast physiological ageing. SEE GLOSSARY AND REFERENCES 11 & 12 Poor sprouting of seed.
Define requirements for tubers and bins entering the store if you do not use your own seed and store **Communicate requirements in writing to storage operator / bin supply, etc.**	Tubers should be free from damage, rots, disease, and insect damage, and be **must be dry** and reasonably free from dirt before entering the store. Seed should be stored in new or disinfected bins that are clearly marked for easy identification and traceability. Gaps of 3-4 cm between the boards of the bins will allow free airflow around the tubers.	Cross contamination between lots that may belong to different clients. Poor airflow and / or small gaps between boards lead to heating up of tubers and CO_2 accumulation in the centre of bins, which accelerates ageing and reduces performance. .

Storage (cont.)

Critical Activity	Specification, Preventive Action	Potential Risk – Corrective Action
What has to be done?	**The required method or standard**	**What can go wrong?**
Plan loading the store well in advance **Consider allocation of varieties to stores** **Consider disease risks and risk of cross contamination** **Consider removal dates**	Free airflow around bins and above bin stacks. Easy access to the bins for inspection. Disease suspected or affected bins must be isolated or at least enter the store last, after being well cured, allowing easy access for inspections or removal, if required. Store together varieties or lots that are compatible in: harvest time, sprouting behaviour, disease susceptibility, temperature requirement, estimated removal time, etc. DIAGRAMS 4-10, PHOTOS 2 & 3	Cross contamination between lots, which may belong to different clients. Poor airflow leads to heating up of tubers and CO_2 accumulation in the centre of bins, which accelerates ageing. Conditions that are optimum for one variety may affect another one negatively, eg. its physiological ageing process. SEE GLOSSARY AND REFERENCES 11 & 12
Store filling and bin location plan	A plan, identifying the location of each variety from the same generation/crop from the same grower in the store is required. As each box enters the store, the storage supervisor records the variety, generation/crop ID, grower's name, and contract or job number, as required. The storage supervisor then records the location within the store on the plan. RECORD SHEET 1	Inaccurate treatment of seed, waste of time in trying to locate seed lots and unload / re-load the store. Tubers may warm up (dormancy breaking).
Monitoring of tuber temperature in different positions in the store	The storage temperature for seed (tuber pulp temperature) is 2-5°C (optimum 3-4°C) A stable tuber pulp temperature should be maintained at all times. Monitoring needs to be conducted daily during pull down until tuber temperature is stable. If tuber temperature increases or decreases, the supply air temperature should be changed. If condensation is forming and tuber temperature is as required, small circulating fans should be installed. REFERENCE 3	Temperatures > 6°C accelerate respiration and ageing. Most pathogens favour higher temperatures. Temperatures around 4°C lead to slightly higher respiration than higher or lower. Low temperature injury: temperatures just below freezing for a short time can lower quality, and shorten storage life without showing any visible symptoms. Older stores with poor air circulation must not have a store set temperature below 3°C to avoid potential freezing damage.

Storage (cont.)

Critical Activity	Specification, Preventive Action	Potential Risk – Corrective Action
What has to be done?	**The required method or standard**	**What can go wrong?**
Store monitoring for air temperature in different positions in the store	The better the airflow, the more even the temperature distribution. The store set temperature does not usually equal the air or tuber temperature. The automatic store temperature readout gives information from one location only. Monitoring of supply and return air of stores with a plenum is required. Conduit placed into bins during filling allows for a temperature probe to be lowered into the middle of the bin. If feasible, the store's temperature probe should be located inside a bin. Point measurements with a hand held temperature probe should be taken throughout the store to assure temperature distribution is as even as possible. It should not vary by more than 1^0C. Temperature probes attached to data loggers can be placed in several locations, including inside bins. Continuous monitoring with temperature data loggers should show minor temperature fluctuations over time and a consistent temperature distribution throughout the store. Stores can be fitted with an automatic warning system eg. sending a phone message when the temperature is outside a certain range. Varieties may be placed in different parts of the store according to temperature requirements and store performance, if temperature distribution is not even. If tuber temperature increases or decreases, the supply air temperature should be adjusted. If condensation is forming and tuber temperature is as required, small circulating fans should be installed. REFERENCE 3	Low temperatures reduce the tubers' ability for wound healing, which is why they need curing at higher temperatures before cooling down. Seed kept at 2-3^0C will sprout slower, compared to seed stored at 3-4^0C. Low temperature injuries: Chilling: If temperatures go to or below 2^0C, tissue damage, expressed as internal browning, may occur. Freezing: temperatures just below freezing for a short time can lower quality, and shorten storage life without showing any visible symptoms. Storage above 4^0C can lead to sprouting of the apical, dominant bud (eye) and thus suppression of sprouting of the remaining buds (eyes). Too high temperatures accelerate respiration and thus weight loss (burning up sugars) and ageing. Most pathogens favour higher temperatures. Sprouting and diseased (stressed) tubers produce more respiratory heat and carbon dioxide than dormant ones. They may affect store temperature and atmosphere.

Storage (cont.)

Critical Activity	Specification, Preventive Action	Potential Risk – Corrective Action
What has to be done?	**The required method or standard**	**What can go wrong?**
Store humidification	For normal storage conditions, the relative humidity of the supply air should be maintained near 98% to achieve storage humidity for seed of 95% relative humidity (rh). Poor crop condition (REFERENCE 8) or storage design (inadequate insulation and excessive condensation) may require different conditions. REFERENCE 3 Generally, humidifiers are the only way of adding sufficient moisture to the air. The best position of the humidifier to get moisture into the air stream depends on the store design. Ideally it should be installed immediately downstream from the fan(s). A humidistat will be inaccurate when the relative humidity is >90% and is therefore of limited value for automatically controlling humidity in a potato storage. Three types of humidifiers are commonly used: high-pressure nozzles, centrifugal spinning disk, and water-saturated fibrous media. The first two types are used less frequently as they are difficult to regulate, resulting in either too much or not enough water added to the air streams. The third type humidifies the air as it passes through a fibrous media without the pressure of free water droplets that can affect potato quality. This type of humidification unit will create resistance to the airflow and must be sized accordingly. The design of a humidifier is critical and must be undertaken by someone with expertise in ventilation and humidification. The humidifier should be wired so it cannot operate without fans running.	When humidity is below 95% rh, tubers dehydrate, lose weight and become soft. Pressure from other tubers causes depressions in the dehydrated tuber surfaces (pressure bruises). The depressions persist if the humidity remains below 90%. Tuber quality is reduced and affected areas become very susceptible to black spot bruise when handled. Above 90% rh can be hazardous in poorly designed/operated stores due to potential condensation on storage structures, particularly on the roof, and free water on tubers, which can lead to increased decay. Condensation on tubers and walls and ceilings should be avoided at all costs. Such condensation can usually be controlled by adequate ventilation and airflow unless the store is extremely poorly insulated. f tubers are diseased, it desirable to maintain a low humidity to keep the decaying tissue relatively dry and reduce disease spread to other tubers. If the water supply to humidifier is not clean (no filter) disease or OH&S issues arise.

Storage (cont.)

Critical Activity	Specification, Preventive Action	Potential Risk – Corrective Action
What has to be done?	**The required method or standard**	**What can go wrong?**
Monitoring for humidity in different positions in the store	Point measurements with a hand held humidity probe should be taken regularly throughout the store to ensure that humidity distribution is as even as possible. Continuous monitoring with temperature data loggers should show minor humidity fluctuations over time, and a consistent humidity distribution throughout the store. Weight loss should not exceed 5%.	See comments made above under 'store humidification'. Uneven distribution o humidity may exacerbate disease problems or leave some lots too dry. Problems can only be fixed, if known.
Store monitoring for atmosphere control (CO_2, O_2,) in different positions in the store	Carbon dioxide (CO_2) concentrations should not exceed 2%. If carbon dioxide is in the correct range, oxygen (O_2) levels will be sufficient as the two gases always balance out to about 21% (eg. If. CO_2 is at 2%, O_2 will be about 19%.) If a controlled atmosphere (CA) apple store is used, the atmosphere can be monitored through the system used for fruit. Advanced systems with carbon dioxide (CO^2) sensors that can activate fresh air intake whenever CO^2 levels exceed a pre-set limit are now available.	Very low O_2 levels cause black heart, due to suffocation and death of tissue. Damaged or diseased tubers have a higher respiration rate and use oxygen quicker, producing more carbon dioxide and heat at the same time. High CO_2 and low O_2 levels may lead to 'suffocation', (changing the respiration from an aerobic process to and anaerobic process). Often there will be no physical evidence in the tubers that 'suffocation' has take place. The damage will show up in poor performance of the subsequent crop.
Ethylene control in the store	Ethylene levels should be below 0.1μL/L. Ethylene monitoring systems are expensive. Options of ethylene control include: Keep gas and diesel forklifts out of the store. Keep fruit out of the store. If the store was used for fruit, send an air sample to a laboratory that can analyse ethylene with a gas chromatograph to ensure that the residual ethylene level is low. Fresh carrots placed in an environment with excessive ethylene levels turn bitter. They could be used as an indicator for too much ethylene in the seed store.	Accelerated ageing, loss of dormancy, sprouting (some chemicals used for the artificial breaking of dormancy contain ethylene).

Storage (cont.)

Critical Activity	Specification, Preventive Action	Potential Risk – Corrective Action
What has to be done?	**The required method or standard**	**What can go wrong?**
Assess for conditions of imminent or existing disease risks	Grading record will give information on 'risky' lots. Store and bin inspection, especially if harvest and / or curing conditions were not optimal. Odours are one of the best indicators of storage problems. TABLE 2	Disease risk overlooked due to lack of documentation and / or monitoring.
Ventilation / air circulation through stacks of bins	When the fans are running, air movement should be felt at any point in the store. Use additional fans (eg. in headspace) and / or deflectors (on structural obstacles) to ensure uniform air movement. Bins should be level over the entire store area. Bins with the smallest tubers should be located where airflow is highest. Ventilation, intermittent 2-6 hours, twice per 24 hours. The best systems blend air to the correct temperature, add humidity and blow it through the potato bins. Ventilation rates for seed potatoes are 6-7[L/s/t] or 0.6-0.7 [m^3/min/t] (36-42 [m^3/hr/t]). The ventilation fans should be selected to provide the desired air flow at a static pressure of 0.30 – 0.35 [kPa] and a maximum air velocity of 5 [m/s] Ventilation meters are available that measure ventilation (velocity) as well as temperature, differential pressure, humidity, dew point, wet bulb temperature and heat flow.	Poor ventilation will lead to CO_2 accumulation in some areas of the store, leading to stress, uneven ageing and uneven emergence / substandard crop performance. Rapid air circulation may lower the humidity around tubers too much and promote dehydration (pressure bruise risk). Ventilation air temperature of more than 4^{0}C above tuber temperature will cause condensation on tubers. If dry tubers are at, eg. 12^{0}C, the ventilating air is 20^{0}C and its dew point temperature is 16^{0}C (ie. at 78% rh), the air will wet the tubers. The tubers on the bin surface will become colder than in the bin centre, which may cause warm air from the bin centre to rise and its humidity to condensate on the colder tubers on top of the bin as it cools down there. REFERENCE 3 Separation into seed and ware potatoes may make ventilating small seed more difficult as gaps between seeds are smaller. Bins containing mixed sizes from very large to very small and / or dirt may be poorly ventilated as well due to the small 'pore space'.
Condensation checks	No water dripping from store roof and construction parts into bins	Condensation and wet tubers will support the development of diseases and rots.

Storage (cont.)

Critical Activity	Specification, Preventive Action	Potential Risk – Corrective Action
What has to be done?	**The required method or standard**	**What can go wrong?**
Frequent tuber inspections for management of storage problems (sprouting, bruising, bacterial soft rot, weight loss, etc.)	Prior to curing, 20 randomly selected tubers per 20 bins are bagged in an onion net and placed amongst the top tubers in a marked box. Every week they are removed and weighed in the storage area and inspected for sprouting, rots and condensation. REFERENCE 3 Weight loss in storage should not be greater than 5%. There should be no untimely sprouting and no rots. If condensation is evident, increase speed of circulating fans. It rots are found, isolate lot, cure and re-grade, if possible. If soft rots are found, completely open outside air intakes and increase ventilation rate until the diseased potatoes dry up. This is best done after isolating the affected lot. Hot spots can be identified using an infrared gun that picks up heat generation due to increase respiration of rotting tubers. Auxiliary fans may be used on hot spots. PHOTO 6 Most diseases infect tubers in the paddock. Health monitoring and control during crop growth will eliminate surprises. REFERENCES 7 & 8 Odours are one of the best indicators of storage problems, especially soft rot. TABLE 2	Loss of seed quality, a percentage of tubers and / or yield potential of following crop. Contamination of 'clean' lots. Excessive weight loss.
Preparing seed tubers for removal from the store	Tubers should be warmed to at least 7°C (0.5^0 C to maximum 2^0 C per day) before they are moved out of storage. They should be warmed to 15^0C for several days just before shipping or during transit, to stimulate healing after cutting, and rapid sprouting after planting.	

Cutting

Critical Activity	Specification, Preventive Action	Potential Risk – Corrective Action
What has to be done?	**The required method or standard**	**What can go wrong?**
Decision on timing of seed cutting	The physiological age of the seed may determine the order in which seed lots are cut. SEE GLOSSARY AND REFERENCES 11 & 12 Pre-cutting seed advances the physiological age of the seed, but allows the cutting to begin earlier, when labour is less in demand. It allows more flexibility when planting. Hand cutting is recommended as hygiene will be easier to maintain and staff can discard unsuitable (diseased, damaged etc) tubers. (see below in this table under pre-cutting and re-storing)	Seed is cut too early, leading to seed piece breakdown. Cut seed has to be treated with an agent that promotes wound healing and cured, especially if not planted as soon as possible. Pre-cutting by machine may be risky due to poor disinfection of cutters, blunt cutters, little grading out of diseased or damaged tubers prior to cutting.
Equipment maintenance and calibration (fungicide applicators)	Repair, calibrate and test equipment as required in good time. Eliminate drops.	95% of cut seed piece bruising occurs on edges and happens after cutting. In a trial, a> 10 cm drop bruised 82% of pieces at 10^0C; round seed was not bruised under these conditions.[1] Poorly calibrated or worn nozzles may lead to too much, too little or too uneven fungicide application with the risk of phytotoxicity (leading to seed piece breakdown) or lack of protection.
Disinfect all equipment	Before each seed cutting session, and between seed lots. Dip or spray; surfaces must remain wet for at least 10 minutes for the disinfectant to destroy disease organisms. Keep a pair of rubber boots soaking in disinfectant and change boots when entering the store. Provide workers with plastic disposable booties and new gloves daily. REFERENCE 1	Disease transmission and seed piece breakdown.

[1] Holland S., 1994; Important aspects of potato seed cutting and seed piece bruise. Proceedings of the 1994 Washington State Potato Trade Fair.

Cutting (cont.)

Critical Activity	Specification, Preventive Action	Potential Risk – Corrective Action
What has to be done?	**The required method or standard**	**What can go wrong?**
Warm seed prior to cutting	Before cutting, (or planting after pre-cutting and re-storing) seed should be slowly warmed to about 13^{0}C (10-15^{o}C) for 10 days unless sprouts have already appeared. If sprouted, warm up to 7-10^{0}C and cut as soon as that temperature is reached. Warming the seed increases the physiological age and enhances sprout formation. Control the warming period, to produce seed with sprouts just emerging (white points). If the rate of sprout formation is too rapid, or a delay in planting is anticipated, keeping the tubers cool slows sprout development. Through-the-bin-ventilation with a large volume of high humidity air also helps to slow sprout growth. SEE GLOSSARY AND REFERENCES 11 & 12 Chitting is another way of pre-spouting (see Glossary).	Slow, uneven emergence if seed is used straight out of cold storage Long sprouts are tender and susceptible to mechanical damage. Cutting of cold seed < 10^{o}C can cause it to shatter and increase disease and breakdown risks.
Cutting operation	Seed tubers should not be above 300-350 g depending on variety and commercial customer. REFERENCE 9 The seed pieces should have 2 or 3 eyes and preferably weigh around 40 g (35 mm). Keep the number of cut surfaces per tuber to a minimum to reduce bruising during handling and planting. Keep cutter knives sharp and straight. Check and sharpen cutters or knives before each seed cutting session and between seed lots. Protect cut seed from dehydration and bruising (drops > 5). Grade out off-size and blind (no eyes) pieces.	Too many pieces that are either too small or too large (leading to a poor commercial crop). Large seed pieces have a larger cut surface; more stored energy will be used on wound healing and less is left to support new plant growth. They do not flow well in the planter. Bruise problems are more severe with large cut seed pieces. Excess bruising increases the risk of seed decay problems. Ripping and creating an area for disease attack due to blunt implements.

Cutting (cont.)

Critical Activity	Specification, Preventive Action	Potential Risk – Corrective Action
What has to be done?	**The required method or standard**	**What can go wrong?**
Pre-cutting of seed and re-storing - any time between harvest and 4 weeks before planting ('normal' cutting should occur 2 - 3 days before planting)	After warming and cutting, suberise (cure) at 13-16 ^{0}C with humidity levels of 90-95% and good air movement and fresh air supply for about 10-14 (an absolute minimum of 5) days. The higher the temperature, the shorter the curing time. Cool down slowly, as for seed after curing. A room may have to be set aside for warming and curing before and after pre-cutting. REFERENCE 10 Hand cutting is recommended as hygiene will be easier to maintain and staff can discard unsuitable (diseased, damaged etc) tubers.	Carbon dioxide may build up and interfere with wound healing. Pre-cutting and storing seed can help spread the work load and reduce weather related risks at planting time; however, this practice should only be attempted on a large scale, if recommended temperature, air flow, and humidity can not be provided. Pre-cutting by machine may be risky due to poor disinfection of cutters, blunt cutters, little grading out of diseased or damaged tubers prior to cutting. Higher curing temperatures may favour disease.
Determine seed size **Remove small seed pieces before planting**	A seed lot with an average seed-piece weight of 50 g has the potential to produce high yields, provided the lot contains a high portion of single cuts. ASSESSMENT SHEET 3 Pieces less than 45 g to be discarded.	Poor crop performance if small seed pieces are kept. A better plant stand and more vigorous plants compensate for the extra cost associated with removing these pieces.
Calibrate the seed cutter	Daily and between lots.	Incorrect seed piece sizing and low eye numbers, leading to poor, uneven emergence of the commercial crop, reducing overall crop performance.
Good air circulation and uniform temperature (curing) after cutting, before planting	Relative humidity of 90-95% is needed to promote healing and prevent dehydration. Temperature should be at 13-16^{0}C for a minimum of 5 days, better 10-14 days.	Condensation on or moisture oozing from cut surfaces, poor suberisation, seed piece breakdown. REFERENCE 3 Poor air circulation and fresh air supply causing carbon dioxide built up and damage tubers invisibly, leading to poor seed performance.

Cutting (cont.)

Critical Activity	Specification, Preventive Action	Potential Risk – Corrective Action
What has to be done?	**The required method or standard**	**What can go wrong?**
Treatment with appropriate products after cutting	Consult with local suppliers about products, label rates and safe application procedures (obtain Material Safety Data Sheets - MSDS).	Some cultivars (especially the early maturing ones) are more susceptible to *Fusarium* and low in forming wound-healing substances.
Calibrate fungicide application equipment	Consult with equipment suppliers regarding procedure.	Wrong rates or conditions (humidity, seed temperature) provide no protection, or damage the seed.
Warm pre-cut seed prior to planting	At planting, seed should be at about the same temperature as the soil . Temperatures of 10-18^{0}C are acceptable to match the soil temperature. If the soil temperature is below 10^{0}C, aim for a seed temperature of 10^{0}C.	Dormancy not broken prior to planting. Injury during planting, poor crop performance.

Seed transport from store to commercial grower pre-planting

Critical Activity	Specification, Preventive Action	Potential Risk – Corrective Action
What has to be done?	**The required method or standard**	**What can go wrong?**
Removal from store	Uncut tubers should be at least 7^0C (0.5 ^{o}C to maximum 2 ^{o}C per day) before they are moved. They should be warmed to 15^0C for several days just before shipping or during transit to stimulate healing if cut, and rapid sprouting after planting.	Transporting tubers that are close to storage temperature (4^oC) can lead to shatter bruise.
During or after transport, match tuber temperature with soil temperature	If soil temperature is below 10^oC, the tuber temperature should be increased to 10^oC before planting, otherwise the tuber temperature should match the soil temperature. If it is not possible to warm the tubers inside the store, they should be moved to an area designed to maximise airflow through the boxes until the desired temperature is achieved. The area should be out of direct sunlight and protected from rain.	Planting seed that is far colder than the soil temperature will delay emergence. Slow emergence makes tubers and emerging shoots more prone to disease attack.
Transport from store to commercial grower	Air temperatures have to be controlled. Condensation, eg. sweating under tarps or in bulk bags, must not occur. It is possible to let tuber temperatures increase from an initial 7^0C to 15^0C, or the desired planting temperature during transport, if this can be controlled. It is better, however, to transport at 15^0C.	
Receival and holding of tubers after transport, before cutting or planting	After receival, the seed must be removed from the truck at once and should be stored in a clean area out of direct sunlight, designed to maximise airflow around the tubers. They should be cut or planted as soon as possible.	

Chitting (green sprouting) / pre-sprouting of seed

In general, chitting or pre-sprouting is advisable if:

- The growing season is fairly short (seed & early ware potatoes, climate);
- The soil is rather heavy;
- The planting conditions are unfavourable;
- The seed is weak/old;
- The variety matures late and has to be harvested early.

Tubers warmed and then sprouted in the presence of light form short, compact, tough, green sprouts. These short sprouts are less exposed to damage than longer white sprouts formed in the dark.

Chitting ages seed (refer to 'physiological age') and will thus result in earlier emergence, tuberisation, bulking and maturity, enhancing yield capacity. The greatest advantage of chitting occurs for short growing seasons (seed crops) or early harvested crops (early ware potatoes), as it may advance the maturity by about two weeks. Advantages diminish as crops are allowed to grow out to maturity.

In order to obtain chitted seed tubers, tubers are warmed at 15-20^{o}C until the sprouts just emerge (white point stage). These tubers are then exposed to light. This is best accomplished in special stacking trays or bags. No more than 2 layers of tubers should be placed in these trays in order for the light to reach every tuber.

The light requirement is not high. One 40-watt fluorescent tube per 4 square meters, hung vertically between rows of stacked trays, is sufficient. Trays could also be stacked on a wagon, which can be moved outside each day, or stacked in a plastic greenhouse shelter. The recommended temperature is 5-10^{o}C. Tubers must be kept dry.

Chitted tubers must be carefully handled and planted. Cup-type planters are the most suitable for chitted seed. Pick-type planters are not designed to handle chitted seed without sprout damage. Some belt-type planters with additional modifications to reduce sprout damage may be suitable.

Chitting is usually not practical for large size operations. A less effective, but much more practical method is warming the tubers until one sees the white sprouts just emerging (pre-sprouting).

Sprouting potatoes respire more heavily than dormant ones, producing more heat and carbon dioxide (CO_2).

Dew point

The dew point is a temperature at which the air becomes saturated. In a store, condensation forms when the air temperature has cooled to dew point temperature. It means that the air temperature and dew point temperature are the same, and relative humidity is 100%.
The following links are to sites that assist with dew point temperature calculations:
http://www.kw-engineering.com/psych.htm
http://www.uwsp.edu/it/itmm/psychtut/celsiusChart.htm

Dormancy

Dormancy is the resting period after harvest during which the tubers will not sprout, regardless of temperature, light or moisture conditions. The length of this period is dependent on the variety and storage conditions, especially temperature. There are chemical and non-chemical means to break or greatly reduce the dormancy period. Tubers may be induced to sprout earlier by high (20^{o}C) and low temperature alterations.

Ethylene

Ethylene is a colourless gas and a plant growth regulator (plant 'hormone'). It induces physiological processes leading to ageing and senescence. Most fruit and vegetables produce it. Potatoes have low ethylene production rates. Diesel, petrol and gas fumes also contain ethylene. All plants or plant parts undergo accelerated ageing processes under high levels of ethylene, including speeding of maturity and development of decay symptoms. The sensitivity of plants or plant products to ethylene varies. Potato tubers are moderately sensitive and should be kept away from ethylene sources (gas and diesel forklifts, fruit).

Oxygen (O_2) and Carbon Dioxide (CO_2)

Oxygen and carbon dioxide are gases, which are components of air. Air is a mixture of gases, 78% nitrogen and 21% oxygen 0.03% carbon dioxide, some argon and traces of water vapor and various other components.

Pathogen

A pathogen is an organism (eg. bacteria, fungus, virus) that can cause a disease of other organisms. Most pathogens are specific in the organisms they can affect, the conditions that lead to a successful infection and the symptoms they cause.

Pre-sprouting (see Chitting)

Physiological age (P-age)

Different from the ***chronological age*** (number of days between harvest and the current date or storage duration), the ***physiological age*** considers the effects of further factors on tuber condition.

The physiological age of seed potatoes determines their yielding ability through influencing the stem number per seed piece (given uniform seed piece quality), and thus stem density per hectare. The P-age concept is still not well enough understood to reliably predict crop outcomes under all circumstances. The lack of clarity about physiological age effects may also have to be attributed to the lack of a precise universally used definition, and criteria for its measurement. Sprouting capability is so far the best mean of characterising P-age. REFERENCE 11

Factors that can affect tuber condition include:

- Climate and location effects during crop growth

  Seed produced without a major stress is physiologically younger at harvest, than seed that was stressed – water, nutrients, disease - in the paddock. An approximate prediction of physiological age at harvest may be based on 'thermal time' or accumulated day degrees. Production records kept by the seed grower and supplied to the store operator and seed buyer can assist in estimating P-age.

- Haulm (vine) killing time or time of natural death
  Killing vines too early or waiting for natural dying off appears to have a 'stress effect', ageing seed.
- Storage temperature
  Fluctuation of storage conditions (temperature, humidity, high carbon dioxide or ethylene levels) and disease can stress seed, increasing its age. If no stress has occurred, an approximate prediction of physiological age at any time during storage may be based on 'thermal time' or accumulated day degrees in the paddock and store.
- Handling
  Stress during handling (bruising, mechanical damage cutting, chitting, pre- or de-sprouting) ages seed.
- Cold soil at planting enhances physiological age
- Seed size

  Small tubers age more slowly than large tubers.

DIAGRAM 11

Seed cutting and physiological age

Seed cutting sufficiently 'shocks' the seed tuber to promote sprouting of buds (eyes) if the tuber is beyond the dormant period. In this way, the practice of seed cutting compensates for improperly aged seed by promoting the premature sprouting of some eyes. Planting cut seed, which has not been properly warmed, will result in poor or uneven plant stands. It is, therefore, important to properly warm and size seed for the intended purpose prior to seed cutting.

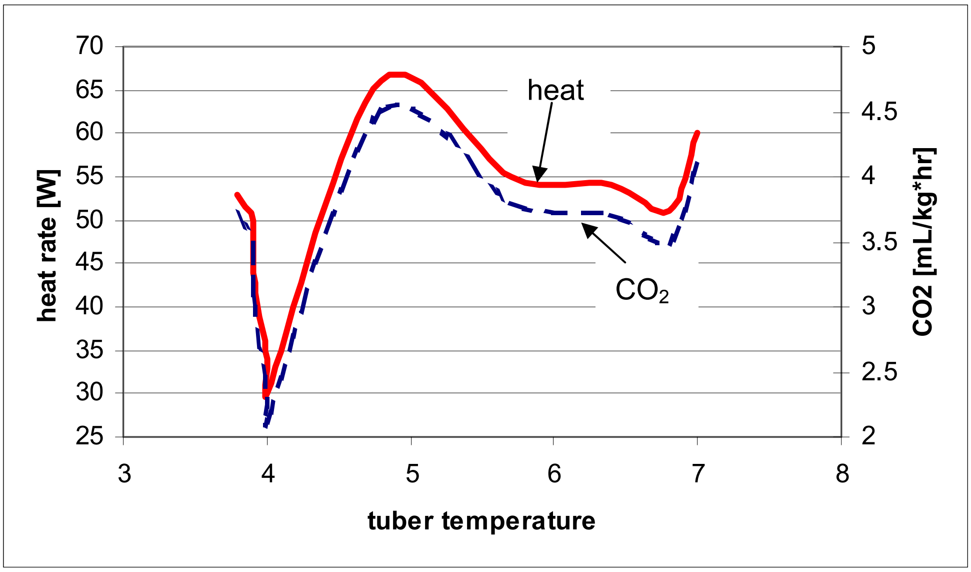
Soil temperature at planting and physiological age

Sprouting is delayed when the soil temperature is low, especially with very young seed, and the result may be a late emergence. That's when *Rhizoctonia* and *Fusarium* have ample opportunity to attack the sprouts. Therefore, when planting physiologically very young seed, it is important to match soil and seed pulp temperature. On the other hand when seed is very advanced in physiological age, cold soils may result in small tuber syndrome ("potato no top"), and no yield can be expected at all from such seed.

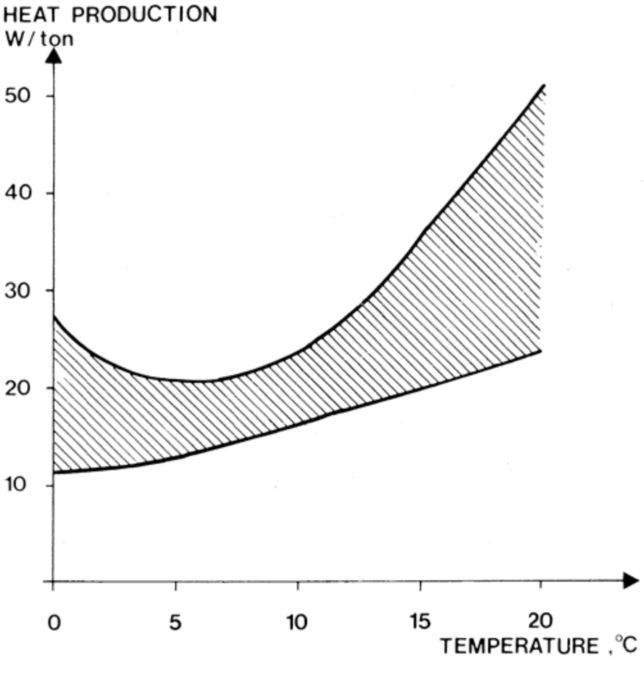
Respiration

During respiration (breathing), the potatoes transform stored sugars into energy to stay alive. In the process, they consume oxygen (O_2) from the air and release water, carbon dioxide (CO_2) and heat. Respiration rates vary among vegetables and fruit. Potatoes have relatively low respiration rates; others such as asparagus and sweet corn have high respiration rates. Still, freshly dug potatoes release respiratory heat of about 30 [W/t], which, after curing and storage under ideal conditions, may fall to about 20 [W/t]. Respiration is affected by temperature; as the temperature decreases, so does the respiration rate. In an enclosed environment, potatoes can use up enough available oxygen and produce enough carbon dioxide to cause 'suffocation' (anaerobic respiration). Even short periods of too low oxygen and excess carbon dioxide can cause lasting damage, and the stress will speed up the ageing process. These conditions can occur more easily in overfilled stores and / or poorly ventilated / aired stores. The higher the temperature, the greater is the risk of 'suffocation'.

The following graph shows the relationship between tuber temperature and respiration expressed as heat and CO_2 development. The measurements conducted in a commercial potato store[1] confirm the findings of a range of authors that the respiration of potatoes is lowest at around 4^{0}C. The graph illustrates the same principle as the diagram below, published in a food transport book.



The diagram below shows the relationship between storage temperature and heat production of potatoes[2]. Heat production is a measure for the intensity of respiration.



[1] Fennir1, MA et al, 2003; Respiration rate of potatoes (*Solanum tuberosum L.*) measured in a two-bin research scale storage facility, using heat and moisture balance and gas analysis techniques. Canadian Biosystems Engineering, Vol. 45

[2] Anonymous, 1989; Guide to food transport. Fruit and vegetables. Mercantile Publishers, ISBN 87 89010 981

Rot

An infection or disease that is caused by a pathogen and leads to wet or dry breakdown symptoms, is often called ‘rot’.

Suberisation

The process of wound healing during curing, which is important for sealing potential disease entry points.
Suberisation is a 3-stage process:

1. The wounded surface is blocked off by production of suberin, the substance that gives the skin its protective properties.
2. Cell division takes place beneath the wound and a number of layers of cork cells are formed.
3. The cork cells are impregnated with suberin (periderm formation)[1]

[1] Mitchell, B., Scottish Agricultural College, Crop Services Unit

Condensation

Tubers are sweating or have free water on them

Possible Cause(s)

- Potatoes in the bin center are warmer than on top;
- Warm, moist air from recently added bins is hitting cold tubers;
- Outside air is leaking into the store or hitting cold seed after removal from storage;
- Sudden drop in outside temperature causing headspace air to cool and condensation on cold surfaces;
- Defrost water from evaporator coils is dripping on produce;
- Humidification system droplets are too large;
- The roof is not well insulated and thus warm, water condensing on the ceiling drips on the top bins.

Possible Solution(s)

- Keep cold seed already stored for long periods in a separate room from warm seed that is to be cooled; install more refrigeration to reduce dramatic air temperature increases;
- Allow seed coming out of storage to warm up gradually; condensation is unavoidable if it is put directly into a warm, moist atmosphere;
- Drain condensate away, eg. from ceiling and walls using drip trays let it run onto the floor, if possible, to help humidify the store;
- Install humidification equipment that can supply ultra-fine or atomized mist.

Walls, other structural components and/or ceiling are covered in condensation

Possible Cause

- Interior surfaces are colder than the room air hitting them.

Possible Solution

- Install more insulation to warm wall surfaces above the room air's dew point;
- Provide better airflow (re-circulation or top ventilation) in the affected areas;
- Heat the headspace.

PHOTO 4

Ceiling is dripping

Possible Cause(s)

- Poor roof room ventilation allowing a build up of hot, moist air in the roof space above the store ceiling;
- Insufficient roof and ceiling insulation causing condensation, which drips through the cracks;
- Improper installation or missing vapour barrier.

Possible Solution(s)

- Provide 1 m² of unrestricted air inlet / vent area into the roof space for every 600 m² of ceiling, and some unrestricted ventilation area in the peak (if the roof is not flat), or forced ventilate the roof area at 1 air change every 2 minutes;
- Add insulation to prevent the warm, 'attic' side of the insulation from approaching the cold temperature of the storage below;
- Vapour barrier location depends on vapour pressure drive direction; a vapour barrier may not be advisable depending on building use.

Floor is drying out even if floor is sprayed with water to keep up humidity

Possible Cause(s)

- Storage relative humidity is too low;
- Floors have cracks for water to escape.

Possible Solution(s)

- Flood floors to see if water runs away, especially along concrete foundation; seal if necessary;
- Install more coils so they can operate at a lower temperature difference between "cold" air leaving the coils and air that the seed "feels"; this reduces air dehumidification;
- Install humidification equipment that can supply ultra-fine or atomized mist.

Shriveling and weight loss, pressure bruises

Possible Cause(s)

- Storage relative humidity too low;
- Vapour pressure differential too high; warm, moist seed versus cold, dry air;
- Wooden containers and storage structure itself is drawing moisture out of the air and seed.

Possible Solution(s)

- Install more coils so they can operate at a lower temperature difference between "cold" air leaving the coils and air that the seed "feels"; this reduces air dehumidification;
- Install humidification equipment that can supply ultra-fine or atomized mist;
- Cool seed promptly and as rapidly as possible using the step by step approach after curing to reduce vapour pressure difference between seed and storage air, thus less incentive for moisture to leave it, causing desiccation;
- Wet walls and floor as well if possible (this will not alleviate problems with really low humidity due to high intake of with low humidity fresh air);
- Reduce fresh air intake without 'suffocating' seed.

Inside air temperature fluctuates during storage period

Possible Cause(s)

- Thermostat not located in the right position and does not sense (and represent) average room temperature;
- Airflow not uniform throughout store;
- Evaporator coils have too large a temperature difference across them;
- Poor quality or insensitive thermostats.

Possible Solution(s)

- Install thermostats in average room airflow, usually in the return airflow to evaporator coils; relocate thermostats away from warm/cold walls, doors, lights, cold air leaving the coils, or warm incoming seed;
- Use a smoke generator to determine the location of dead air spots; relocate evaporator coils or increase the capacity of their fans (if possible); install air tubes and/or extra fans; rearrange storage configuration to allow more uniform airflow;
- Lower the temperature difference across the evaporator coils, recognizing that this will result in a lower potential heat removal capacity;
- Use good equipment, since uniform temperature control is vital for maintaining seed quality.

Inside air temperature is warmer than desired during storage period

Possible Cause(s)

- Inadequate refrigeration;
- Insufficient insulation for use during warm outside temperatures;
- Poor ‘attic’ ventilation;
- Hot sunny days with dark, roof surface;
- Airflow not uniform or of insufficient capacity in the store;
- Poor thermostat location; sensing cold temperatures.

Possible Solution(s)

- Install more refrigeration cooling capacity;
- Install sufficient insulation in walls, ‘attic’, roof and on foundation;
- Provide 1 m² of unrestricted eave inlet area per 600 m² of ceiling, with same unrestricted peak area, or mechanically ventilate at 1 air change per 2 minutes;
- Paint roof chalk-white and provide adequate ‘attic’ ventilation, since ‘attic’ temperatures can reach 60°C if the roof is a dark colour;
- Use smoke generators to determine location of dead air spots; relocate evaporator coils or increase the capacity of their fans (if possible); install air tubes and/or extra fans; rearrange storage containers to allow more uniform airflow;
- Install thermostats in average room airflow, usually in return airflow to evaporator coils; avoid locating thermostats on outside cold walls, near doors, or near the cold air leaving evaporator coils.

Inside air temperature is colder than desired during the storage period

Possible Cause(s)

- Thermostat poorly located; sensing warmer temperatures.

Possible Solution(s)

- Install thermostats in average room airflow, usually in return airflow to evaporator coils; avoid location thermostats on outside warm walls, or near doors or lights;
- Install sufficient insulation in walls, ‘attic’, roof and on foundation.

Inside air temperature is not uniform

Possible Cause(s)

- Airflow not uniform or of insufficient capacity in store;
- Short-circuiting of air directly back to the evaporator coils because of poor bin arrangement inside the store, or overfilling.

Possible Solution(s)

- Use smoke generators to determine location of dead air spots; relocate evaporator coils or increase the capacity of their fans (if possible); install air tubes and/or extra fans; rearrange bins to allow more uniform airflow.
- Avoid bin configurations that allow air to simply by-pass bins; air will always take the easiest path and must be forced to travel a meandering path (fans) to maximise cooling potential; use a smoke generator to inspect for short-circuiting.

The store air smells bad or is difficult to breathe

Possible Cause

- Gases such as carbon dioxide, carbon monoxide and / or ethylene may be present in excessive quantities as a result of rotting tubers, intense respiration or gas / diesel forklifts.

Possible Solution

- Look for and dispose of rotting seed;
- If the store is not purpose built for optimum ventilation, install a small exhaust fan that provides ventilation with at least 2 air changes/day;
- Use electric forklifts inside and near the store.

Evaporator coils are icing up and run a lot of condensate

Possible Cause(s)

- Coils running at too low a temperature;
- Defrost system not running properly;
- Storage relative humidity is high but air circulation poor.

Possible Solution(s)

- Increase coil temperature; this may require larger capacity evaporator coils;
- Repair defrost system or install a more effective one;
- Install a more effective defrost method, since the relative humidity should be high.

Electrical consumption is rising

Possible Cause(s)

- Insulation is wet or missing;
- Higher volume of seed being cooled than before;
- Seed is entering storage at a higher temperature than in previous seasons;
- Building less air tight or doors open more often;
- Higher fresh air intake;
- Malfunctioning refrigeration equipment.

Possible Solution(s)

- Correct moisture problem and re-insulate with an insulation that is more suitable for cold stores;
- Install more refrigeration as heat load increases; one rarely has 'too much refrigeration capacity', but the system should be properly sized to manage costs;
- Get equipment serviced by a qualified refrigeration contractor familiar with the needs of seed stores.

Further Reading

Studying the Internet and literature references listed below has formed an important part of the desk research phase for this guide on seed potato handling and storage. The information contained in this guide is based on the combined information form all sources including personal discussions with people mentioned in 'Acknowledgements', colleagues and industry members offering advice after reading about the preparation of this guide in the 'Potato Australia' magazine.

Throughout the guide, references are made in footnotes, if information is taken directly from a certain source.

Storage related Internet information

Australia

Potato web link through Australian Potato Industry Technology Transfer Project – Version 5

http://www.postharvest.com.au/Default.html	(storage)
http://www.sardi.sa.gov.au	(general)
http://www.organicdownunder.com/potato_diseases.htm	(field diseases)
http://www.nre.vic.gov.au/agvic/ihd/r&d/doc-065.htm	(storage diseases)

Overseas

http://oregonstate.edu/potatoes/potliv.html	(link to further potato sites)
http://www.spud.co.uk/	(general)
http://www.gov.mb.ca/agriculture/crops/potatoes/	(general)
http://www.spudman.com	(general including storage)
http://www.css.orst.edu/potatoes/	(general including storage)
http://www.chipweek.co.uk/	(general including storage)
http://www.potatonews.com/directory/directory.asp	(general including storage)
http://www.panhandle.unl.edu/potato/	(potato education site - general)
http://oregonstate.edu/potatoes/potliv.html#Storage	(storage sites)
http://www.kimberly.uidaho.edu/potatoes/	(storage)
http://www.uidaho.edu/ag/plantdisease/pstore.htm	(storage diseases)
http://www.agric.gov.ab.ca/agdex/potato/storage.html	(storage and handling)
http://www.gov.mb.ca/agriculture/crops/potatoes/bda04s04-3-2.html	(storage and handling)
http://www.growermagazine.com/home/2001_potstor09.htm	(storage, variety)
http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/opp4768?opendocument	(bruising)
http://www.mnseedpotato.org	(general and physiological age)
http://www.extension.umn.edu/distribution/horticulture/DG6239.html	(post harvest handling)
http://www.jaybird-mfg.com/	(humidification)

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Assessment, Record and Calculation Sheets

Assessment Sheet 1 - Pre-harvest soil moisture and temperature

A) Soil moisture probe readings

PADDOCK ID:					
PLANTING DATE:					
SOIL TEXTURE:					
Operator name	**Date**	**Time**	**Soil Moisture**	**Temperature**	**Soil Moisture Rating (high, good, low)**

B) Visual soil moisture assessment (refer to next page for guidelines)

Perform 5-10 random checks on up to 3 different days per paddock in the time leading up to harvest, and enter the average assessment rating below. Enter the temperature reading in the column that describes the soil moisture condition.

Date:_________________

AVERAGE SOIL MOISTURE		**1- Dry**	**2- Moderate**	**3- Moist**	**4- Wet**
From top of mould	0 – 15 cm				
	15 – 30 cm				
Between moulds	0 – 15 cm				

Date:_________________

AVERAGE SOIL MOISTURE		**1- Dry**	**2- Moderate**	**3- Moist**	**4- Wet**
From top of mould	0 – 15 cm				
	15 – 30 cm				
Between moulds	0 – 15 cm				

Date:_________________

AVERAGE SOIL MOISTURE		**1- Dry**	**2- Moderate**	**3- Moist**	**4- Wet**
From top of mould	0 – 15 cm				
	15 – 30 cm				
Between moulds	0 – 15 cm				

Comments/Recommendations (ON BACK OF SHEET)

Assessment Sheet 1 - Pre harvest soil moisture (cont.)

Soil Water Status Assessment[1]

SOIL WATER STATUS		BEHAVIOUR OF SOILS SUBJECT TO FIELD TEST		
		Sands, Sandy loams	Loams	Clay Loams, Clays
1	D – Dry	Will flow through fingers or fragments. Will powder.	Will not ball when squeezed in hand. Fragments will powder.	Will not ball when squeezed in hand. Fragments will break to smaller fragments or pads.
2	T – Moderately Moist	Appears dry. Ball will not hold together.	Forms crumby ball on squeezing in hand.	Will ball. Will not ribbon.
3	M – Moist	Forms weak ball but will break easily.	Will ball. Will not ribbon.	Will ball. Will ribbon easily.
4	W – Wet	Ball leaves wet outline on hand when squeezed, or is wetter.	Ball leaves wet outline on hand when squeezed, or is wetter, sticky.	Ball leaves wet outline on hand when squeezed, or is wetter. Sticky.

1. **Dry is below wilting point. Material becomes darker or a lower colour value when moistened.**
2. **Moderately Moist is the drier half of the available moisture range.**
3. **Moist is the wetter half of the available moisture range.**
4. **Wet is at, or exceeding, field capacity.**

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[1] McDonald, R.C. Isbel, R.F. Speight, J.G. Walker, J. and Hopkins, M.S. (1990) Australian Soil and Land Survey – Field Handbook 2nd edn. CSIRO Australia

Assessment Sheet 2 - In-store environment monitoring

Storage Facility____________________________________ Store ID______________

Variety____ Delivery Date__________

Storage Operator/Supervisor__________________________ Contract No___________

Please tick: **Curing phase** ☐ **Storage period** ☐

Date	Average tuber temperature	Humidity		Air temperature		CO_2 % in different positions			
	10 tubers per box for 1 box in every 20 boxes	Supply air	Return air	Supply air	Return air	1	2	3	4

Assessment Sheet 3 - Grading line damage potential

1. Tuber inspection during grading will show if damage occurs.
   20 tubers sampled immediately after each drop point, and other potential damage areas, should be inspected regularly for bruising and splitting.

2. A boiled egg should go over the line without the shell breaking.

3. Spray-painting tubers will show damage points easily if they are sampled from strategic points on the line.

4. An electronic device (electronic potato) can be used to evaluate drops and impacts. Contact your government department for further information

Grading line damage potential test results from painted tubers

Use sufficient tubers and collect a random number after each suspected damage point.
Repeat after fixing damage points.

Date	Number of tubers collected at damage point											
	1		2		3		4		5		6	
	Total	Dam.	Total	Dam.	Total	Dam.	Total	Dam.	Total	Dam.	Total	Dam.

Assessment Sheet 4 - Determining cut seed size

Checking a weighed, sorted **5 kg sample** can determine any required cutter adjustments.

- At the start of cutting each different seed lot, collect a 5 kg sample of cut seed.
- Make up **six containers** for weighed seed pieces (groups 1-6 listed in the table below).
- Weigh each seed piece from the sample using a **scale**, accurately weighing in grams, and place the weighed seed piece in the appropriate container.
- Count the seed piece numbers in each group and record in table.
- To calculate the percentage of pieces in each group, add up the total number of seed pieces (5 kg sample), divide the seed piece number in each group by the total and multiply by 100.

Seed Piece Size Assessment

Cutting Supervisor____________________________ Contract/Job No_______________

Seed Grower/Lot_____________________________ Cutting Date_________________

Variety_____________________________________ Delivery Date_________________

Record dates or number of days

Curing time__________________________________ Storage time_________________

Pre-cutting warming time____

<table>
<tr><th>Group</th><th>Weight class</th><th>Seed piece number per group</th><th>% in each group</th><th colspan="2">Target %</th></tr>
<tr><td>1</td><td>< 29 g</td><td></td><td></td><td colspan="2">0</td></tr>
<tr><td>2</td><td>30 g – 40g</td><td></td><td></td><td colspan="2">0</td></tr>
<tr><td>3</td><td>41 g – 55 g</td><td></td><td></td><td>10-30</td><td rowspan="3">70-75</td></tr>
<tr><td>4</td><td>56 g – 69 g</td><td></td><td></td><td>35</td></tr>
<tr><td>5</td><td>70 g – 85 g</td><td></td><td></td><td>10-30</td></tr>
<tr><td>6</td><td>>86 g</td><td></td><td></td><td colspan="2">0</td></tr>
<tr><td colspan="2">Number of seed pieces in the 5kg sample = Total</td><td></td><td></td><td colspan="2"></td></tr>
</table>

The ideal distribution for, eg. Russet Burbank would be 70 - 75% in groups 3-5 (41 - 85 g), with 35% in group 4 (56 - 69 g).

Assessment Sheet 5 - Early curing environment adjustment

Storage Facility______________________________________Store ID_______________

Variety____Delivery Date___________

Storage Operator/Supervisor___________________________Contract No____________

Soil temperature at harvest	Tuber temperature at harvest	Soil moisture at harvest

Curing approach to take: 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐

1. **If soil and tuber temperature above <u>25^{0}C</u> and soil is <u>dry</u> at harvest:**

- Run the fans and the humidifier continuously during store filling until tuber temperature is 15^{0}C (aim for 95% rh)
- Supply air should be 1-2^{0}C below tuber temperature during cooling down

2. **If soil and tuber temperature above <u>25^0</u>C and soil is <u>wet</u> at harvest:**

- Run fans continuously with the humidifier off until all free moisture is removed from tubers
- Supply air should be 1-2^{0}C below tuber temperature until it is 15^{0}C

3. **If soil and tuber temperature is <u>10 - 15^{0}C</u> and soil is <u>dry</u> at harvest:**

- Run fans intermittently with humidification (aim for 95% rh)
- Supply air temperature 0.5-1^{0}C lower than tuber temperature

4. **If soil and tuber temperature is <u>10 - 15^{0}C</u> and soil is <u>wet</u> at harvest:**

- Run fans continuously without any humidification until tubers are dry
- Supply air temperature 0.5-1^{0}C lower than tuber temperature

5. **If soil and tuber temperature below <u>10^{0}C</u> and soil is <u>dry</u> at harvest:**

- Run fan and humidifier intermittently (aim for 95% rh)
- Supply air temperature 0.5-1^{0}C higher than tuber temperature until tubers are at 10-13^{0}C

6. **If soil and tuber temperature below <u>10^{0}C</u> and soil is <u>wet</u> at harvest:**

- Run fans continuously without humidifier until tubers are dry
- Supply air temperature 0.5-1^{0}C higher than tuber temperature until tubers are at 10-13^{0}C

Once ideal curing conditions are reached (REFERENCE 4), intermittent ventilation is required to provide oxygen.

Record Sheet 1 - Store bin ID and location plan

Storage Facility______________________________Store Number /ID_____________________

Storage Supervisor___________________________

STORE PLAN (copies may be used to record store climate and atmosphere)
Mark doors, location of cooling equipment and fans and numbers rows of bins

Row No.	Date entered store	Variety, generation/ paddock ID	Grower ID	Contract No.	No. of bins	No. of stacks

Record Sheet 2 - Notifications for store operators[1]

Delivery Note to Store - Seed Crop Health Management

Grower / Contract number	
Paddock ID	
Variety	
Planting date	
Harvest date	
Crop spray schedule attached	**Yes ☐ No ☐ Will be faxed to number:**
Disease risks *(please list)*	
Adjustment to curing conditions required *(please list)*	
Adjustment to storage conditions required *(please list)*	

Delivery Note to Store - Harvest Conditions

Grower	
Paddock ID	
Variety	
Planting date	
Harvest date	
Soil temperature at harvest	
Soil moisture at harvest **see** *Assessment sheet 1*	
Adjustment to curing conditions required *(please list)*	
Adjustment to storage conditions required *(please list)*	

[1] In Victoria, a pre-printed seed delivery docket book is available.

Calculation Sheet 1 - Yield and bin estimate

Operator	**Paddock ID**
Date	**Grower**
Planting Date	
Variety	**Generation**

CALCULATIONS		**RESULTS**
Tuber weight / 2 m row [kg]	*Assess in paddock*	
Estimated yield [t/ha]	*= Tuber weight per 2m row [kg] x 6*	
Total paddock area [ha]	*Use planted area, excluding headlands & irrigation runs. Etc.*	
Estimated paddock yield [t]	*= Estimated paddock yield [t/ha] x Total paddock area [ha]*	
Number of bins required for paddock	*= Estimated paddock yield divided by bin capacity – paddock [t]*	
Estimated graded yield [t]	*Deduct % loss on paddock yield (waste tubers)*	
Bin numbers required for grading	*= Estimated paddock yield divided by bin capacity [t]*	

GENERAL GUIDES	
Bin capacity – paddock *(deduct average soil weight depending on soil type)*	½ tonne bin = app. 0.45 tonne tuber capacity – minus 5-60kg (soil) 1 tonne bin = app. 0.95 tonne tuber capacity – minus10-120kg (soil)
Truck capacity	
Bin capacity – post-grading	½ tonne bin = app. 0.45 tonne tuber capacity 1 tonne bin = app. 0.95 tonne tuber capacity

Calculation Sheet 2 – Pre-grading, grading, curing and storage capacity alignment

HARVEST CAPABILITY__________________________tonnes/ha GRADING CAPABILITY_____________________tonnes/hour

STORAGE CAPACITY___________________________tonnes

Consider airflow, headspace and gaps between bins when calculating storage capacities

Crop ID	Variety	Generation	Expected[1] paddock yield [tonnes]	Expected[1] graded yield [tonnes]	Harvest date	Capacity [tonnes] per day	Grading date	Actual graded tonnes per day	% of curing area filled	% of storage area filled

[1] Take from calculation sheet 1

References

Reference 1 - Disinfectants and their use

In most cases, thorough cleaning with hot soapy water or steam, followed by drying will be sufficient and safer than using disinfectants. Bins can be freed of debris, cleaned with a hot pressure washer and dried in the sun for effective sanitation.

Effective sanitation requires a thorough cleaning (avoid sweeping) of all surfaces before a disinfectant is applied. Soil, clay particles and organic material quickly neutralize the biocidal properties of most disinfectants available for potato storage and equipment surfaces.

Most disinfecting materials require that treated surfaces remain wet for up to ten minutes (15 minutes for chlorine) to assure the death of residual bacterial and fungal spores. The addition of a wetting agent to the spray solution may aid in keeping surfaces moist for the required period. When disinfecting solutions are used for dipping knives, crates, picking baskets or foot dip tanks, the solution should be changed frequently, definitely between seed lots, to avoid neutralisation. Residual slime from Ring Rot has been found to survive for up to seven years on protected wooden surfaces. Therefore, steam or pressure washing prior to disinfecting is critical where Ring Rot contamination has occurred. It is very difficult to kill Ring Rot bacteria in contaminated burlap bags. Preferably, contaminated bags should be burned. Contaminated bags must not be re-used for handling seed potatoes.

Material[1]	Effectiveness		Inactivation		Corrosive-ness	Safety	Conc.	Exp.Time	Shelf Life
	Wet Bact, Slime	Dry Bact, Slime	Org. Matt.	HardWater					
Quarternary Ammon. Cpds.	Ex.	Ex.	Slight	No	Slight	Caution	See Label	10 min	1-2 yr
Hypochlorites, 5.25% bleach	Ex	Ex.	Yes	No, ex. Iron	Yes	Irritant, caustic	1:50, 0.1%	10 min	3-4 months. Un-diluted
Iodine Compounds.	Ex.	Ex.	Slight	No, ex. Iron	Yes	Caution	See Label	10 min	1-2 yr
Phenolics	Ex.	Ex	Slight	No	No	Oral poison	See Label	10 min	1-2 yr
Form-aldehyde	Gd.	Poor	No	Yes	No	Unsafe vapour	0.37-1.0%	30 min	1-2 yr
Copper Sulfate	Gd.	Gd.	No	Yes	Yes	Caution	0.1kg/100L	30-60 min	>10 yr as solid

1 [Adapted from: Disease Control Guidelines for Seed Potato Selection, Handling, and Planting, Extension Publication PP-877, North Dakota State University. Registrations may vary. Check with local authorities.

Reference 1 - Disinfectants and their use (cont.)

Comments:

Quarternary Ammonium Compounds:

Diluted solutions are relatively safe but concentrated form is poisonous. Slightly corrosive, use stainless steel containers to make up the solution.

Hypochlorites - 5.25% bleach

Quick acting, inexpensive; caustic to skin and clothing. Use at 1:50 when mixing with water only. For maximum effectiveness, use 1 part 5.25% bleach: 200 parts water: 0.6 parts white vinegar. Very corrosive.

Iodine Compounds

Not for internal use. Becomes ineffective as yellow-brown color is lost. Tamed iodophor compounds work best.

Phenolic Compounds

Provide residual action. These compounds show "phenol" in the list of ingredients.

Formaldehyde

Produces irritating, choking fumes. Not generally recommended due to OH&S issues.

Copper Sulfate

Not widely used; mostly for soaking crates and bags.

Chlorine based disinfectants

They are one of the popular groups of disinfectants used in the industry. Chlorine is a surface sterilant. Chlorine does not disinfect the internal tissue of the potato but does prevent the build-up of disease-causing fungi and bacteria on the surface. The most common chlorine-based disinfectants are sodium hypochlorite, chlorine dioxide and calcium hypochlorite. The hypochlorite containing chlorine compounds form the spore-killing active ingredient hypochlorous acid when added to water. In this case the disinfectant activity of a chlorine solution is influenced by its pH. pH is the measure of whether a solution is acidic or alkaline. The lower the pH (more acidic), the greater the amount of hypochlorous acid formed from the chlorine compound. This is why it is important to apply the right mix in water. At very low pH levels, odour problems and corrosion of equipment will occur. At levels above pH 7.5 (slightly alkaline), hypochlorous acid will dissociate to form the hypochlorite ion, which is less toxic to fungi and bacteria. Therefore, for the most effective chlorine disinfectant, the pH should be maintained between 6.0 and 7.5. At this pH, the damage to the equipment will also be minimal. The pH of the tank mix can be checked by using pH test paper (which changes color at different pH's) or by using pH meters. The chlorine dioxide-based disinfectants are active at a pH range from 2.3 to 2.5.

Other factors to consider when using chlorine disinfectants

- Organic Matter: Organic matter reacts with chlorine to lower its effectiveness. The more organic matter in the solution, the more chlorine is tied-up. This organic matter in the water can be a critical problem. Consequently, flumes and dump tanks should be cleaned at regular intervals, definitely between seed lots.
- Temperature: Chlorine exhibits a complex reaction to temperature. Generally, as temperature increases chlorine becomes more active as a disinfectant. However, raising the temperature increases the ability of organic matter to tie-up chlorine. In addition, raising the temperature also speeds up the loss of chlorine into the atmosphere.

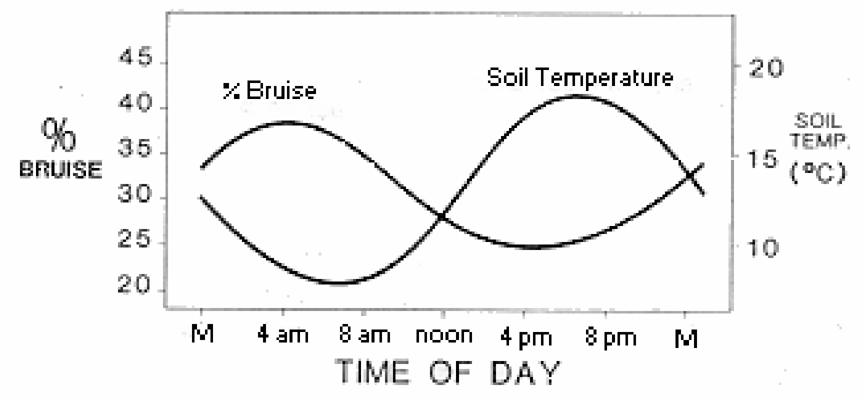
Reference 1 - Disinfectants and their use (cont.)

- Exposure time: As exposure time to chlorine is reduced, less disinfection occurs. A minimum of 15 minutes of exposure to chlorine is required for adequate disinfection. However, efficient disinfection depends upon accurately monitoring the concentration of chlorine in the tank. Treatment is most effective when chlorine is metered continuously. It is ineffective to simply dump chlorine into the tank. For fungi, an effective concentration of 500 ppm of free chlorine is required. This is not a case where "if a little is good, more is better". If the concentration of chlorine is too high, or if the pH of the chlorine solution is too low, chlorine gas is wasted into the air. This creates an odor problem, wastes chlorine, and corrodes equipment. It is better to meter in the chlorine and control the pH of the solution than to double the amount of chlorine in the solution. An automatic dosing system is recommended.

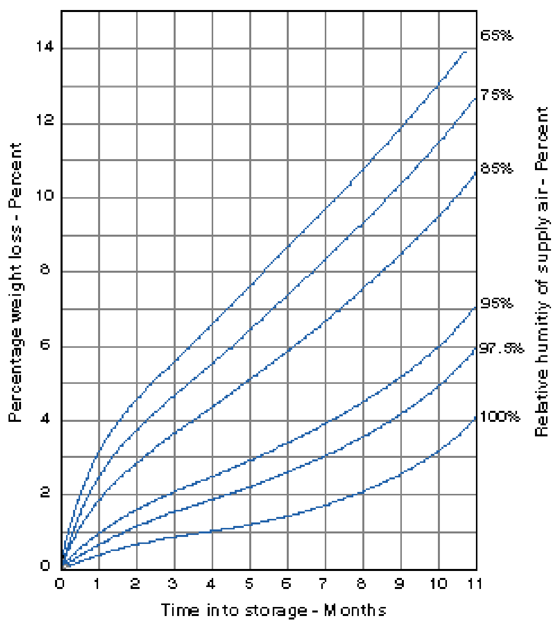
In addition to the disinfectants in the above table, live steam can be used to sanitise. The temperature of the steam contacting the surface to be disinfected must exceed 66°C. Caution: Do not confuse condensed water vapor with colourless steam. Condensed water vapor (clouds) may be at less than the required temperature. Exposure time should be five seconds for fresh, wet bacterial material, and 20 seconds for dried bacterial material. Steam must be used properly to be effective. Do not rush steam cleaning. Steam may be more useful for equipment, rather than the entire store, because of the need for high temperatures and the small surface area covered with a steam appliance.

Reference 2 - Temperature and hydration effects on physical tuber damage and tuber weight

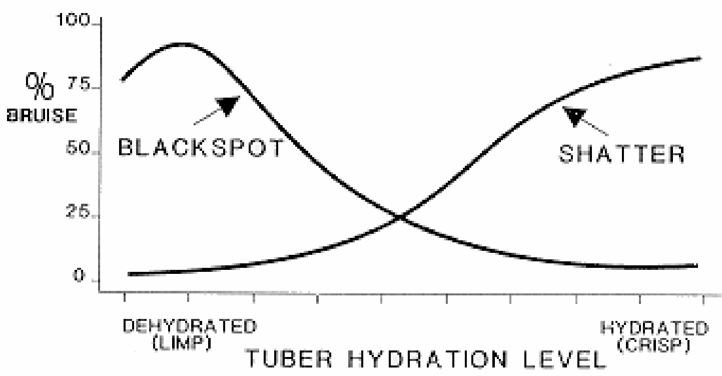
Relationship between soil temperature, tuber damage, and time of day during potato harvest



Weight loss as influenced by relative humidity and storage time

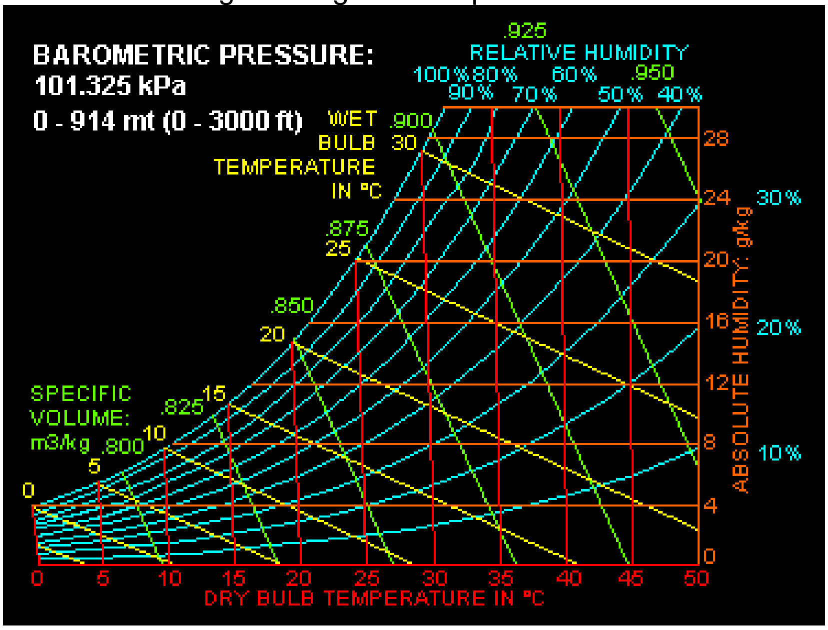


Effects of tuber hydration level on shatter and black spot bruise at 7 to 10°C



Reference 3 - Condensation and weight loss [1]

Psychrometrics concerns the relationship between water vapour and dry air. An understanding of psychrometric conditions in a potato store provides valuable insight to storage management that will give a more complete picture of both humidification and condensation. Since a principal element of psychrometrics is temperature, no other single subject is more fundamental to effective storage management of potatoes.



The psychrometric chart (above) shows the following properties of moist air:

1. Dry bulb (=air) temperature (vertical lines: 0-50^{0}C)

2. Absolute humidity (horizontal lines: 0-28 g/kg)

Absolute humidity is the water vapour content of air, given in grams of vapour per kilogram of air (g/kg). Air at a given temperature and pressure can support only a certain amount of moisture and no more. This is referred to as the dew point (or saturation humidity). When plotted on a graph against the dry bulb (air) temperature, it gives the basis of a psychrometric chart showing what is called the saturation humidity or dew point line.

3. Relative humidity (curved lines leading to right side of graph: 10-30% and curved lines leading to top of graph: 40-100%).

Relative humidity (rh) is an expression of the moisture content of a given atmosphere (eg. the potato store atmosphere) as a percentage of the saturation humidity at the same temperature.

4. Wet bulb temperature (moderately steep diagonal lines: 0-30^{0}C)

Wet bulb temperature is measured by a hygrometer (or psychrometer). It consists of two thermometers, one of which is measuring the dry bulb or air temperature. The bulb of the second thermometer is enclosed in a wet wick. The wet wick thermometer is cooled down by the evaporation on the wick. The wet bulb temperature is reduced by the amount of evaporation from the wick, which depends on air temperature and humidity. It is, therefore, a direct indication of the moisture carrying capacity of the air at that temperature and that wet bulb temperature.

5. Specific volume (steep diagonal lines: 0.800 - 0.900 m^3/kg)

This is useful for the conversion of volumetric airflow quantities into mass-flow rates, eg. in air conditioning calculations. It does not have to be considered in the following explanation.

[1] Adapted from: Hesse. B., 2000; Storage for the new millennium – Part 3. Spudman, Vol. 7, September/October 2000.

Reference 3 - Condensation and weight loss (cont.)

If any two of the properties in the psychrometric chart are known, the others can be determined from it.

A major benefit from the psychrometric chart concerns condensation. Condensation means that air at a given state has been cooled to dew point temperature. For instance, relatively warm, moisture saturated (outside) air supplied to several degrees cooler than potatoes in the store will hit dew point (saturation humidity). The cooler potatoes will get soaking wet from condensation.

For example, pulp temperatures of 16^0C for incoming, freshly harvested seed requires a store supply air set point of 15^0C; a sudden weather change reduces pulp temperatures coming into the store to 10^0C. The psychrometric chart will show, eg., that 15^0C supply air at 70% relative humidity, cooled to 10^0C will hit dew point (saturation humidity), and water will condense on the 10^0C potatoes.

Another benefit of the psychrometric chart is that it shows what happens during early storage when moisture saturated supply air enters a warmer stack of bins during harvest. Pulp temperatures from 15-16^0C are not uncommon during harvest. The psychrometric chart will show what using a 10^0C supply air set point does when 10^0C saturated (humidified) air is warmed by the warmer potatoes. Warm air can hold more moisture, so the relative humidity drops. This means during early storage that if the seed is quite warm relative to the supply air temperature, the tubers will be subjected to undesirably low humidity, even if the supply air is close to saturation. This situation will be even worse if relatively warm tubers are shifted straight into stores running at low temperature, without humidification. If the seed has not been cured sufficiently, the water, and thus weight loss, of tubers will be substantial. The graph of weight loss as influenced by relative humidity (REFERENCE 2) highlights the importance of humidity control and avoiding placing warm tubers straight into substantially colder temperatures.

The graph shows that with a supply air relative humidity of 95%, and a storage period of seven months, the total weight loss would be about 4%. Actual weight loss in storage for a seven-month storage period is often much greater. The slope of the 75% rh weight loss curve is not substantially different from the 95% rh curve. After the first month or two in storage, weight loss potential is not drastically affected by supply air relative humidity. The 75% RH curve is somewhat steeper after two months of storage than the 95% curve, but during the first month and a half of storage, the rate of weight loss is highly dependent on the supply air relative humidity. The conditions during suberisation, and thus the degree of suberisation achieved, will largely determine the amount of weight loss during the in-store period.

Reference 4 - Ideal curing / early storage conditions

Ideally, for effective suberisation, potatoes are harvested when the pulp temperature is around 15^0C, and for this condition the initial storage temperature is set 1^0C lower than harvest pulp temperatures. A continuous supply of air, at a slow rate, will help equilibrate the pulp temperature, reducing the chances of temperature differential in different areas of the store. The relative humidity should be maintained at 90-95% unless the tubers are wet or diseased (see below). Once the store is filled to capacity, tuber temperature is best maintained at 10-13^0C for two to three weeks to cure the potatoes (suberisation = healing of wounds). This would include the time for bringing the pulp temperature to 10-13^0C. If rot problems are expected eg. silver scurf infection or soft rot, a curing temperature of 9-10^0C and a humidity of 85-90% may be required. Forced ventilation is essential during curing to get rid of respiratory heat and carbon dioxide (CO_2) and supply oxygen (O_2) to all tubers. Once the curing is complete and tubers are suberised, the pulp temperature is slowly cooled to the final storage conditions. Exceptions

Although the above conditions are the optimum for curing, there may be exceptions. For example, if bad soft-rot or *Pythium* infection is suspected, the best curing temperature is below 10^0C, which means that the actual set temperature is much lower while the store is being filled.

In some cases, the initial store temperature is set at 9-10^0C during the entire filling period, running the fans only at night for 3 to 4 weeks. Subsequently, tuber temperatures are decreased gradually, at the rate of about 0.5^0C per week; or when return air gets within 1^0C of set point, the set point is decreased by 0.5^0C. This procedure is continued until the tubers are down to holding temperature. This practice may minimise the incidence of silver scurf disease.

If the weather is too warm during the day (pulp temperatures at or above 25^0C), the best time to harvest is in the morning or late evening. It is important to note that if the warm weather persists, the primary objective should be to remove the field heat first. These potatoes should be cooled as they are put into storage using ventilating air at 10-13^0C. This temperature, along with 90-95 % humidity, is ideal for suberising and wound healing.

Is there an advantage in rapid cooling of seed?

It is generally believed that decreasing the initial store temperatures quickly to near holding conditions may help to prevent storage disease problems. However, this procedure is not without its risks for normal or over-mature tubers. One disadvantage of rapid cooling is that tubers at the bottom of bins may show pressure flattening and excessive shrinkage loss. This is due to the temperature of cool air entering the area of warm potatoes increasing, thus reducing its vapor pressure. As a result, the air around the tubers will have a vapor pressure deficit, compared to the internal water content of the potatoes. This will force the internal water to move out of tubers to compensate for the deficit. The moisture loss will affect the integrity of the internal cell structure of the potato. In addition, the potatoes at the bottom of bins are subjected to significant pressure due to the weight of tubers above them, especially in 1 tonne bins. This increases the risk of pressure bruises and shrinkage losses.

The second disadvantage of rapid cooling is, if faced with a long spell of warm weather during/after cooling down, fresh air intake will have to be stopped for extended periods, which deprives the seed of oxygen (O_2), leading to a build-up of carbon dioxide (CO_2). Over-mature seed will be particularly sensitive to this situation. Cold temperatures and elevated carbon dioxide tend to slow down the wound healing process.

Reference 4 - Ideal curing / early storage conditions (cont.)

Cool down to holding condition after curing

The temperature of ventilating air is reduced at the rate of 0.5-1ºC per day until holding conditions are reached. Measurement of pulp or return air temperature is used to drive the process. Pulp temperature measurement is the more accurate method. If the return air temperature is within 0.5-1ºC of the set temperature, it will be necessary to lower the set temperature at the rate mentioned above. The best time to measure the return air is early morning, because the store would have had an extended period of cooling during the night. During cool down, ventilation should always run. Once the conditions inside the store have stabilised, daily ventilation should be long enough to maintain a 0.5-1ºC differential between bins at the bottom and top, and back and front of the store. Increasingly, fans are being run in shorter cycles (at the rate of 2 to 4 hours per run and a break of at least 2 hours). The shorter cycles tends to reduce extreme temperature differences within the store. If the fans are stopped for long periods, the tubers tend to warm up; therefore, the entire load will require more time cool down to holding temperature. Store managers are advised to check the efficiency of the air system before making any changes to ventilation.

Days to various stages of wound healing (suberisation)

Temperature [^{0}C]	Light suberisation	Complete suberisation	Start of periderm formation	Two layers of wound periderm formed
2.5 – 5[1]	7-14	21-52	28	28-63
10	4	7-14	7-14	9-16
20[2]	1-2	3-6	3-5	5-7

(Summarised from various authors listed under 'Further Reading)
The listed time periods apply at optimum humidity

[1] Some authors claim that there will not be complete suberisation at low temperatures.
[2] The risk of disease expression and spread is high at high temperatures.

Reference 5 - Curing environment adjustment for harvest condition

[1]Ideally, potatoes are harvested when the following conditions are met:

- Good skin set;
- Availability of cool air during the night if store/curing set up is not refrigerated;
- Appropriate soil moisture to move the harvester without clods;
- Pulp temperatures at or around 15^0C.

In some cases, the condition of the soil and pulp temperatures may be far from ideal, and adjustments in the initial storage settings may be required. Some general guidelines to correct extreme conditions are as follows:

For extremely warm and dry soil harvest condition

1. Run the fans and the humidifier continuously while filling the storage and for the first day or two.
2. Modulate the incoming air temperature to no less than 1^0C of the pulp temperatures. If possible, take advantage of existing high air capacity using the outside cool night air, and decrease ventilation during the day if warm temperatures persist. Refrigerated storages can use the refrigeration to remove the field heat; however, close monitoring of the tuber temperature is required because gradual cool down is better than rapid cooling.
3. Once the pulp temperatures reach 10-13^0C (10^0C is better if a condition of *Phythium* leak or soft rot is suspected), normal suberising conditions can be set.

For extremely warm weather with wet soil harvest condition

1. Run fans continuously (with the humidifier off, if installed) until all free moisture on the surface of the potatoes is removed.
2. Modulate the incoming air to about 1^0C less than the pulp temperature.
3. Once pulp temperatures reach 10-13^0C, regular suberising conditions can be set.

Cool weather (10-15^0C) with dry soil harvest condition

1. The potato pulp temperatures are already at or around curing temperature. In this case, run fans intermittently so that the pulp temperature equilibrates, and this will also help to provide the required oxygen for curing the potatoes.
2. If possible, use a fresh air intake temperature close to the existing pulp temperature.
3. If daytime temperatures increase drastically, the fresh intake may be reduced or closed and internal air can be re-circulated to equilibrate the tuber temperature.
4. Potatoes brought into the storage under these circumstances need 2 to 3 weeks to complete wound healing at 10-13^0C and with 95% relative humidity.

1 Adapted from Shetty, K.K., 2001; Potato storage management for disease control. Publication by Potato Storage Research, Kimberly Research and Extension Center, 3793 North 3600 East, Kimberley, Idaho 83341

Reference 5 - Curing environment adjustment (cont.)

Cool weather (10-15^{0}C) with wet harvest condition

1. It may be possible to windrow potatoes that are being dug wet. This will help to dry the surface of the tubers.
2. Wet conditions on the surface of tubers will encourage diseases and also block air exchange through the lenticels. If the pulp temperatures are near curing condition, the fans need to operate continuously without any humidification. This will dry the surface of the tubers.
3. The air entering the store should be slightly (0.5-1^{0}C) lower than the pulp temperatures.
4. Once the potatoes are dried, normal curing conditions of 10-13^{0}C should resume, with 95% relative humidity. These potatoes require a 2 to 3 week curing period because they came in cool.

Cold weather (5-10^{0}C) with dry soil harvest condition

1. Under these conditions, potatoes are very susceptible to bruises and need to be handled carefully.
2. There is no need to remove the field heat in these potatoes, but instead the potatoes may need to be warmed up to 10-13^{0}C. To achieve this, the fans can be run intermittently, and this will help the potatoes to increase the temperature on their own accord due to the heat of respiration. This heat may be required for a short time.
3. Humidification is required under this situation and can be timed along with the fans.
4. If this weather condition persists while filling the storage, continue the intermittent fan operation with humidity until the storage is filled and closed. On the other hand, if the weather warms up then the set points need to be adjusted accordingly. It is advisable to pay extra attention to the potatoes brought in last.

Cold weather (5-10^{0}C) with wet soil harvest condition

1. The first requirement, as soon as the potatoes are brought into storage, is to dry the surface of the potatoes; therefore, continuous running of the fans may be required without any humidity added.
2. The cold wet condition may slow down the drying; therefore, supplemental heat could be provided to warm the tubers slightly.
3. When drying is complete, intermittent ventilation will provide the required oxygen, and at the same time spread a little of the heat of respiration to warm the stack.
4. Once the potatoes reach curing temperatures of 10-13^{0}C the potatoes can be cured for 2 to 3 weeks, with 95% relative humidity.

Reference 6 - Seed treatment – fungicides and active ingredients

Properly suberised and treated seed will provide a better, more uniform stand of plants. Correct application of the appropriate material, under suitable conditions, is necessary to protect tubers from disease. Too much chemical may be phytotoxic, especially if accumulated in the eyes of the tubers. Sweating and condensation on tuber surfaces may lead to phytotoxicity. Inadequate coverage may not totally protect seed pieces.

Dust formulations are preferable for cut seed. Some seed treatments are now formulated with bark as a carrier, or should be used in combination with bark seed dressing, for improved healing of cut surfaces.

Australia[1]

Fungicide	**Active ingredient**	**Diseases controlled**
Formalin	formaldehyde	*Rhizoctonia*
Fungaflor	imazalil	*Fusarium*; Silver scurf, Gangrene
Maxim	fludioxinil	*Rhizoctonia*, Silver scurf, Black dot
Moncerene	pencycuron	*Rhizoctonia*
Rizolex	tolclofos-methyl	*Rhizoctonia*
Rovral	iprodione	*Rhizoctonia*
Shirlan	fluazinam	Powdery scab
TBZ	thiabendazole	*Fusarium*, *Phoma*, Gangrene

<u>CAUTION:</u>
Always refer to label instructions and Material Safety Data Sheets when using fungicides.

Train your staff in responsible handling of chemicals.

Do not use unregistered products.

Dip treatments are not recommended, as they can spread pathogens to seed pieces that were previously not affected.

Do not use treated seed for food, feed or fodder.

[1] Source: South Australian Research and Development Institute 2001

Reference 6 - Seed treatment (cont.)

USA[1] - Examples of active ingredients, diseases controlled and efficacy ratings

Seed Treatment (active ingredient)	Diseases controlled and efficacy rating					
	***Rhizoctonia* on stems and stolons**	***Rhizoctonia* on daughter tubers**	***Fusarium***	**Silver scurf on daughter tubers**	**Seed-borne Scab**	**Seed-borne Late blight**
thiophanate – methyl, mancozeb, cymoxanil formulation[2]	E	P	E	G	E	E
fludioxinil	E	E	E	E	P	P
fludioxinil MZ	E	E	E	E	E	G
Flutolanil[2] MZ	E	E	E	E	E	G
thiophanate - methyl[3] 2.5D	E	P	E	P	P	F
thiophanate - methyl 5D	E	P	E	P	P	F
thiophanate - methyl MZ	E	P	E	G	E	G
thiophanate - methyl MZ plus Imidacloprid[4]	E	P	E	G	E	G
E=Excellent, F=Fair, G=Good, P=Poor						

CAUTION:
Always refer to label instructions and Material Safety Data Sheets when using fungicides.

Train your staff in responsible handling of chemicals.

Do not use unregistered products.

Dip treatments are not recommended, as they can spread pathogens to seed pieces that were previously not affected.

Do not use treated seed for food, feed or fodder.

[1] Source: University of Maine potato 2002 pest management guide (IPM)
[2] US Trade name: Moncut - Not registered for potato seed in Australia
[3] Australian trade name: Tecto
[4] Confidor insecticide: Not registered for potato seed in Australia

Reference 7 - Summary of field diseases causing storage problems

<table>
<tr><th>Disease & relevance to storage</th><th>Symptoms</th><th>Favourable conditions</th><th>Prevention</th></tr>
<tr><td>Soft Rot
(Erwinia carotovora pv carotovora)

Causes breakdown in storage</td><td>An unpleasant odour in storage: degeneration of tubers into a rancid pool of slime.</td><td rowspan="2">Thrives in warm, moist conditions. Needs wounds to infect. Bacteria and fungal spores are widespread. However, these diseases do not become serious if tubers are healthy, mechanical damage is minimised, and sanitation is good.
The diseases can be spread with seed.</td><td rowspan="2">A total disease management program to maintain good tuber resistance.
Good storage practices prevent spread of rot organisms.</td></tr>
<tr><td>Dry Rot
(Fusarium spp.)
Causes breakdown in storage</td><td>Potato flesh turns dry and grainy, large hollow cavities develop inside tuber.</td></tr>
<tr><td>Pink Rot
(Phytophthora erythroseptica)

Causes breakdown in storage</td><td>Wilting occurs, usually late in the season. Aerial tubers form.
Brown spots develop on potato skins; the flesh becomes soft and mushy and turns pink when cut.
A clear line can be drawn between healthy and diseased areas of infected tubers.</td><td>A soil borne disease that develops in very wet areas subject to poor drainage, heavy precipitation or irrigation.</td><td>Plant seed tubers in soils with good drainage.
Spray with a combination contact/systemic product.
Avoid excessive irrigation late in growing season.
Minimise mechanical damage during harvest.</td></tr>
<tr><td>Pythium Leak
(Pythium ultimum)

Causes breakdown in storage</td><td>Potato skin looks bruised, tubers become soft and the skin moist.
After infection, skin ruptures and tuber exudes liquid with slight pressure.
A clear line can be drawn between healthy and diseased areas of infected tubers.</td><td>Infection usually occurs at harvest as tubers come into contact with spores in the soil.
Spores are released into films of soil water when soil temperatures exceed 18^0C.</td><td>Spray with a combination contact/systemic product.
Delay harvesting until tuber skins are mature.
Avoid mechanical injury.
Increase ventilation if rot occurs in storage area.</td></tr>
</table>

Reference 7 - Summary of field diseases causing storage problems (cont.)

Disease & relevance to storage	Symptoms	Favourable conditions	Prevention
Late Blight *(Phytophthora infestans)* Causes breakdown in storage	Leaves and stems develop brownish spots that spread rapidly under wet conditions. Skin turns purple and looks bruised. Flesh appears grainy and turns to orange, tan or brown.	High humidity (95%), for 18 hours or more per day, especially in lush canopies. Failure to identify and treat early can result in significant crop loss.	Follow a total disease management plan. Apply a combination contact/systemic product. Consult Late Blight forecasting services, if available, for recommendations on risk of Late Blight occurrence and fungicide spray intervals.
Silver Scurf *(Helminthosporium solani)* Transmitted during storage	Unsightly silver to gold blemishes develop along with black specs. Skin may thicken, creating a rind.	The fungus that causes the disease is distributed on tubers and survives in the soil and in dust in the store. Wet tubers (condensation) support the disease spreading.	Regular crop rotation. Good sanitation and culling practices. Proper hygiene and storage conditions.
Black Dot *(Colletotrichum coccodes)*	Early vine decline, small pepper like specs on dying stems and tubers.	Can remain in the soil for long periods, can be spread on tubers and in dust from the store and soil. Latent infections that are not detected at harvest may occur frequently. The pathogen is able to develop at low temperatures, especially if free moisture is available.	Rotation, fungicide treatment (in-furrow, seed piece, foliar). Proper hygiene and storage conditions.

Reference 8 - Management of storage problems[1]

Non disease related problems

Sprouting

- Keep tuber temperature below 5°C
- Keep store and tuber temperature steady

Shrinkage and Softening

- Minimise handling damage
- Control sprouting
- Store mature crops with good skins
- Cure adequately
- Store at coolest temperature acceptable
- Ventilate intermittently, as required, for temperature control
- Maintain high humidity, particularly when outside air is used for cooling

Pressure Bruising

- Store mature crop, vine-kill if required for timely skin set
- Cure adequately
- Minimise shrinkage (high humidity)
- Pressure damage is related to time in storage

Bruising

- Minimise handling damage
- Mature crop
- Use a fungicide when filling storage
- Manage crop nitrogen; do not overfeed

Condensation on top of stacked bins or on ceiling

- Ventilate through the stack
- Ventilate continuously; some air can be re-circulated over the stack of bins
- Add heat to back of storage so it warms the air returning over the bin stack by about 2°C
- Have adequate ceiling insulation
- Dark coloured ceiling is better

[1] adapted from: Potato storage and handling. www.agric.gov.ab.ca

Reference 8 - Management of storage problems (cont.)

Disease related problems[1]

General

- Avoid problems by harvesting dry, sound potatoes with a pulp temperature between 7-13^{0}C.
- For blighted potatoes, if possible, wait a few days for symptoms to fully develop before harvest.
- Grade on the harvester; this may need additional people.
- Grade prior to storage; provide sufficient light, people and time to do the job properly.
- Have your storage ready (and at the proper temperature) with the air delivery and control systems in good order. Be certain you provide adequate airflow rates in all areas of the store. Add portable systems to otherwise airless stores. Good air movement is absolutely essential for storing problem potatoes.
- Omit the traditional curing period. Since problem potatoes are usually wet and infected with decay organisms, the goal is to cool and dry the crop as quickly as possible.
- Quickly cool to the final storage temperature (3-5^{0}C). Do not humidify; the potatoes are probably much too wet already.
- Run fans (install additional ones, if needed) continuously until the crop is dry and decay is under control. Circulate air through the potatoes at all times during the problem period, even when not pulling in outside air.
- Promote air movement through bins (DIAGRAM 1). Rotting potatoes and dirt form barriers to air movement.
- Monitor the store daily. Thermometers in various positions in the store provide a good indication of the average temperature. Infrared "guns" are helpful in locating hot spots before they begin to smell and spread.
- Do not expose cold potatoes to warm outside air. A layer of free water will condense on the tubers. Try to use air no warmer than about 1^{0}C above the desired tuber temperature. Water on the tubers tends to suffocate the tubers, while at the same time favoring soft rot bacteria.
- When unloading the store, do not wash dry seed potatoes unless they are covered with dried slime. Washing will probably help wet, slimy seed. If you do wash seed, use sprays as opposed to a dip tank. Try to use multiple nozzles so that all surfaces are washed clean. Misting washed potatoes with a 10% sodium hypochlorite solution is recommended (check the labeling). Add 10 L bleach to 90 L water and mix well before applying in a well-ventilated area. Problem seed, which requires washing, should be planted as soon as possible, provided soil conditions are suitable.

[1] Adapted from: Shetty, K.K., 2001; Potato storage management for disease control. Publication by Potato Storage Research, Kimberly Research and Extension Center, 3793 North 3600 East, Kimberley, Idaho 83341; and
Anonymous, 2001; Disease Control Guidelines for Seed Potato Selection, Handling, and Planting, Extension Publication PP-877, North Dakota State University.

Reference 8 - Management of storage problems (cont.)

Disease related problems - related to specific diseases

Soft rot in storage is caused by the bacteria *Erwinia caratovora*

Disease characteristics

1. The soft rot infection that occurs in the field via infected stolons of mother plants is called black leg. There may be some vascular discoloration in the stem end and sometimes sunken black tissue extending deep into the tuber flesh.
2. In storage, the bacterial soft rot organism is opportunistic and can cause severe problems in association with other diseases.
3. Infection can enter through lenticels and wounds and external infected areas can be tan to dark brown with water soaked texture to the skin.
4. Internal soft rot tissue is wet, mushy or creamy, associated with white to grayish-brown ooze. The affected areas will show a black border separating it from the healthy tissue.
5. During the early stages of soft rot the decay is odourless, but eventually a foul odour will develop. When large amounts of tubers are affected, there may be a characteristic ammonia like smell in the storage. If the decay dries out, the affected areas will be chalky white.
6. The ooze from decaying potatoes can initiate soft rot in surrounding tubers by blocking their respiratory passages.
7. A seed lot that is severely affected by this disease may show one or more of the following characteristics:
    a. The volume in the bin may appear to decrease;
    b. A thick dark liquid may run from bins;
    c. Heat may be generated and can be near or over affected bins. An infra-red heat detecting instrument can differentiate healthy from affected lots;
    d. Generally, a severely affected lot will emanate a foul odor.

Causes:

1. Extreme wet conditions during growth and harvest.
2. Poor weed control. Weeds tend to harbour this organism.
3. Infected seed will increase the chances of infection in progeny tubers.
4. Harvesting immature tubers.
5. Harvesting when temperatures are above 20°C.
6. Excessive air leaks into the storage, along with dysfunctional louvers.
7. Free moisture on tubers (condensation, poor airflow / ventilation).
8. Adding excessive soil with the tubers into storage and failure to remove vines and clods. These things will lead to compact loads in bins, impede air movement and thus cut off oxygen supply and carbon dioxide removal.
9. Diseases, such as water rot and dry rot, will facilitate soft rot infection.
10. Excessive bruising and improper wound healing will promote soft rot infection.

Management:

There is little information to support the use of bactericides or disinfectants through humidification to directly control bacterial soft rot in storage. From a store management perspective, the following may be considered:

1. Store and bins must be thoroughly cleaned (and disinfected if diseased potatoes were stored previously) before use.
2. Store seed from healthy crops only (certified seed), which had monitoring of watering and nutrition, and good weed, insect and disease control during production.
3. Encourage good skin set and maturity before harvest.
4. Harvest with care and prevent bruising, do not harvest wet tubers.
5. If only some loads are suspected to have soft rot infection, place these potatoes closer to the access doors so that they can be removed quickly if they begin to deteriorate.

Reference 8 - Management of storage problems (cont.)

6. If a high percentage of the disease is noticed during pre-harvest checks or harvest, use little or no humidity with continuous airflow during curing/early storage.
7. Proper curing of healthy potatoes for 2 to 3 weeks at 10-13°C and 95 % humidity.
8. Do not cure at higher temperatures (>15^{0}C).
9. Keep tuber pulp temperature low (below 5°C)
10. If the disease is seen after curing, the temperature pull down to holding conditions should be rapid, with a lot of air movement through the bins.
11. Prevent condensation on tubers. Ventilation systems are available that can provide a continuous but low speed supply of air for better temperature equilibration throughout stacked bins. This prevents free moisture formation and also provides oxygen and removes carbon dioxide.
12. Use supplemental air, ventilate continuously without humidification, for severely affected lots; isolate them, if possible, for that treatment.

Dry rot is a fungal disease caused by *Fusarium sambucinum* and other *Fusarium* spp.

Disease characteristics

1. This fungus can be both seed and soil borne.
2. The fungus enters tubers through wounds and bruises inflicted during harvest and handling operations.
3. Generally, this disease can be detected under a bruised area in a tuber. Internally, infected tuber areas are black and white with a crumbly decay. The spread inside the tuber is irregular but there are distinct walled-off areas between the healthy tissue and the affected tissue.
4. The external surface of the affected areas can be sunken and wrinkled.
5. Occasionally, white or pink fungal growth may be seen outside.
6. Secondary bacterial soft rot may eventually take over the dry rot problem.

Causes

1. Temperatures above 10°C generally favour the fungus.
2. This disease is usually seen if growing conditions are dry.
3. This disease can spread quickly if potatoes are improperly cured during the first 2 to 3 weeks.
4. Generally, this disease is a problem if potatoes are mixed with too much soil.
5. Bruising of potatoes during harvest and handling will encourage infection.

Management

1. Minimise bruising during harvest and handling.
2. Avoid harvesting potatoes when pulp temperatures are cold because cold potatoes are highly susceptible to bruising.
3. Ensure proper skin set and maturity of the potatoes before harvest (vine kill, if required).
4. Remove excess dirt and clods during harvest and before curing.
5. Post harvest treatments of dirt free tubers are recommended.
6. A curing environment of 13°C with 95% relative humidity encourages wound healing. Wound healing is complete in 2 to 3 weeks.
7. When curing is complete, gradually reduce the temperature at the rate of 0.5°C per day until holding conditions are reached.

Reference 8 - Management of storage problems (cont.)

Pink rot is a fungal disease caused by *Phytopthora erythoseptica*

Disease characteristics:

1. This is a soil borne fungus.
2. When plants and tubers are infected in the field, the plants may show wilting symptoms and the leaves may appear chlorotic.
3. Potato tubers are infected through the eyes, lenticels and wounds, and this usually occurs in the field.
4. The affected external tissue on the tuber may show brown discoloration, especially around natural openings such as the lenticels and in the eyes.
5. Internally, the infected area spreads almost in straight line across the potato tissue.
6. When affected tubers are cut, the internal tissue is spongy and turns pink in 30 minutes.
7. Eventually the affected tissue can express a clear watery odorless fluid when squeezed.

Causes:

1. Pink rot infection is likely when the potato plants and tubers are subjected to water saturation in the fields.
2. Warm temperatures (above 35°C) late in the growing season will support development of the disease.
3. Soft rot bacteria can eventually infect pink rot infected potatoes, and cause rapid deterioration of the tubers, resulting in a foul smell.

Management:

1. Avoid excess watering late in the growing season, particularly if temperatures stay above 35°C.
2. Look for this disease in low-lying water stagnated areas of the field, eg. around the pivot shaft. If detected, handle these potatoes separately after the rest of the field is harvested. Delay harvest of these potatoes and confirm the presence of pink rot. If confirmed, disregard and avoid harvesting. If harvested, sort and discard.
3. If potatoes in the field are affected in pockets, and the choice is to harvest along with other healthy potatoes, pay extra attention during grading, and discard the affected potatoes away from storage buildings. These potatoes should be placed last into storage, closer to the access doors, so that they can be removed first, or removed if and when they begin to deteriorate.
4. If the disease is detected after the potatoes are in storage, provide adequate airflow. The early curing condition should be 7-10°C for the length of time it takes to dry the potatoes. If only a small portion of the stack is affected, the healthy potatoes should be cured at 10°C. Subsequently, a rapid cooling to holding condition may be advantageous. Continuous airflow is a must during this period.

Reference 8 - Management of storage problems (cont.)

Pythium leak is a fungal disease caused by *Pythium ultimum*

Disease characteristics

1. *Pythium* is a soil borne fungus.
2. The fungus normally infects through natural openings on the surface of the potato.
3. The internal affected areas are usually clearly demarcated from healthy tissue by a dark boundary.
3. Rotted tissue is spongy, and affected areas may deteriorate internally leaving the skin and cortical area intact. This is often referred to as shell rot.
4. Cut tissue will turn white to gray to dark brown.
5. The disease can show within 2 to 3 weeks in storage. The first sign of the problem appears as wet spots on the surface of the bins, resulting from watery fluid from affected tubers.

Causes

1. There is a high potential for this disease to occur under extremely wet conditions in the field followed by a short period of dryness during tuber maturation.
2. The disease is particularly troublesome when pulp temperatures exceed 20°C.
3. *Pythium* increases the risk of infection by bacterial soft rot in storage. Although *pythium* does not spread in storage, bacterial soft rot will.

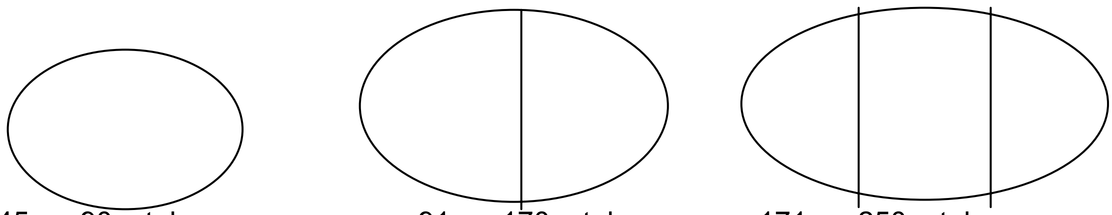
Management

1. Collect tubers from suspected areas in the field and place them in a plastic bag under warm (room temperature) conditions. Affected potatoes will decay rapidly. If confirmed, avoid harvesting these potatoes. If harvested, grade and discard infected tubers.
2. Generally avoid harvesting potatoes under extremely warm conditions.
3. Avoid mechanical injury to the potatoes during harvest.
4. If significant amounts of potatoes are affected, it is advisable to cure between 7-10°C for a minimum of 3 weeks.
5. If the disease persists, consider rapidly cooling the potatoes to 3-7°C. Provide continuous forced air until the affected areas are dry. Reducing the humidity during this process will facilitate drying.
6. Place these potatoes closer to the access doors for easy removal.

Reference 9 - Seed cutting guide

Sizes of potato pieces affect early plant vigor.[1] Properly cut seed pieces feed correctly in the planter and provide uniform plant stands. Mechanical cutters can handle large volumes of seed and tubers cut into two or four pieces. Hand cutting minimises the number of blind pieces, but is slow and labour intensive. Seed tubers should not be washed. Grade seed potatoes into size classes before cutting. Hand-cut deformed or very rough tubers.

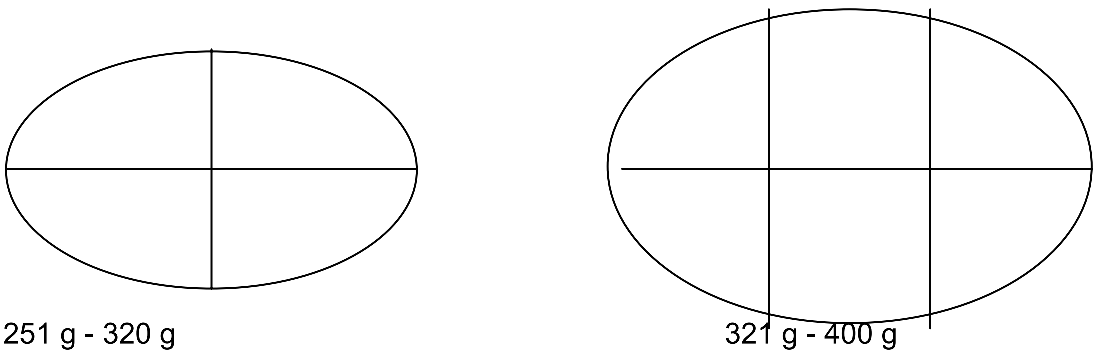
Tubers under 45 g should not be planted.



45 g - 90 g tubers
plant whole

91 g - 170 g tubers
cut once = 2 pieces

171 g - 250 g tubers
cut twice = 3 pieces



251 g - 320 g
cut 1 x horizontally and 1 x vertically
= 4 pieces

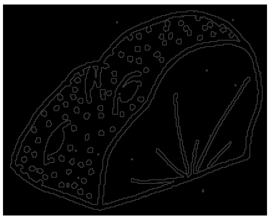
321 g - 400 g
cut 1 x horizontally and 2 x vertically
= 6 pieces

- Small seed pieces (< 45 g) produce weak, unproductive plants.
- Large seed pieces (greater than 90 g) are no more productive than good (45-90 g) seed pieces but cost more to plant. Aim at seed pieces of around 55 - 75g.
- Oversize tubers will result in a cut seed lot with many pieces that are too large or too small. Individual pieces will also have fewer eyes and there may be many blind pieces (no eyes), leading to a low plant number per area and thus low yield potential.
- On average, seed pieces cut from large mother tubers (> 250g) are not as productive as pieces of the same weight cut from smaller tubers.

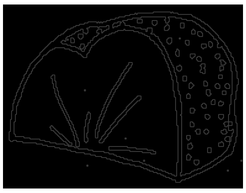
[1] Source: The University of Maine Cooperative Extension

Reference 9 - Seed cutting guide (cont.)

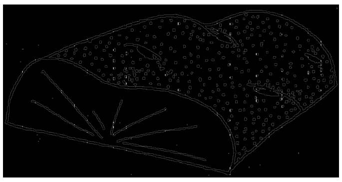
Good cutting result - seed piece with several eyes and correct size

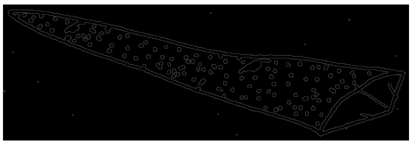


Bad cutting result - blind, no eyes, due to the use of oversized tubers

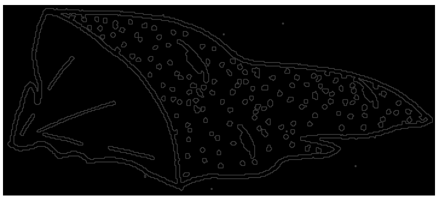


Bad cutting result - undersized - slab or sliver





Bad cutting result - ripped due to blunt cutting equipment



Reference 10 - Pre-cutting[1]

Pre-cutting seed potatoes involves warming the tubers, cutting them to size and cooling the seed pieces back down to a holding temperature. Not all seed potatoes should be pre-cut.

Only seed of young or medium physiological age should be pre-cut, since pre-cutting ages the seed. Seed that is young can be pre-cut one month or more before planting. If the seed has previously sprouted, the seed should be cut only two weeks ahead.

Middle-aged seed can be pre-cut up to two weeks ahead of planting only if it has not sprouted. Middle-aged seed that has sprouted and been de-sprouted is old seed.

Seed that is physiologically old should not be pre-cut. Old seed should be cut as close to planting as possible; not more than a few days ahead. Cutting any earlier may cause tuber 'senility' ("Potato No Top").

The temperatures to warm the seed to, and to hold the cut seed at, vary for seed of different ages. The younger the seed, the higher the cutting and holding temperatures should be. Young seed can be cut and held at about 10^0C. Older seed should not be warmed or held above 7^0C. Since sprouting ages the tuber, temperatures should be lower for seed that has already sprouted. Pre-cutting offers several advantages that will help potato seed overcome adverse soil conditions at planting and avoid dormancy issues with some varieties.

Pre-cutting allows the cutting operation to begin earlier, and even out the workload, before planting starts. Pre-cut seed may have a better opportunity to cure under controlled storage conditions. Properly cured cut seed, if held for at least three or four weeks, will overcome dormancy and give more uniform sprouting. Pre-cut seed will provide earlier emergence, vigorous early growth and higher plant and stem populations. Varieties that have slow seed curing ability, such as "Atlantic" and "Kennebec," are good candidates for pre-cutting.

Delayed emergence, slow, uneven establishment and reduced plant stands are all symptoms of planting seed in soil that may have been either too cold, too wet or even too dry. Freshly cut seed planted under these unfavorable conditions often fails to heal properly; it becomes dehydrated or infected by decay organisms and is not capable of good growth. Erratic and slow plant growth also interferes with timely herbicide applications; and smaller plant canopies later in the season offer less competition to weeds. If pre-cutting, carefully adhere to temperatures and timing according to the physiological age outlined above. Cutting, warming and holding will all advance the physiological age of the seed. Pre-cutting is not recommended for all seed. Hand cutting is recommended as it allows better hygiene and grading out of diseased or damaged tubers by staff cutting the seed.

[1] Maine CooperativeExtension, the Land Grant University of the state of Maine and the U.S. Department of Agriculture cooperating. CooperativeExtension and other agencies of the U.S.D.A.

Reference 11 - Evaluation of physiological age

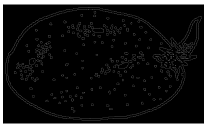
Because the factors influencing physiological age are still so difficult to quantify, comparing the history (stresses) of the seed crop during growth, handling and storage, in comparison with earlier years, can assist with estimating physiological age. A long-term relationship with your seed potato producer and store operator may be in your best interest. Knowing the purpose of the seed determines the P-age required at planting.

Accumulated day degrees also give an indication of P-age. Taking representative samples from a seed lot at the start and end of, or during the storage period, and inducing sprouting at 15-18^{0}C in the dark, can provide more information on P-age. The sampling time depends on when the information is required. An assessment of sprouting characteristics (sprout number, length and position) will give an indication of seed age. It is worthwhile to record the time it takes for sprouts to begin to emerge. This will give an estimate of the length of time and warming required for that particular lot to sprout.

Sprouting characteristics

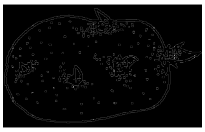
Dormant seed

If the potatoes do not sprout at all, they may still be dormant. The length of dormancy (resting period) varies with the variety. Dormant seed is young.



Young (apical dominant)seed

Young seed will have one or just a few sprouts. These sprouts emerge from eyes on the apical or bud end of the tuber (apical dominance). Young seed will produce a plant with few stems. A low stem number leads to a low tuber set. Larger, but fewer, tubers would be expected from young seed. Young seed is best for long growing seasons.

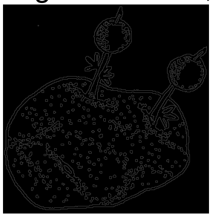


Middle-aged (medium age, multi sprouting) seed

Middle-aged seed will have multiple sprouts. All the eyes on the potato could sprout. Middle-aged seed produces plants with multiple stems that lead to high tuber sets. The time of emergence will depend on whether the sprouts are broken off or not, and will be influenced by soil temperature. Both low and high soil temperatures age seed. This stage in the physiological age is optimal for high yielding capacity of seed, if the growing season is long enough (high tuber set combined with sufficient time for bulking).

Old seed

Old seed will have branched sprouts that can appear hairy. These sprouts are weak, and they will not produce a vigorous plant. Typically, plants from old seed will produce high tuber sets, but the plants lack the vigor to bulk the tubers to a good size.



Small tuber syndrome (“Potato No Top”)

Seed can be so old that small tubers form on the sprouts once they emerge from the eyes. “Potato No Top” is the name given to this disorder of extremely old seed. Seed with “Potato No Top” disorder should not be used.

Reference 12 - Which physiological age for which purpose?

A different physiological age is required for optimum performance for different commercial end uses, ie. processing, ware or seed production. Basically, the length of the growing season for the commercial crop determines which physiological age is most advantageous to the seed buyer / commercial grower.

In short: a seed tuber that is dormant will produce few sprouts, especially in cool soils; often only an apical dominant sprout. It will produce a one-stem plant that will have a small number of large size tubers. Emergence of the plant is late compared to physiologically older seed tubers.

Processing crops

Physiologically young seed produces few but strong stems, creating a plant that grows for a long time before reaching maturity. For processing stock, where large size tubers are required, young seed in the early stage of multiple sprouting is ideal, because it allows tubers to develop during a long growing season into large tubers.

The optimal yield of a variety that has a tendency to produce a large number of tubers (eg. Russet Burbank) may be obtained from physiologically young, not de-sprouted seed. In a variety with a tendency to produce few stems and / or a smaller tuber number (eg. Shepody), the physiological age may be more advanced, eg. seed warmed up or cut earlier in relation to planting date.

Fresh market crops

Potatoes for the fresh market (ware potatoes) do not have the same size requirements as for processing. This means that a slightly advanced (medium) physiological age may not have any negative effect on the marketable yield of the crop. Again, it is good to know the history of the crop, the stresses and the temperatures during growing, handling and storing (and anticipated at planting, eg. cold or warm soil) to be able to treat the seed optimally. Seed potatoes for the early fresh market often should have a physiological age similar to seed potatoes, where one wants an early emergence and an early crop.

Seed Potatoes

Seed potatoes need a good set, an early emergence and an early maturity. The physiological age will determine the quality potential of the seed, i.e. the number of stems, which is related to the number of tubers and the timing of maturity. Since vine (haulm) kill is early, the seed planted for the next seed generation should be physiologically advanced (medium age). Increasing tuber set through planting older seed will result in a better yield of seed size tubers. Physiologically advanced seed produces a crop with an earlier maturity, besides a larger number of stems. This is important, because for most varieties, it makes the plant less susceptible to viruses later in the season. Do not use seed in the earliest stage of multiple sprouting; it should be older. Again, it is good to know the history of the seed, to decide whether it needs to be warmed up early or whether that should be done as late as possible. De-sprouting physiologically young seed generally will produce more sprouts, more tubers, but a smaller size. On smaller farms, green sprouting of seed potatoes may be used,

Reference 12 - Which physiological age for which purpose? (cont.)

Characteristics of physiologically young versus old seed

Young seed	Old seed
Slow emergence	Rapid emergence
Few stems per seed piece	More stems per seed piece
Low tuber set	High tuber set
Long bulking period	Short bulking period
Long tuber set period	Uniform tuber set
Large tubers at harvest	Small tubers at harvest

Diagram 1 - Curing set up, 'letterbox' system

The letterbox system is designed to force air through the bin contents. The tyne pockets are lined up with the 'letterbox' slots. The fan on top of the 'letterbox' sucks air into it. As shown in the diagram, the tyne pockets of the last stack of bins have to be sealed. Unlike this diagram, unused 'letterbox' slots have to be blocked as well.

The letterbox system can be built inside a conventional store. It works best if bins have sufficiently large gaps between boards to get air moving through the tubers. Bins should be full to prevent the air from short-circuiting. The 'letterbox' system works very effectively with solid sided bins that have a mesh bottom and no cover over the top of the bin stack.

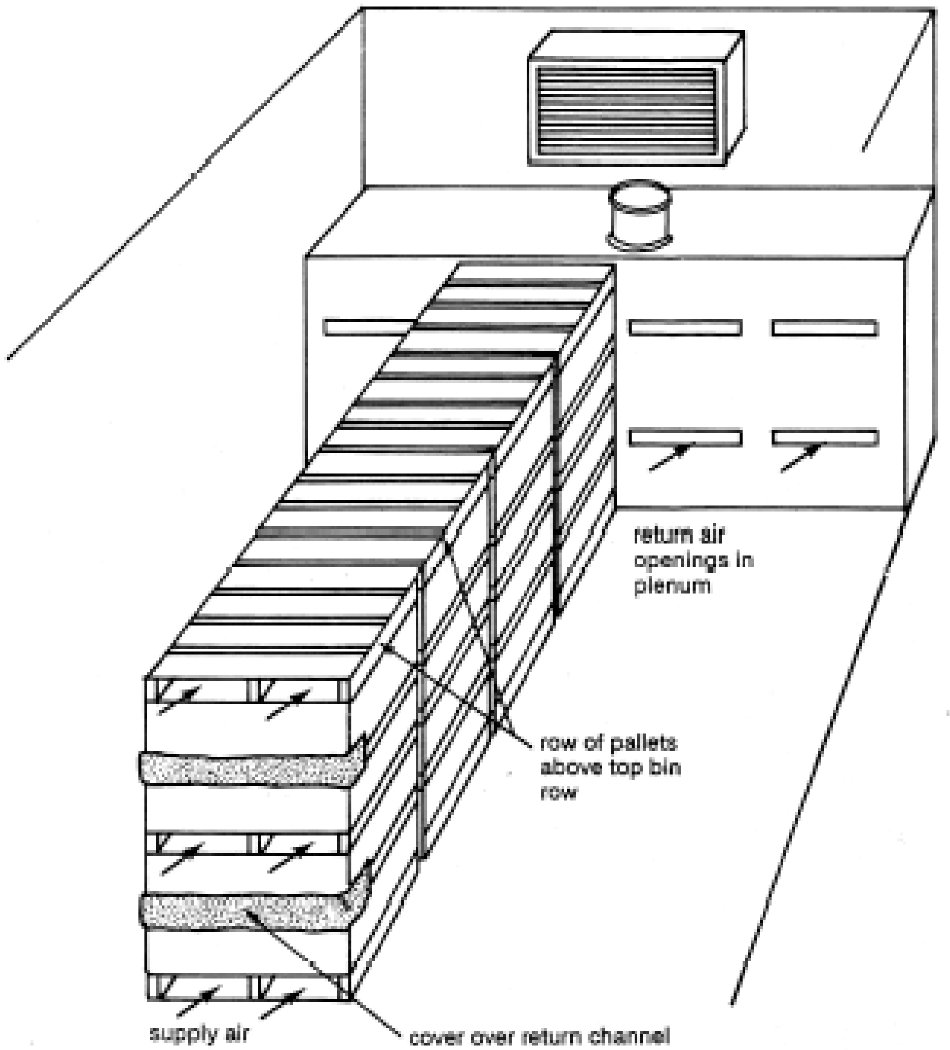
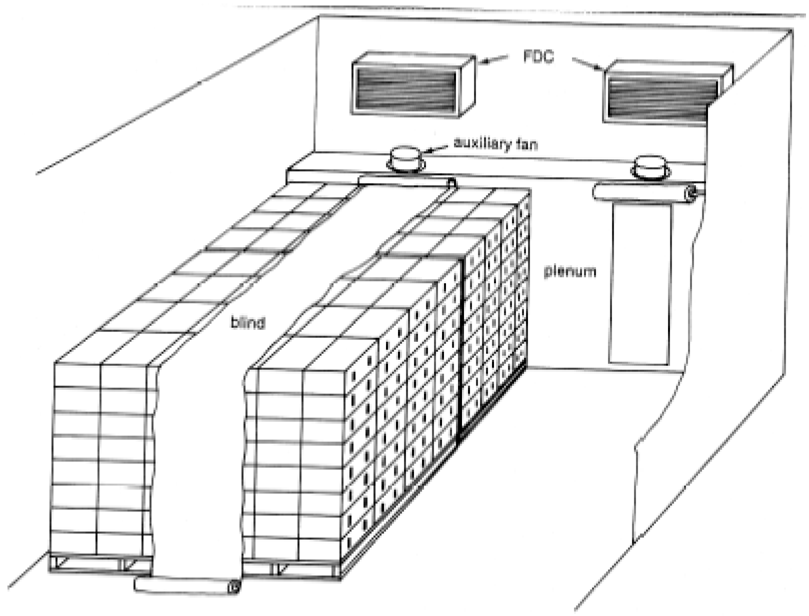


Diagram 2 - Curing set up, plenum and blind system

The plenum and blind system works in a similar fashion to the letterbox one. A fan on top of the plenum box sucks air through the bins (cartons in the diagram below). The bins are lined up in two rows on either side of the plenum opening. The rolled out trap covers the gap between the rows and runs right down the front of the stack. Rolling the blind up and down manually over bins stacked 4-6 high is not a simple process, and OH&S issues have to be considered. The blind should be sufficiently wide and reinforced with thin, strong rods across its width every 1-2 meters to prevent it from being sucked into the gap between the two rows of bins by the force of the fan. Similar to the 'letterbox' system, bins should be full, to avoid air short-circuiting.

The top diagram shows the front, and the bottom one shows the side view of the plenum and blind system, which can be installed in a conventional store.



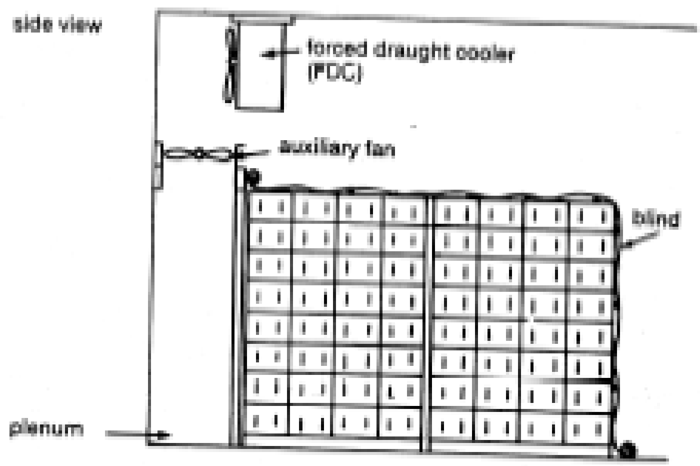


Diagram 3 - Curing set up, blind and fan system

This system is suitable for curing small loads of tubers or isolated loads of wet or diseased tubers. It can also be used to assist suberisation after cutting. Similar to the plenum and blind system, bins (cartons in the diagram) are stacked in two rows with a gap between them, which is covered by a sufficiently wide, reinforced tarp. A fan is installed on one side of the gap, sucking air out of the gap and thus through the tubers. Again, bins have to be full and should have reasonably wide gaps between boards for optimum effectiveness of the system.

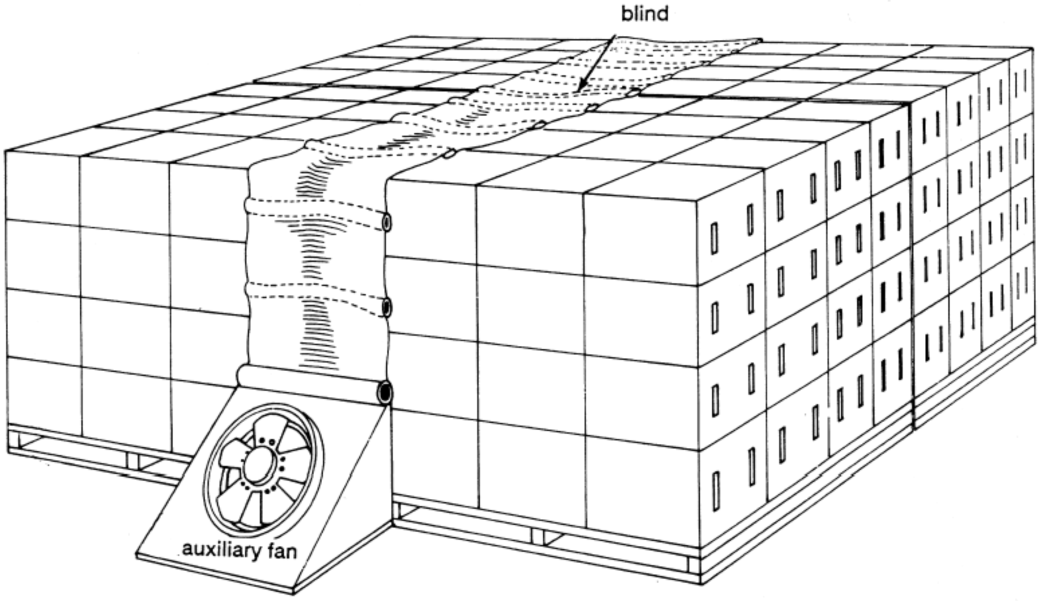
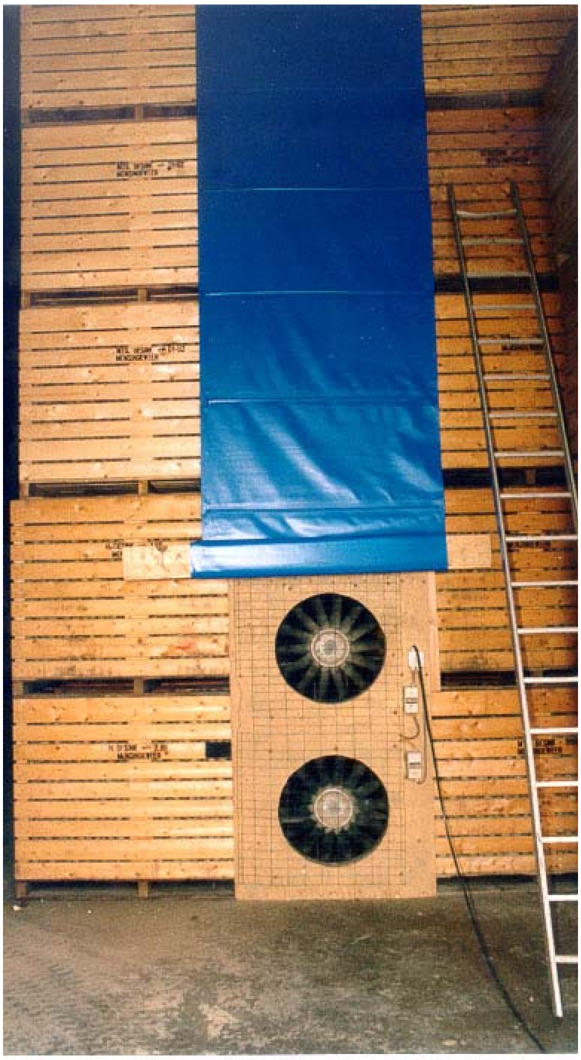


Photo 1 - Dutch curing set up

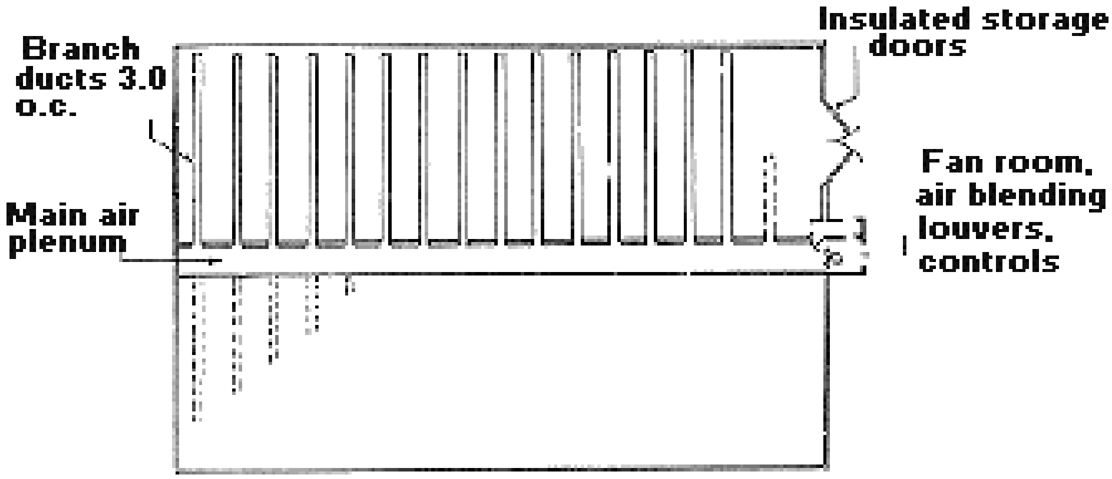
The photo shows a plenum and blind system in combination with a fan in front of the bin stack to improve airflow through bins. Two stacks of bins are lined up on either side of a plenum. The plenum fan sucks air through the bins and gap, while the auxiliary fans shown in the photo provide additional suction. Bins were stacked six high. Air temperature and the temperature pull down were computer controlled. The system was only used for curing, and the seed was transferred to a suitable cool store after curing.

Note the good size gaps between boards and cleanliness of bins and floor.

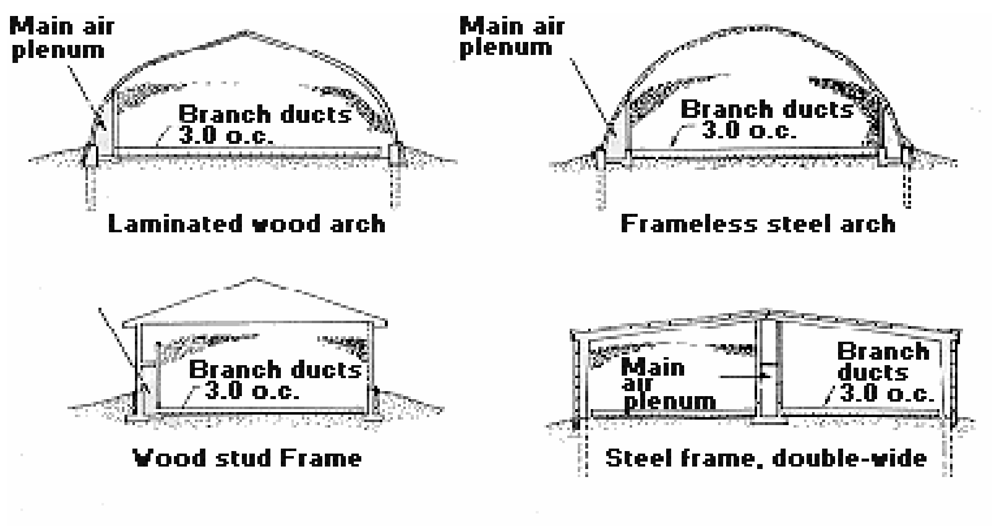


Diagrams 4 - 9 - Bulk storage systems used in the USA[1]

Diagram 4 - Typical potato storage plan, single or double-wide



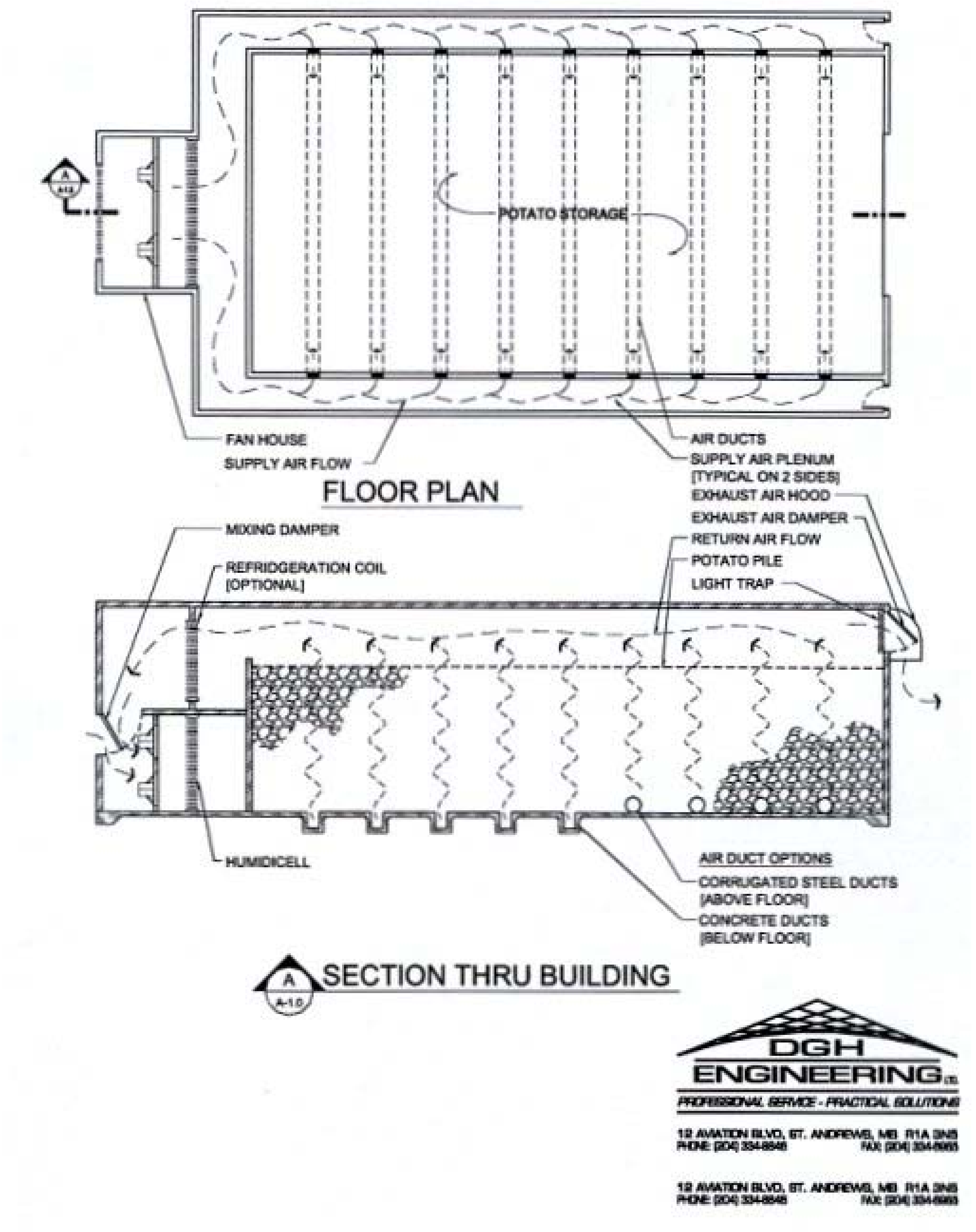
Diagrams 5 - 8 - Typical potato storage plan and alternate building types



[1] Growing quality potatoes in Alberta, Agriculture, Food and Rural Development
http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/opp4768?opendocument#top

Diagrams 4 - 9 - Bulk storage systems used in the USA (cont.)

Diagram 9 - Potato storage plan for bulk storage



Photos 2 & 3 - Internal view of UK potato stores

Internal view of a bin loaded potato store with large roof space, which is important for even air distribution and inspection of top bins for moisture.

Photo 2

Photo 3

Photos courtesy of

Farm Electronics Limited
Woodland Drive, Alma Park
Grantham, Lincolnshire, NG31 9SR
Tel: +44(0) 1476 591592,
Fax: +44(0) 1476 591188
Email: info@farmelec.co.uk

Photos 4 & 5 - Aids for problem management[1]

Photo 5 - Auxiliary heater to control condensation in the roof area

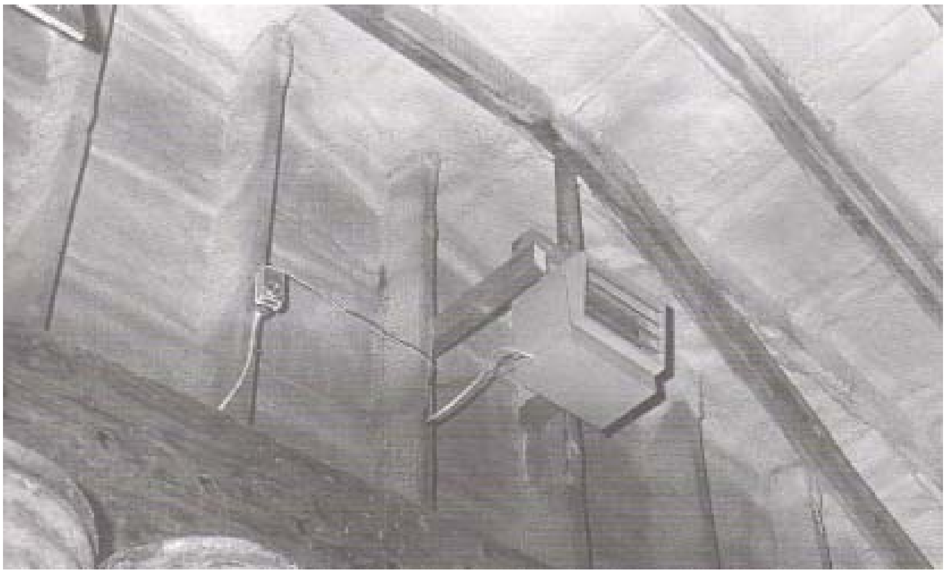


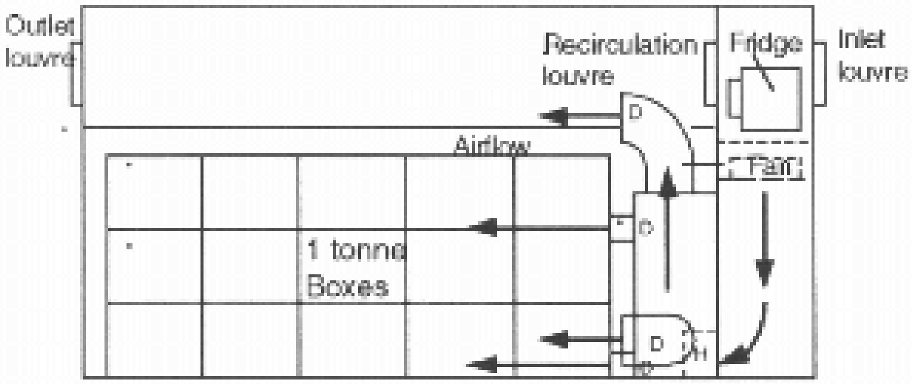
Photo 6 - Auxiliary hot spot ventilation fan
(could be used on top of bin stacks or individual bins)

[1] Hallee, N.D. et al, 1984; Potato storage design and management. University of Maine Cooperative Extension Bulletin #1092

Diagrams 10a and 10b - Store set up for bins, UK

The diagram below shows set up of a potato store for bin storage with fresh air inlet and re-circulation facilities (louvers) and fans to provide air exchange in bins.

10a



Engineering & Mechanisation Department, The Scottish Agricultutral College
Cruickshank Building, Craibstone Estate, Bucksburn, Aberdeen AB21 9TR

The store diagram below shows a letterbox store set up

10b

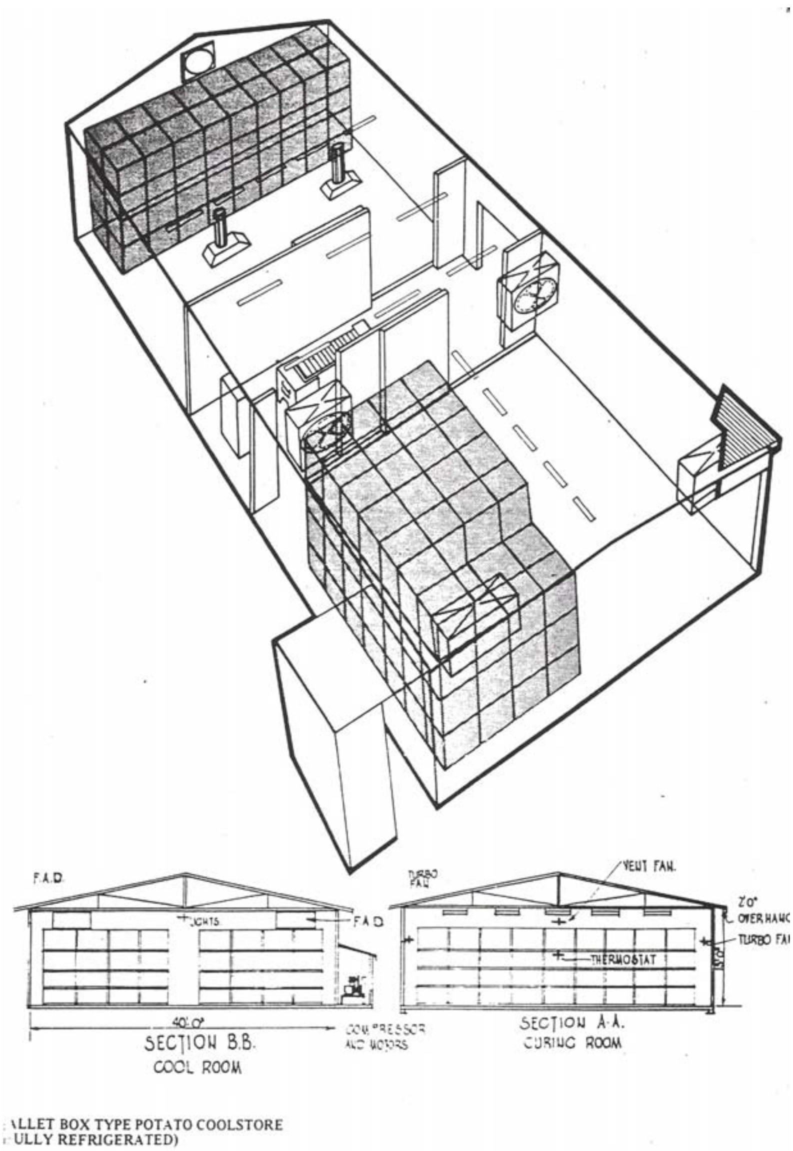
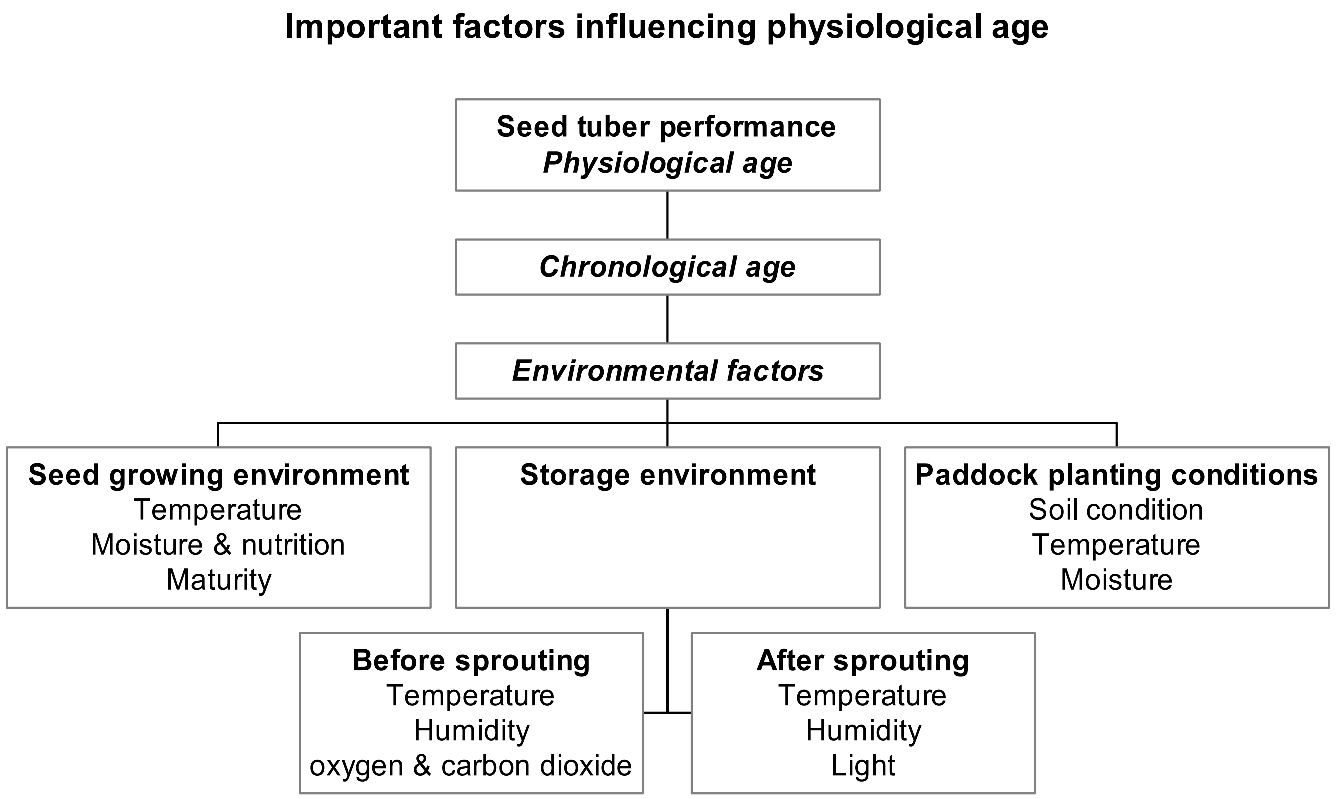


Diagram 11 - Factors influencing physiological age



Appendix 1 - Conversion Table

To convert Column 1 into Column 2, multiply by	Column 1 SI Unit	Column 2 non-SI Unit	To convert Column 2 into Column 1, multiply by
AREA			
2.47	hectare, ha	acre	0.405
247	square kilometer, km^2 $(10^3\ m)^2$	acre	4.05×10^{-3}
0.386	square kilometer, km^2 $(10^3\ m)^2$	square mile, mi^2	2.590
2.47×10^{-4}	square meter, m^2	acre	4.05×10^3
10.76	square meter, m^2	square foot, ft^2	9.29×10^{-2}
1.55×10^{-3}	square millimeter, mm^2 $(10^{-6}\ m)^2$	square inch, in^2	645
LENGTH			
0.621	kilometer, km $(10^3\ m)$	mile, mi	1.609
1.094	meter, m	yard, yd	0.914
3.28	meter, m	foot, ft	0.304
1.0	micrometer, µm $(10^{-6}\ m)$	micron, µ	1.0
3.94×10^{-2}	millimeter, mm $(10^{-3}\ m)$	inch, in	25.4
10	nanometer, nm $(10^{-9}\ m)$	Angstrom, Å	0.1
VOLUME			
9.73×10^{-3}	cubic meter, m^3	acre-inch	102.8
35.3	cubic meter, m^3	cubic foot, ft^3	2.83×10^{-2}
6.10×10^4	cubic meter, m^3	cubic inch, in^3	1.64×10^{-5}
2.84×10^{-2}	liter, L $(10^{-3}\ m^3)$	bushel, bu	35.24
1.057	liter, L $(10^{-3}\ m^3)$	quart (liquid), qt	0.946
3.53×10^{-2}	liter, L $(10^{-3}\ m^3)$	cubic foot, ft^3	28.3
0.265	liter, L $(10^{-3}\ m^3)$	gallon	3.78
33.78	liter, L $(10^{-3}\ m^3)$	ounce (fluid), oz	2.96×10^{-2}
2.11	liter, L $(10^{-3}\ m^3)$	pint (fluid), pt	0.473
MASS			
[b] 2.20×10^{-3}	gram, g $(10^{-3}\ kg)$	pound, lb	454
3.52×10^{-2}	gram, g $(10^{-3}\ kg)$	ounce (avdp), oz	28.4
2.205	kilogram, kg	pound, lb	0.454
0.01	kilogram, kg	quintal (metric), q	95
1.10×10^{-3}	kilogram, kg	ton (2000 lb), ton	907
1.102	megagram, Mg (tonne)	ton (U.S.), ton	0.907
1.102	tonne, t	ton (U.S.), ton	0.907
TEMPERATURE			
1.00 (K - 273)	Kelvin, K	Celsius, °C	1.00(°C + 273)
(9/5 °C) + 32	Celsius, °C	Fahrenheit, °F	5/9 (°F - 32)
WATER MEASUREMENT			
9.73×10^{-3}	cubic meter, m^3	acre-inches, acre-in	102.8
9.81×10^{-3}	cubic meter per hour, $m^3\ h^{-1}$	cubic feet per second, $ft^3\ s^{-1}$	101.9
4.40	cubic meter per hour, $m^3\ h^{-1}$	U.S. gallons per minute, gal min^{-1}	0.227
8.11	hectare-meters, ha-m	acre-feet, acre-ft	0.123
97.28	hectare-meters, ha-m	acre-inches, acre-in	1.03×10^{-2}
8.1×10^{-2}	hectare-centimeters, ha-cm	acre-feet, acre-ft	12.33

Appendix 1 - Conversion table (cont.)

To convert Column 1 into Column 2, multiply by	Column 1 SI Unit	Column 2 non-SI Unit	To convert Column 2 into Column 1, multiply by
	YIELD AND RATE		
0.893	kilogram per hectare, kg ha^{-1}	pound per acre, lb $acre^{-1}$	1.12
1.425×10^{-2}	gram per hectare, g ha^{-1}	ounce (avdp) per acre, oz $acre^{-1}$	70.148
1.49×10^{-2}	kilogram per hectare, kg ha^{-1}	bushel per acre, 60lb (wheat & soybeans)	67.19
1.59×10^{-2}	kilogram per hectare, kg ha^{-1}	bushel per acre, 56 lb (corn, rye & sorghum)	62.71
1.86×10^{-2}	kilogram per hectare, kg ha^{-1}	bushel per acre, 48 lb (barley & triticale)	53.75
2.79×10^{-2}	kilogram per hectare, kg ha^{-1}	bushel per acre, 32 lb (oat)	35.88
893	tonnes per hectare, t ha^{-1}	pound per acre, lb $acre^{-1}$	1.12×10^{-3}
893	megagram per hectare, Mg ha^{-1}	pound per acre, lb $acre^{-1}$	1.12×10^{-3}
0.446	megagram per hectare, Mg ha^{-1}	ton (2000 lb) per acre, ton $acre^{-1}$	2.24
2.24	meter per second, m s^{-1}	mile per hour	0.447
13.676	liter per hectare, L ha^{-1}	fluid ounce per acre, fl oz $acre^{-1}$	7.311×10^{-2}
0.428	liter per hectare, L ha^{-1}	quart per acre, qt $acre^{-1}$	2.336
0.107	liter per hectare, L ha^{-1}	gallon per acre, gal $acre^{-1}$	9.344
7.77×10^{-2}	kilogram per cubic meter, kg m^{-3}	pound per bushel, lb bu^{-1}	12.87
	ENERGY, WORK, QUANTITY OF HEAT		
9.52×10^{-4}	joule, J	British thermal unit, Btu	1.05×10^{3}
0.239	joule, J	calorie, cal	4.19
10^{7}	joule, J	erg	10^{-7}
0.735	joule, J	foot-pound	1.36
2.387×10^{-5}	joule per square meter, J m^{-2}	calorie per square centimeter (Langley)	4.19×10^{4}
10^{5}	newton, N	dyne	10^{-5}
1.43×10^{-3}	watt per square meter, W m^{-2}	calorie per square centimeter minute (irradiance), cal cm^{-2} min^{-1}	698
	PRESSURE		
9.90	megapascal, Mpa (10^{6} Pa)	atmosphere	0.101
10	megapascal, Mpa (10^{6} Pa)	bar	0.1
1.00	megagram per cubic meter, Mg m^{-3}	gram per cubic centimeter, g cm^{-3}	1.00
2.09×10^{-2}	pascal, Pa	pound per square foot, lb ft^{-2}	47.9
1.45×10^{-4}	pascal, Pa	pound per suare inch, lb in^{-2}	6.90×10^{3}
	SPECIFIC SURFACE		
10	sq meter per kilogram, m^2 kg^{-1}	sq centimeter per gram, cm^2 g^{-1}	0.1
950	sq meter per kilogram, m^2 kg^{-1}	sq millimeter per gram, mm^2 g^{-1}	0.001
	CONCENTRATIONS		
1	centimole per kilogram, cmol kg^{-1} (ion exchange capacity)	milliequivalents per 95 grams, meq 95 g^{-1}	1
0.1	gram per kilogram, g kg^{-1}	percent, %	10
1	milligram per kilogram, mg kg^{-1}	parts per million, ppm	1