Potato Storage Management, Postharvest Physiology & Quality Maintenance

Potato Science Lecture 23
N.R. (Rick) Knowles, Washington State University
Reading Assignment Potato Science Lecture 23


rknowles@wsu.edu
**Challenge & Objective** = limit the loss of tuber quality following harvest by implementing handling & storage practices that preserve quality for as long as possible.

- Tuber quality does not improve during storage. At best it is held, at worst tubers become unmarketable.
- Store only healthy, sound tubers
  - Do not store tubers from a stressed crop
  - Do not store tubers with > 5% rot
  - Do not store tubers with frost damage
  - Do not store wet tubers
Preharvest factors
Cultivar, Growing Conditions, Agronomic Practices, Stress

Harvesting Conditions

Tuber Maturity

Postharvest Behavior

Seed-tuber Physiology & Productivity

Storage
- Time
- Temperature

Yield & Grade

Cold sweetening, sugar ends, senescent sweetening

Causes of Postharvest Losses

- Bruising
- Improper curing
- Weight loss
- Starch breakdown
- Sugar buildup
- Decay
- Sprouting
- Greening – chlorophyll development
Pre-harvest Considerations in Timing the Harvest

- Physiological maturity – Tuber CHO’s & skin set
- Vine condition
- Soil & tuber temperature
- Potential for mechanical damage
- Target yield & desired tuber size distribution
Alpine Russet Growth & Maturation Profile (Othello, WA)

Healthy tubers harvested at PM will retain quality the longest in storage.

Physiological Maturity = avg of DAP to:
- max sp. gravity
- max tuber yield
- min sucrose
- min stem red. sugars
- skin set

~146 DAP

32 days PM to harvest

Knowles & Pavek, WSU
Timing of Attainment of Physiological Maturity in Relation to Harvest can affect Retention of Process Quality

Reduction Sugars (mg/g dry wt)

<table>
<thead>
<tr>
<th></th>
<th>Days After Planting</th>
<th>60</th>
<th>80</th>
<th>100</th>
<th>120</th>
<th>140</th>
<th>160</th>
<th>180</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low N Alpine</td>
<td></td>
<td>1.075</td>
<td>1.080</td>
<td>1.085</td>
<td>1.090</td>
<td>1.095</td>
<td>1.100</td>
<td></td>
</tr>
<tr>
<td>Low N Sp gravity</td>
<td></td>
<td>R² = 0.99***</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low N 190 lb/A N</td>
<td></td>
<td>PM 146 DAP</td>
<td></td>
<td></td>
<td></td>
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</tbody>
</table>

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<th>160</th>
<th>180</th>
</tr>
</thead>
<tbody>
<tr>
<td>High N Alpine</td>
<td></td>
<td>1.035</td>
<td>1.040</td>
<td>1.045</td>
<td>1.050</td>
<td>1.055</td>
<td>1.060</td>
<td>1.065</td>
</tr>
<tr>
<td>High N Sp gravity</td>
<td></td>
<td>R² = 0.98***</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>High N 453 lb/A N</td>
<td></td>
<td>PM 151 DAP</td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

© N.R. Knowles, Washington State University
Soil Temperature (°F)

Soil Temperature (5-inch depth)

© N.R. Knowles, Washington State University
## Retention of Process Quality - Alpine Russet

<table>
<thead>
<tr>
<th>Nitrogen (lbs/A)</th>
<th>150</th>
<th>250</th>
<th>350</th>
<th>450</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>54°F</strong></td>
<td><img src="image1" alt="image" /></td>
<td><img src="image2" alt="image" /></td>
<td><img src="image3" alt="image" /></td>
<td><img src="image4" alt="image" /></td>
</tr>
<tr>
<td>10/24/11</td>
<td><img src="image5" alt="image" /></td>
<td><img src="image6" alt="image" /></td>
<td><img src="image7" alt="image" /></td>
<td><img src="image8" alt="image" /></td>
</tr>
<tr>
<td><strong>48°F</strong></td>
<td><img src="image9" alt="image" /></td>
<td><img src="image10" alt="image" /></td>
<td><img src="image11" alt="image" /></td>
<td><img src="image12" alt="image" /></td>
</tr>
<tr>
<td>6/1/12</td>
<td><img src="image13" alt="image" /></td>
<td><img src="image14" alt="image" /></td>
<td><img src="image15" alt="image" /></td>
<td><img src="image16" alt="image" /></td>
</tr>
<tr>
<td><strong>44°F</strong></td>
<td><img src="image17" alt="image" /></td>
<td><img src="image18" alt="image" /></td>
<td><img src="image19" alt="image" /></td>
<td><img src="image20" alt="image" /></td>
</tr>
<tr>
<td>6/1/12</td>
<td><img src="image21" alt="image" /></td>
<td><img src="image22" alt="image" /></td>
<td><img src="image23" alt="image" /></td>
<td><img src="image24" alt="image" /></td>
</tr>
</tbody>
</table>

- **(8 days from harvest)**
- **(229 days from harvest)**

- **54°F**
  - bud: ![image](image25)  
  - stem: ![image](image26)  
- **48°F**
  - bud: ![image](image27)  
  - stem: ![image](image28)  
- **44°F**
  - bud: ![image](image29)  
  - stem: ![image](image30)  

% change (avg Photovolt) over 150:

- **54°F**
  - bud: +2%  
  - stem: +5%  
- **48°F**
  - bud: +12%  
  - stem: +7%  
- **44°F**
  - bud: +15%  
  - stem: +28%

Alpine 2011

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Prolonged Maturation from PM to Harvest can Increase Sugar Ends in Ranger

Ranger Russet 2005

Days After Planting

Percent Sugar Ends

R² = 0.96**

n = 7

Martin & Knowles, WSU
Percent Bruise Free Decreases with Prolonged Maturation of Ranger Russet

\[ R^2 = 0.43^{**} \]

Martin & Knowles, WSU
Estimation of Tuber Physiological Maturity (PM)

<table>
<thead>
<tr>
<th>Index</th>
<th>Alpine</th>
<th>Sage</th>
</tr>
</thead>
<tbody>
<tr>
<td>PM (DAP)</td>
<td>150-154</td>
<td>142-146</td>
</tr>
<tr>
<td>Deg day (45°F base)</td>
<td>2750-2850</td>
<td>2600-2700</td>
</tr>
<tr>
<td>Vine (% dead)</td>
<td>65</td>
<td>60</td>
</tr>
</tbody>
</table>

Avg 3-yr, 2011-13

Estimated at optimum N ~370 lb/A
Maturation & Skin-set

- Skin set occurs during maturation under dead vines, typically within 10-21 days of vine death (skin set occurs more rapidly on russet cultivars than red-skinned ones).

- Skin-set involves death of the phellogen (cork cambium), which cements the outer phellem layer firmly to the underlying cortical cells.

- If tubers are immature (e.g. from green vines), skin set will continue in storage.

- Native periderm (skin) is fragile while actively growing – high susceptibility to skinning (excoriation damage).

- Can test for skin set by “slipping the skin” on freshly dug potatoes.

- Water loss from non-damaged immature tubers (prior to skin set) is up to 28 times greater than from mature tubers in which periderm has “set”. Lenticels have not yet suberized and sealed off.

- Water loss through skinned and scuffed areas of tubers is 250-1000 times greater than non-skinned areas of freshly harvested tubers.
Result of Chemical desiccation of Russet Burbank vines with Reglone (Diquat = a.i.)

Choices
- Chemical desiccation
- Mechanical flail mowing & rolling
- Green vine harvest
Skinning/excoriation injury to immature native periderm

Lulai, E.C. 2007 In Potato Biology & Biotechnology, Elsevier
Fully suberized tuber lenticel

Suberin

O₂

CO₂ + H₂O

Lulai, E.C. 2007  *In Potato Biology & Biotechnology, Elsevier*
Sources of Mechanical Injury (%)

- Harvester (70%)
- Bulk Truck (14%)
- Bin Piler (14%)
- Rollback on Pile Face (2%)

Percent Bruise Damage

Areas of Harvester & their Relative Contributions to Bruise Damage

Bruise Damage to more than 3-4% of the crop is excessive

Location in Harvester

Load the harvester to capacity by adjusting chain speeds relative to forward speed of tractor to minimize damage

Harvesting tubers at physiological maturity – note condition of vines

Note drop height into truck (≤6 inches is ideal)

Uniform tuber distribution
A stepped bin-piling procedure minimizes roll back and damage on the pile face.

Top surface of 18 ft pile
0.5 – 2°F warmer than floor

Storage Management
(dictated by physiological stage of tubers)

- Immediate post harvest — transporting to storage & loading in storage
- Wound healing (curing) and sweat
- Cooling
- Holding
- Reconditioning and removal
Management

Immediate post harvest period

- Maintain high air flow rates to remove field heat
- Initial temp of supply air will be dictated by temp of tubers
- Regulate humidity according to potential problems
  - high humidity for healing a healthy crop
  - low humidity for drying rot or frost damage (2-5 days)
<table>
<thead>
<tr>
<th>Period of Storage</th>
<th>Curing</th>
<th>Cooling</th>
<th>Holding</th>
<th>Marketing</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Temperature</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maintain tuber pulp temperature at:</td>
<td>Rapidly cool seed and fresh-market tubers to the appropriate holding temperature</td>
<td>Maintain tuber pulp temperature at:</td>
<td>Warm slowly to 50-55°F over several weeks</td>
<td></td>
</tr>
<tr>
<td>• 55-60°F if tubers are healthy</td>
<td>Slowly cool processing tubers, lowering pulp temperature by 2-3°F per week</td>
<td>• 38-40°F for seed</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• 50°F if some tuber decay is present</td>
<td></td>
<td>• 38-50°F for fresh market</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• 44-50°F for French fry processing</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• 50-55°F for chip processing</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Rel. Humidity</strong></td>
<td>95-99%</td>
<td>95-99%</td>
<td>90-95%</td>
<td>90-95%</td>
</tr>
<tr>
<td><strong>Ventilation</strong></td>
<td>Supply at high rates to remove field heat, stabilize pile temperature, reduce CO₂ buildup and provide O₂ for wound healing</td>
<td>Supply at high rates to control cooling and maintain differential of 0.5-2°F from bottom to top of pile during cooling</td>
<td>Supply at reduced rates, adjusted as necessary to supply O₂, remove CO₂ and maintain differential of 0.5-2°F across pile</td>
<td>Supply at reduced rates to allow heat of respiration to raise pulp temperature to 50-55°F and thus minimize bruising during removal from storage</td>
</tr>
</tbody>
</table>

*Knowles et al. 2008. In Potato Health Management 2nd ed. APS Press*
Management
Curing after Harvest

- Potatoes need to be stored for approximately three to five weeks (in practice) at 50 to 60°F and ≥95% relative humidity.

- Supply high rates of ventilation (20 cfm/ton).

- During this time, potatoes become more resistant to storage diseases and shrinkage.

- Wound healing and suberization (formation of a protective layer between the tuber surface and the interior tissue) take place during this period.

- Required for all potato lots, regardless of storage time and intended use.
Tuber weight loss vs. storage time as affected by RH
Wound healing (curing)

- Three step process:
  - (a) Initial wound response – 0-36 hrs
  - (b) Suberization
  - (c) Wound periderm (phellogen) formation

- Clean cuts heal faster than crushed wounds
- Occurs at temps from 36-70 degrees
- Most rapid at higher temps
- Most rapid at RH near 100%
- Aerobic process
### Initial Wound Response

**Visualization of Superoxide Production Induced by Wounding**

<table>
<thead>
<tr>
<th>Tuber Disks</th>
<th>hours</th>
<th>Autoluminograph</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="Tuber Disks" /></td>
<td>0</td>
<td><img src="image2" alt="Autoluminograph" /></td>
</tr>
<tr>
<td><img src="image3" alt="Tuber Disks" /></td>
<td>24</td>
<td><img src="image4" alt="Autoluminograph" /></td>
</tr>
</tbody>
</table>

Tuber Disks were placed in 73°F; 95% RH environment with Luminol and X-ray film. Luminol reacts with superoxide ($O_2^-$) to produce photons, which are recorded on the X-ray film.

Kumar & Knowles. WSU
Initial Wound Response

Wound-Induced Superoxide Radical Production

6-month-old  18-month-old  30-month-old

Role of NADPH Oxidase (NOX)

NADP$^+$

NADPH

Cytosol $\leftrightarrow$ PM

$\text{O}_2$

Anti-microbial agent

$\text{O}_2^-$

Initial Wound Response

Wound Induced Induction of NOX Activity

Inhibition of Wound-Induced Superoxide Radical ($O_2^-$) Formation by DPI Increases Susceptibility to Soft Rot

1-mo-old RB – 60 h @ 73°F, 95% RH

Control  12.5 $\mu$M DPI  25 $\mu$M DPI

DPI = diphenyleneiodonium chloride

Note loss of tissue due to soft rot during 60 h of wound healing

Suberization

- Deposition of suberin on walls of cells near the wound site.
- Seals the wound from water loss and infection
- Time of occurrence
  - 3-6 weeks @ 36°F
  - 1-2 weeks @ 50°F
  - 3-6 days @ 70°F
Poly(phenolic) domain

Poly(aliphatic) domain

Primary cell wall

Suberin lamellae

Phenylalanine Ammonia-Lyase

Buchanan et al. (2000)

Phenylalanine Ammonia Lyase

(phenylalanine ammonia lyase)

PHENYLALANINE

CINNAMIC ACID
Wound Periderm Formation

- Cortical parenchyma cells de-differentiate into phellogen = cork cambium (meristematic layer)
- Phellogen produces phelloderm (one cell layer) to the inside and phellem cells to the outside (multiple cell layers)
- Phellem cells become suberized and die at maturity (wound periderm consists of multiple layers of suberized phellem cells)
- Time of occurrence:
  - 4-9 weeks @ 36°F
  - 2-3 weeks @ 50°F
  - 5-7 days @ 70°F
- Best balance of wound healing and quality maintenance at 50-60°F
  - tradeoff between disease & desiccation and hastening formation of a suberized wound periderm
Wound Healing

Suberization of wound surface

Increased \( \text{H}_2\text{O} \) loss &
Wound respiration = heat & loss of dry matter

Suberized cells

New phellem (cork) cells

New phellogen (cork cambium)

Storage parenchyma

Kumar & Knowles, WSU
Effect of Wound-healing on Resistance to Fresh Weight Loss in Russet Burbank

Cores of tuber tissue were healed at 73°F, 98% RH for 14 days before desiccating at 147°F.

Fresh cut
21% loss per hr

6-mo-old tubers
5.2% loss per hr

18-mo-old tubers
7.6% loss per hr

Suberized tissue is highly resistant to H₂O loss

18-month-old
periderm thickness = 13 µm

6-month-old
periderm thickness = 33 µm

Cores (RB) healed at 73°F, 98% RH for 14 days.

Minimizing Weight Loss – “Shrink”

- Sources of weight loss = dry weight (respiration), fresh weight (transpiration)
- Proper skin set and minimizing damage at harvest – respiration & desiccation
- Effective wound-healing initially in storage
- Minimize decay
- Inhibit sprouting

Vapor Pressure Deficit = driving force for water loss

\[ \text{VPD} = \text{difference in vapor pressure of water between the tuber and surrounding atmosphere.} \]
Moisture Loss – Basic Principles

- For practical purposes, air in the tuber is saturated with H$_2$O (i.e. 100% RH)
- Transpired H$_2$O moves through the skin barrier from the high H$_2$O vapor pressure side to the low H$_2$O vapor pressure side.
- VPD = difference in vapor pressure of water between the tuber and surrounding atmosphere.

<table>
<thead>
<tr>
<th>°F</th>
<th>°C</th>
<th>50% RH</th>
<th>100% RH</th>
</tr>
</thead>
<tbody>
<tr>
<td>32</td>
<td>0</td>
<td>2.29</td>
<td>4.58</td>
</tr>
<tr>
<td>50</td>
<td>10</td>
<td>4.60</td>
<td>9.21</td>
</tr>
<tr>
<td>77</td>
<td>25</td>
<td>11.88</td>
<td>23.76</td>
</tr>
</tbody>
</table>

Example

Tuber Temp = 77°F, RH = 100%, VP = 23.76
Storage temp = 50°F, RH = 100%, VP = 9.21
VPD = 14.55

H$_2$O is being pumped out of the tuber under a pressure difference of 14.55 mm Hg

If saturated cool air is used in cooling, the tuber will lose H$_2$O as long as it is warmer than the air.

Objective is to attain approximately equal VP values between the tuber and storage atmosphere (i.e. minimize VPD).
Tubers in storage B will lose 78% more weight than tubers in storage A.

A nomogram can be used to determine the water vapor pressure deficit (VPD) between a fleshy product and its surrounding environment using the air temperature and relative humidity. A line is drawn from the air temperature (left) through the relative humidity (right) of the air (1 mbar = 0.1 kPa). The intercept on the VPD line gives the VPD between the product and its environment – the higher the VPD, the greater the rate of water loss (i.e. desiccation). Accurate use of the nomogram requires that the product and air be at the same temperature and that the product’s internal relative humidity be 100%. The latter is not a valid assumption with low moisture crops (e.g. grains).
Management
Cooling Period

- Rate of cooling depends on intended use:
  - seed & fresh market potatoes can be cooled more rapidly
  - processing tubers should be cooled slowly until reaching final holding temperature (rate of 0.3 to 0.5°F per day or ~2 to 3.5°F per week)

- Avoid sudden temperature changes
- Avoid temperature fluctuations
- Use cooling air with 95-99% RH
Temperature Profile of Commercial Seed Storage from Harvest to Planting

- **Wound healing**
- **Russet Burbank**
- Stored from 10-17-07 to 4-1-08
- **French fry potatoes**
- **Fresh market potatoes**
- **Seed potatoes**

Temperature Profile:
- **Storage Temperature**: 10°C to 14°C
- **Storage Temperature**: 48°F to 56°F

- **Pull down**: 0.4°F/day
- **Days from Vine Kill**: 32 to 200
- **Harvest (10-17-07)**
- **Planted (4-11-08)**
- **209 DAH**

Knowles, WSU
Management
Holding Period

- Ventilate periodically (5 to 20 cfm/ton)
  - Daily to supply oxygen
  - As needed to prevent condensation
  - Top of pile should not be more than 1-2°F warmer than bottom tubers ($\Delta T \leq 2^\circ F$, supply air & return air)
  - Utilize air cooler than bottom tubers

- Cool with outside air as needed

- Maintain relative humidity above 95%

- Apply sprout inhibitors as needed (early decision)
Hold at a constant temperature as dictated by intended end use:

- 50-55°F for chipping potatoes
- 45-48°F for frying potatoes
- 40-42°F for fresh potatoes
- 37-39°F for seed potatoes

Main concern is prevention of low temperature sweetening (LTS)
Reducing Sugar (glc + fru) Accumulation

Dependent upon:
- Variety
- Storage temperature
- Physiological maturity
- Stress problems and defects
- Tuber age

- Tubers are more sensitive to LTS during early storage
- Sweetening is not an issue at 50-55°F for most varieties
- LTS is partly reversible depending on tuber age. When tubers reach an age where sweetening cannot be reversed they are said to have undergone “senescent sweetening”

LTS = low temperature sweetening

Knowles, WSU
Low Temperature Sweetening (LTS) Depends on Variety, Temperature & Time

Defender
(LTS Sensitive)

Premier
(LTS Resistant)

Days in Storage
11 45 112 170 227

Glc + Fru (mg/g d wt)
0 10 20 30 40

40°F
44°F
48°F

Defender 2005/06

Premier 2005/06

Oct 22 Nov 25 Jan 31 Mar 30 May 26

Tubers are most sensitive to LTS at the beginning of storage

Knowles, WSU
Tubers are most sensitive to LTS at the beginning of storage. Conditioning at 48 to 55°F increases the resistance of tubers to LTS later in storage.

<table>
<thead>
<tr>
<th>Days in Storage</th>
<th>Red. Sugars (mg/g d wt)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oct 12</td>
<td>USDA 0</td>
</tr>
<tr>
<td>Nov 14</td>
<td>USDA 1</td>
</tr>
<tr>
<td>Jan 14</td>
<td>USDA 2</td>
</tr>
<tr>
<td>Mar 13</td>
<td>USDA 3</td>
</tr>
<tr>
<td>May 13</td>
<td>RB</td>
</tr>
</tbody>
</table>

Knowles, WSU
Ranger Russet - Tuber Maturity Affects Fry Color During Storage

Driskill & Knowles, 2007
Effects of Storage Temperature & Cultivar on Length of Dormancy

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>42°F</th>
<th>45°F</th>
<th>48°F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Russet Burbank</td>
<td>150</td>
<td>135</td>
<td>120</td>
</tr>
<tr>
<td>Ranger Russet</td>
<td>75</td>
<td>60</td>
<td>50</td>
</tr>
<tr>
<td>Summit Russet</td>
<td>150</td>
<td>125</td>
<td>100</td>
</tr>
<tr>
<td>Umatilla Russet</td>
<td>140</td>
<td>120</td>
<td>80</td>
</tr>
</tbody>
</table>

Kleinkopf & Olsen (2003) In Potato Production Systems, Univ. of Idaho
Effects of Cultivar & Tuber Maturity on Dormancy

Sprout Length (mm/6 tubers)

Stored at 48°F
8.3-oz tubers

RR = Ranger
UR = Umatilla
RB = Rus. Burbank

Potato Sprout Inhibitors

CIPC

DIPN

MH

Eugenol

(s)-carvone

3-decen-2-one

Knowles, WSU
## Selected Sprout Inhibitors

<table>
<thead>
<tr>
<th>Inhibitor</th>
<th>Chemical or trade name</th>
<th>Mode of action &amp; application</th>
</tr>
</thead>
<tbody>
<tr>
<td>CIPC</td>
<td>Chloroisopropyl carbamate (chlorpropham)</td>
<td>Cell division inhibitor; postharvest – before dormancy break</td>
</tr>
<tr>
<td>MH</td>
<td>Maleic hydrazide (MH-60)</td>
<td>Cell division inhibitor; preharvest – before vine senescence</td>
</tr>
<tr>
<td>DMN</td>
<td>1,4-Dimethylnaphthalene</td>
<td>Auxin; cell cycle inhibitor; postharvest - before &amp; after dormancy break</td>
</tr>
<tr>
<td>DIPN</td>
<td>2,6-Dimethylnaphthalene (Amplify)</td>
<td>Auxin; postharvest (augments CIPC)</td>
</tr>
<tr>
<td>Eugenol</td>
<td>Clove oil (Biox C)</td>
<td>Pinching agent; postharvest – after dormancy break</td>
</tr>
<tr>
<td>3D2</td>
<td>3-decen-2-one (SmartBlock)</td>
<td>Pinching agent; postharvest – after dormancy break</td>
</tr>
<tr>
<td>(S)-Carvone</td>
<td>Caraway seed oil (Talent)</td>
<td>Pinching agent; postharvest</td>
</tr>
</tbody>
</table>
Management
Reconditioning and Removal

- If needed, reduce sugar levels by reconditioning at 60-65°F for three weeks
- Maintain high humidity during reconditioning
- Senescent sweetening is irreversible
- Warm tubers to 50-55°F before handling

Knowles, WSU
Effects of Temperature on Tuber Respiration Rate During Low Temperature Sweetening & Reconditioning

- Low Temp Sweetening: 48°F
- 39°F
- Reconditioning: 61°F

Respiration (% Initial)

- Increase in vital heat
- Increase in sugar catabolism
- Weight loss

Days in Storage:

- 0
- 3
- 0

2011

Knowles, WSU
Umatilla Russet (Loss of reconditioning ability with tuber age)

Days in Storage

17 48 111 169 230

Driskill & Knowles, 2007
Senescent Sweetening Cannot be Reconditioned

<table>
<thead>
<tr>
<th>Storage Time (39°F)</th>
<th>Reconditioning (days at 73°F)</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
<td>7</td>
<td>14</td>
<td>23</td>
</tr>
<tr>
<td>2-months</td>
<td></td>
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<tr>
<td>14-months</td>
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<tr>
<td>26-months</td>
<td></td>
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</tr>
</tbody>
</table>

Knowles, WSU
Reducing Sugars (mg/g dry wt)

USDA Color Classes

Photovolt reflectance meter

\[ R^2 = 0.87^{***} \]

Knowles, WSU