Integrating Cultivar, Temperature and Quality into Early Storage Management Decisions for Wound Healing in Potatoes (*Solanum tuberosum* L.)

A Thesis

Presented in Partial Fulfillment of the Requirements for the

Degree of Master of Science

with a

Major in Plant Science

in the

College of Graduate Studies

University of Idaho

by

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August 2015

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ABSTRACT

Early storage conditions impact the development of wound periderm and influence long term storability and quality of potatoes. Proper wound healing in storage is critical to minimize shrinkage and disease development. Three curing temperatures (7.2°C, 12.8°C, 18.3°C; 14 days) were chosen to evaluate the effects of temperature on wound healing, processing quality and weight loss in Russet Burbank, Ranger Russet and Clearwater Russet potatoes. In addition, the application of accumulated heat units in potato storage management was introduced and discussed. The curing temperatures of 12.8°C and 18.3°C favored wound healing as well as maintained processing quality through long term storage. Curing at 7.2°C dramatically delayed wound healing and negatively impacted processing quality. Cultivars appeared to respond differently to curing temperatures, indicating a need for cultivar-specific wound healing recommendations in the potato industry.

ACKNOWLEDGEMENTS

I would first like to thank Dr. Nora Olsen for her guidance and advisement throughout my program, as well as presenting me with the opportunity to work with her; your influence on my education will resonate through my career and life. Thank you for your navigation into the potato industry and for imparting passion to contribute to such a great industry. Additionally, thank you to my committee members Dr. Rick Knowles, Dr. Phil Nolte and Dr. Mike Thornton for your advice, perspectives, and support throughout my program.

Also, thank you to Tina Brandt, Mary Jo Frazier, Nicole Kinslow, and Lynn Woodell for the countless hours of help, advice, encouragement and fun. I can't express the impact each of you made on my education experience as well as my life.

Thank you to the Northwest Potato Research Consortium for funding this project.

Lastly, thank you to my family for the unconditional love, endless support, and encouragement to push myself. I would not be who I am or where I am without each and every one of you. Mom and Dad, I can never thank you enough for teaching me good work ethic and determination, the two most valuable tools I have in my life; I love you beyond measure and words.

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LITERATURE REVIEW

In the northern United States (US), the potato (*Solanum tuberosum* L.) growing season spans the spring through fall months with harvest taking place late summer and into the fall. Because of the single growing season in the northern states, potatoes must be held in long term storage, possibly up to 12 months. Storage is vital to ensure year round access to potatoes for the processing and fresh pack industries and proper storage management is critical to maintaining potato quality.

Potato storages in the northern U.S. are described by Brook et al. (1995) as large, ventilated, insulated buildings with climate control technology. The potatoes are bulk piled and exposed to fresh air; air is first humidified and then distributed via a primary (plenum) and lateral ducts, then forced up through the pile (Bethke 2014). Once air is forced through the pile, it is recirculated. Fresh air is introduced to this recirculated air to maintain oxygen and prevent accumulation of carbon dioxide. The outside air provides cooling air to maintain the desired storage air temperature, or a refrigeration system can be used to supplement cooling.

At harvest, typically tubers are placed into a storage building, or cellar, and held at an elevated temperature for two to three weeks (Ware and McCollum 1975, Kleinkopf and Olsen 2003). This period of warm temperature is called wound healing, or curing. Early storage management refers to the conditions of the potato storage immediately after harvest and during the wound healing period. Early storage conditions impact tuber storability and can be detrimental to end product quality (Kleinkopf 1995, Bartz and Kelman 1984, Knowles et al. 1982, Morris et al. 1989).

Tubers may be warm or cold going in to storage, depending upon harvest conditions. Tuber pulp temperatures determine the initial temperature of the pile in storage, and will depend upon soil (Kleinkopf and Olsen 2003) and ambient temperatures during harvest (Kays and Paull 2004). Tuber pulp temperatures impact disease development (Salas et al. 2000, Lambert and Salas 2001, Taylor et al. 2004), water loss (Burton et al. 1992, Hunter 1986, Kays and Paull 2004), sprout development (Davidson 1958, Dwelle and Stallknecht 1978), respiration rate (Hopkins 1924, Craft 1967, Schippers 1977), wound periderm formation (Artschwager 1924, Wigginton 1974, Knowles et al. 1982, Morris et al. 1989, Lulai 2007), bruise susceptibility (Thornton and Timm 1990, Corsini et al. 1999) and processing quality (Barker 1938, Hertog et al. 1997, Laza et al. 2001, Nourian et al. 2003, Kumar et al. 2004). Pulp temperatures must be considered when tubers are placed into storage as the temperature of incoming tubers will affect the existing storage temperature. Industry recommendations are to harvest as long as tuber pulp temperatures are between 10.0°C and 18.3°C to minimize losses that may occur if temperatures fall outside of this range (Bohl 2003).

In addition to harvest pulp temperatures, the temperatures at which potatoes are kept for wound healing will affect the retention of processing quality and weight through entire storage season (Schippers 1971, Daniels-Lake et al. 2014). Current industry recommendations are to keep tubers at relatively warm temperatures (10°C to 12.8°C) for two to three weeks before lowering, or ramping, to the appropriate holding temperature for the cultivar and intended market (Kleinkopf and Olsen 2003). The early storage temperature will affect tuber quality by impacting wound periderm formation (Priestly and

Woffenden 1923, Artschwager 1927, Reeve et al. 1969, Kolattukudy and Dean 1974, Kolattukudy 1980), weight loss (Schippers 1971, Knowles et al. 1982), disease development (Knowles et al. 1982, Bartz and Kelman 1984), and processing quality (Iritani and Weller 1977, Dwelle and Stalknecht 1978, Sowokinos et al. 1990, Driskell et al. 2007).

Tuber Wound Healing

Rapid development of wound periderm is critical to minimize subsequent losses. Understanding the conditions that will quickly and adequately promote suberization and development wound periderm is a significant component of early storage management. Early storage conditions dictate the development of wound periderm and influence the long-term storability and quality of potatoes. Cold or warm harvest conditions may affect the curing process by either shortening or lengthening the time required for suberization and the development of wound periderm.

Tuber wound healing is a physiological process triggered when the internal tissue of a tuber is exposed, such as skinning or shatter bruising. Native periderm is the outermost layer of protection for tubers during plant development and growth. This layer protects the tuber from disease and water loss while the tubers are still underground (Cutter 1992). At harvest, potatoes are mechanically dug and transported to storage, unloaded onto conveyor belts and piled. Damage to the native periderm during this process exposes the internal flesh of the tuber to air and pathogens. To protect the tuber from losing weight and the development of diseases, the tubers form wound periderm through a process known as wound healing (Lipetz 1970, Arschwager 1927). The wound periderm is the

outermost layer of tissue on a potato tuber that forms in response to wounding (Artschwager 1927).

The wound periderm is composed of three layers; the phellem, phellogen and phelloderm; all layers function as one tissue to protect the tuber from pathogens and water loss (Reeve et al. 1969). Wound periderm formation is initiated when cell division increases in response to wounding (Lipetz 1970). Suberin deposition occurs in the top two or three layers of cells on the cut surface in a process called primary suberization which prevents pathogen entrance and evaporation from occurring at the wound site (Priestly and Woffenden 1923). This deposition of suberin sequentially allows for the phellogen to develop underneath the suberized layer in a process known as secondary suberization (Priestly and Woffenden 1923). The “cork” layer, or phellem, forms the outermost layer of the wound periderm and is produced from the underlying phellogen, or cork cambium layer, while the phelloderm layer lies beneath the phellogen layer (Artschwager 1924). The phellogen is a layer of meristematic cells from which the outer and inner most wound periderm layers are derived (Artschwager 1924).

The primary role of suberin is to serve as a barrier to both water loss (Kolattukudy and Dean 1974) and microbial infection (Kolattukudy 1980, 1984, 1987). Suberin is composed of poly(aliphatic) (SPA) and poly(phenolic) (SPP) compounds which are deposited into the cell walls of plants (Bernards 2002). The SPA and SPP domain are cross linked by glycerol and embedded with soluble waxes which are responsible for the reduction in water loss (Bernards 2002). The SPP domain deters bacterial infection while the SPA domain imparts resistance to fungal infection (Lulai and Corsini 1998).

Suberization is the process of synthesis and deposition of suberin into existing cell walls and also the process of formation of suberized cells from a meristematic region of growth (Lulai 2007). Primary suberization is the term used in this document to describe the deposition of suberin into existing cell walls. Primary suberization occurs one cell layer at a time; one layer of cells is not suberized until the previous layer is completely suberized. SPP accumulates in cell walls first on the outer tangential walls of the cells in the first layer followed by accumulation on the radial cell walls and then the inner tangential cell walls (Lulai and Corsini 1998). After the SPP has accumulated in the entire cell wall in the first layer of cells, SPA will accumulate in that layer of cells. Each layer is suberized in this way until two to three layers of cells are suberized. While the closing layer is formed, the wound phellogen is developed. The wound phellogen will give rise to the wound phellem, which is the layer of suberized cells beneath the closing layer (Lulai and Corsini 1998, Lulai and Freeman 2001). Primary suberization may play a more important role than the wound phellem because it provides the first boundary of defense against water loss and bacterial and fungal infection (Lulai 2007).

The development of the wound periderm and primary suberization is favored by high relative humidity, 95-98%, and the presence of oxygen (Priestly and Woffenden 1922, Morris et al. 1989), while temperature is arguably the main factor in suberization (Wigginton 1974, Lulai 2007). Warmer temperatures favor suberization, while cooler temperatures inhibit the synthesis of suberin and the formation of the wound periderm (Thomas 1982).

Currently the recommendation for wound healing potatoes is to store freshly harvested potatoes for two to three weeks in the temperature range of 10°C to 12.8°C (Kleinkopf and Olsen 2003). This range of temperature will minimize weight loss (Schippers 1971) and favor suberization (Wigginton 1974). This recommendation and the practices used for wound healing in the industry are based on data from experiments on select cultivars from which results have been extrapolated to apply to many different cultivars. The common industry practice for wound healing does not consider the incoming tuber pulp temperature, nor potential differences among cultivars, both of which may influence how tubers wound heal.

Weight Loss and Disease

Management of weight loss is an important aspect of long term storage. Weight loss in tubers is greatest in the first thirty days of storage, further implicating the importance of early storage management (Kleinkopf 1995, Thornton and Bohl 1998). Conditions during this early time in storage will impact overall weight loss of tubers, so quickly developing a boundary to water loss is essential for determining overall storability of the tubers.

Wound healing is critical to reduce the amount of water leaving the tubers through open wounds (Lulai 2007). Water will also leave the tuber after removal from the plant due to transpiration and respiratory metabolic processes (Burton et al. 1992). Some factors that affect water loss are storage temperature (Smith 1952, Sparks 1965, Butchbaker et al. 1973, Iritani and Weller 1977), humidity (Neubauer et al. 1967, Butchbaker et al. 1973, Hunter 1986, Daniels-Lake et al. 2014) and airflow (Butchbaker et al. 1973, Sparks 1980,

Hunter 1986). Skin set (Soliday et al. 1979, Burton 1973, Burton et al. 1992), tuber maturity (Iritani et al. 1977, Lulai and Orr 1995), respiration (Burton 1973, Peterson et al. 1981), wounding (Burton 1968, Misener 1994), suberization (Lulai 2007), wound periderm formation (Kolattukudy 1984, Burton et al. 1992), cultivar, and pre-harvest irrigation (Castleberry and Jayanty 2012) also affect weight loss of stored potatoes.

Transpiration is the largest contributor to tuber weight loss (Burton 1966) and is driven by the vapor pressure of water in the air relative to the tuber (Kays and Paull 2004). The difference between the vapor pressure of water within the tuber and the surrounding atmosphere is known as the vapor pressure deficit (WVPD); this deficit is responsible for most of the water loss in fruits and vegetables (Kays and Paull 2004, Burton et al. 1992). Temperature is the driving factor of changing WVPDs. Warm air holds more water vapor than cooler air; it takes more water to saturate warm air than it does cool air. As the WVPD increases, transpiration increases. In consequence to warmer air temperatures and higher WVPD, water will move from the tuber to the surrounding atmosphere until equilibrium is reached. Furthermore, if air temperature is cooler than the tuber temperature, water may condense out of the air on to surfaces such as the storage walls or ceiling or the surface of the tuber creating favorable conditions for disease development (Burton et al. 1992).

Humidity and the amount of ventilation will also affect weight loss of potatoes (Neubauer et al. 1967, Butchbaker et al. 1973, Sparks 1980, Daniels-Lake et al. 2014). Hunter (1986) showed that increased air flow with inadequate relative humidity increased weight loss, but weight loss decreased as relative humidity rose above 95%. Furthermore, low relative humidity at the start of storage was shown to affect quality of potatoes later in

storage, indicating the importance of relative humidity early in potato storage (Daniels-lake et al. 2014).

Physiological characteristics of tubers can also affect weight loss in storage. Skin set and maturity influence water loss by dictating the permeability of the native periderm (Iritani and Weller 1977, Lulai and Freeman 2001). Immature tubers are prone to skinning at harvest which may result in excessive weight loss problems in storage (Murphy 1968, Hiller et al. 1985, Lulai and Orr 1993). In mature periderm, an area of the periderm known as the phellogen has cell walls which are thicker and stronger than cell walls in immature periderm. The mature periderm is more resistant to excoriation than immature periderm, reducing the incidence of skinning injury and potential weight loss problems (Lulai and Freeman 2001).

Respiration is a metabolic process that can influence the weight loss of potato tubers, but respirational losses are lower compared to transpiration losses (Burton et al. 1992). Respiration rate is affected by temperature (Sparks 1973, Boe et al. 1974, Burton 1966). Water, carbon dioxide and energy in the form of ATP are products of respiration (Kays and Paull 2004). Some energy produced in respiration is lost as heat while the remaining energy is used for metabolic processes. Carbon dioxide and water are transferred to the external environment due to gradients; this primarily occurs through lenticels. Since some energy is lost as heat in respiration, this can warm the external environment of the tuber, favoring the movement and potential exchange of water from the internal tissue to the external environment. Any process that increases the respiration rate, will also increase the amount of heat generated by the tubers and the water lost from

the tubers (Kays and Paull 2004). Sprout development (Schippers 1977, Frydecka-Mazurczyk 1978, Hunter 1986), disease development (Gwinn et al. 1989, Fennir et al. 2005), and wounding (van der Plas et al. 1976, Burton et al. 1992, Pisarczyk 1982) are all associated with an increase in respiration rate. Cultivar (Schippers 1977, Freydecka-Mazurczyk 1978, Hunter 1986), fluctuating temperatures (Burton 1974), and chemical application (Burton et al. 1992, Boe et al. 1974, Blenkinsop et al. 2002) can also impact tuber respiration and therefore contribute to tuber weight loss.

Wounds of potato tubers are a consequence of mechanical harvest and storage loading. Exposing the internal tissue of the tuber increases water loss through evaporation since there is no longer the native periderm to serve as a barrier (Soliday et al. 1979, Kolattukudy 1984, Burton et al. 1992). Additionally, wounds will increase respiration, impacting water loss (Pisarczyk 1982). To reduce the impact of wounding, plants have developed the mechanism to wound heal, often by the deposition of suberin. As described earlier, suberin is an extracellular biopolymer produced by many plants to protect cells from desiccation and water loss (Franke and Schreiber 2007). Suberization and the formation of the wound periderm will reduce water loss in wounded tubers (Dean and Kolattukudy 1976, Soliday et al. 1979, Lulai and Corsini 1998) and protect tubers from substantial desiccation, but it must occur immediately after harvest to avoid high initial weight loss.

Processing Quality

In 2013, 7.2 million metric tons of potatoes were processed into frozen french fries (NASS 2014a). Standards of the processing industry require uniform light fry color,

predominately determined by the content of reducing sugars, glucose and fructose, in the tubers (Habib and Brown 1956, Schwimmer et al. 1957, Driskill et al. 2007). The major factor limiting the processing quality of potatoes is the accumulation of reducing sugars during storage (Denny and Thornton 1942, Habib and Brown 1956, Habib and Brown 1957, Shallenberger et al. 1959). Dry matter content affects texture and thus processing quality, but is not as greatly affected by storage conditions (Storey and Davies 1992).

Sugar concentrations are an important quality parameter of processing potatoes due to a prevalence of reducing sugars, glucose and fructose, resulting in darker fry color (Fuller and Hughes 1984, Marquez and Anon 1986). Glucose and fructose react with free amino acids during frying in the Maillard reaction which results in sugar, lipid and RNA degradation products which contribute to the flavor of fried potato products (Duckham et al. 2001). However, the Maillard reaction can result in darker fry color and off-flavors (Shallenberger et al. 1959, Driskell et al. 2007) resulting in decreased marketability of processed potato products (Jansky 2010). In addition to dark fry color, the Maillard reaction produces acrylamide. Acrylamide is identified as a potential carcinogen, which has raised awareness for the presence of the substance in cooked foods (Bethke and Bussan 2013). Due to the consumer demand for lighter fry color (Jansky 2010) and more recently, the demand for lower acrylamide, low sugar levels are essential for good processing quality.

Factors affecting processing quality of potato tubers start while the tubers are still growing in the field. According to Iritani (1981), plant stress during the growing season, both early and late, can cause uneven tuber fry color resulting from an elevated sugar

content in the stem end of tubers. Iritani further describes tuber physiological maturity as the stage of development where tubers have minimal sugar content and high starch content. Physiologically immature tubers can result from harvesting under green vines, from high nitrogen fertilization at the end of the season; these tubers often have higher reducing sugars than properly matured tubers. Over-mature tubers can also be problematic for processing quality. Over-mature tubers can be susceptible to bud-end and stem-end sugar development and may accumulate more sugars in storage than mature tubers (Iritani and Weller 1978, Knowles et al. 2009).

Iritaini and Weller (1977) also described how growing season stress can influence starch accumulation in potato tubers and can alter tuber sucrose content at harvest and throughout storage. Furthermore, temperature during crop growth and storage can impact reducing sugar content of potatoes (Burton 1966, Sowokinos 1990). High soil temperature during crop growth has been shown to impact storage reducing sugar build up during storage (Zommick et al. 2013).

In addition to growing conditions, the storage environment will affect reducing sugar content of tubers (Burton et al. 1992). A lengthy period of warm storage temperatures of 20°C and above can increase sugar concentration of potatoes (Nielson and Todd 1946, Linnemann et al. 1985); likewise cold temperatures can induce the breakdown of starch to sugars (Sowokinos 1990, Isherwood 1973, Pritchard and Adam 1994). This process is referred to as low temperature sweetening and usually happens when storage temperatures fall below 9°C (Workman et al. 1979, Richardson et al. 1990, Zrenner et al. 1996). In some cases, processing quality can be restored by reversing the cold-induced

sweetening by exposing tubers to temperatures above 12.7°C, a process called reconditioning (Knowles et al. 2009, Zommick et al. 2013). Furthermore, senescent sweetening is an age-related, irreversible increase in sugar content which generally occurs late in the storage period (Burton 1966); warm temperatures will only accelerate sugar accumulation in the senescent sweetening process (Burton 1966, Isherwood and Burton 1975).

Increases in tuber respiration will also affect tuber reducing sugar content and therefore processing quality. Respiration uses starch as a substrate to produce energy which can be used in metabolic processes. Starch is broke down into sugars which are then further broke down to release energy in the form of ATP (Kays and Paull 2004). The breakdown of starch into sugars can increase the amount of reducing sugars in tubers, which may be detrimental to processing quality. As described previously regarding respiratory weight loss, sprouting, wounding, temperature, and chemical sprout inhibitor treatments are a few factors that will impact respiration and therefore reducing sugar content (Burton et al. 1992, Kumar et al. 2004).

The storage atmosphere is another important factor that can affect tuber processing quality and is largely impacted by tuber respiration. Availability of oxygen and the flushing out or purging of carbon dioxide in storage is necessary to provide tubers with oxygen for respiration (Burton et al. 1992). Insufficient storage air movement may limit or severely reduce available oxygen and increase carbon dioxide content of the air resulting in increased sugar accumulation (Reust 1984, Mazza and Siemens 1990).

Since temperature plays such a critical role in early storage management in order to enhance the development of the wound periderm, it is important to understand the implications these temperatures have on the biochemical components of the tubers, including sugar concentrations.

Cultivars

Cultivars of potatoes can differ in many ways, including storability and processing quality. Sugar and starch content and periderm attributes are all influenced by the genetic makeup of the cultivar (Kumar et al. 2004, Lulai 2007). Knowing cultivar strength and weaknesses in wound healing will allow growers to make better decisions when managing early storage temperatures to favor suberization, minimize weight loss and maintain processing quality. Market acceptance and economic advantage are two reasons cultivars are selected for use by growers (Love et al. 2003). Agronomic strength and weaknesses may influence the decision to grow a cultivar, but ultimately, consumer preference will determine which cultivars must be grown (Love et al. 2003). Cultivars which are easy to grow and store are favorable to growers, however, those cultivars may not be accepted by processors. A grower will gain a distinct advantage if the demanded cultivars can be grown and managed effectively. Learning how each cultivar responds to a range of storage conditions, both early and late, is critical for a grower to successfully manage the cultivar.

Russet Burbank, Ranger Russet and Clearwater Russet are three cultivars currently used in the processing industry. Russet Burbank is the traditional processing cultivar comprising 37% of all potato acres planted in the United States in 2014 (NASS 2014b); it is a late maturing variety that has high yields. This cultivar serves as the standard for baking

and processing quality. Ranger Russet was developed as an alternative for Russet Burbank (Pavek et al. 1992). This cultivar has a medium crop maturity, being approximately two weeks earlier than Russet Burbank, and is often dug from under green vines as opposed to Russet Burbank, which is usually allowed to set skin under dead vines in the field. Ranger Russet is susceptible to blackspot bruising during warm harvest temperatures and tubers have a medium dormancy, which results in a shorter storage duration for this variety (Love et al. 1998). Ranger Russet accounted for 11% of all acres planted in the United States in 2014, second behind Russet Burbank (NASS 2014b). Clearwater Russet is a new cultivar which may become favored by processors in the future; in 2013 it accounted for 0.5% of U.S. potato acreage, but increased to 0.7% in 2014 (NASS 2014b). Clearwater Russet is another cultivar with a shorter dormancy than Russet Burbank (Brandt et al. 2013). Clearwater Russet has potential as a good processing cultivar due to low glucose concentrations and light fry color throughout storage, even at lower storage temperatures (Brandt et al. 2013).

Heat Unit Modelling

The effect of temperature on potato tuber physiology and the importance of temperature management has been discussed previously. Development of a model to determine the impact of temperature on potato early storage management would be beneficial to the potato industry.

The effect of temperature on a biological process can be measured by calculating heat accumulation (Baskerville and Emin 1968). A daily minimum temperature and daily maximum temperature are averaged and subtracted from a base temperature, producing a

unit which can be used to quantify a biological process of interest (Arnold 1960). Addressing the use of accumulated heat units to predict the biological process of wound healing is of interest. Furthermore, having the ability to quantify the impact of field heat, i.e. harvest pulp temperatures, on wound periderm development may allow for the refinement of early storage management recommendations. Accumulating heat units would allow for time and temperature to be combined into one unit at which a given amount of wound healing would occur.

For the application of wound healing, a curing temperature would be selected, or tuber pulp temperatures known, and a heat unit would be calculated and accumulated for the amount of time tubers were at a given temperature. Finding a use for accumulated heat units in potato storage management could serve as a useful tool for potato growers. The use of accumulated heat units would be most applicable for potato storage maintenance. Accumulated heat units would allow growers to calculate how much time must be spent at a given temperature in order for the tubers to be wound healed sufficiently. Additionally, the use of heat units in the potato industry, particularly in the storage of potatoes, may be applicable in predicting weight loss, disease development or changes in processing quality.

Objectives

Early storage temperatures influence development of the wound periderm and primary suberization processes, which will affect the storability of the crop through influencing weight loss and disease development. Furthermore, temperature can influence processing quality by affecting reducing sugar levels. Cultivar response to early storage

conditions will differ, further influencing storability and processing quality of potatoes. A model quantifying the impact of early storage temperatures would allow for specialized early storage management recommendations based on harvest pulp temperature, curing temperature, and cultivar differences.

The objective of this study was to determine the impact of curing temperature on primary suberization, processing quality, and weight loss in three potato cultivars, Russet Burbank, Ranger Russet and Clearwater Russet. Additionally, tuber weight loss in commercial Idaho storages was assessed and the application of heat units was used to model the impact of early storage temperatures on wound healing.

MATERIALS AND METHODS

Plant Material

Potato cultivars Russet Burbank (RB), Ranger Russet (RR) and Clearwater Russet (CW) were grown at the University of Idaho Kimberly Research and Extension Center (KREC) in Kimberly, Idaho. Seed pieces (50 g to 70 g) were planted April 21, 2014 in 2 row plots (85 m) with 29 cm within-row spacing. The crop was grown using University of Idaho best management practices (Stark and Love 2003). Plants were mechanically vine killed September 4, 2014, 155 days after planting (DAP). Tubers were mechanically harvested on September 23, 2014.

Study 1: Effect of curing temperature and time on wound healing and suberization of Russet Burbank, Ranger Russet and Clearwater Russet potatoes

On the day of harvest, approximately 330 kg of tubers per cultivar were stored in plastic mesh boxes (60.5 cm x 42.6 cm x 42.6 cm) in environmentally controlled storage bins at the KREC Potato Storage Research Facility. Tubers were wound healed at 12.8°C (+/- 0.7°C) for 14 days. Temperature ramping began on the October 8, 2014 (0.3°C/day) until the holding temperature of 8.9°C (+/-0.7°C) was reached. Relative humidity was kept at 95% (+/- 3%) during the entire storage period. Each cultivar was evaluated separately. Refer to Table 1 for explanation of dates of experiments, sprout inhibitor application, and size of tubers used. The experiments were repeated twice for each cultivar. Experiment 1 was conducted using tubers free of sprout inhibitors and had been in storage for 23 days after harvest (DAH) for RB, 44 DAH for RR, and 70 DAH for CW. Experiment 2 was conducted using tubers that had received a thermal application of the sprout inhibitor

chlorpropham (CIPC; Sprout Nip 7A, Loveland Products, Inc. Greeley, Colorado) on November 25, 2014 at 22 ppm and tubers were used 122 DAH for RB, 153 DAH for RR, and 179 DAH for CW.

Table 1. Potato cultivar, date experiment started, sprout inhibitor application and size of tubers used for evaluation of wound healing.

	Date Russet Burbank (DAH[1]) (months)	Date Ranger Russet (DAH[1]) (months)	Date Clearwater Russet (DAH[1]) (months)	Chlorpropham application	Size of Tubers (g)
Experiment 1	10/16/14 (23) (1 month)	11/6/14 (44) (2 months)	12/2/14 (70) (3 months)	No	141-341
Experiment 2	1/23/15 (122) (4 months)	2/23/15 (153) (5 months)	3/21/15 (179) (6 months)	Yes	113-397
[1]DAH=Days after harvest					

Wound Healing Units

A modified wound healing analysis method of Knowles et al. (1982) and Kumar et al. (2003) was used to evaluate for wound healing units. Cores were taken from washed and sized tubers (Table 1) as described below. Cores were placed into wound healing (curing) treatments of 7.2°C, 12.8°C, or 18.3°C temperatures. Samples were evaluated over time at 0, 5, 10, 15, or 20 days. Freshly cored tissue was used as a control at each sample evaluation.

For each washed tuber, 30 to 50 mm was cut from the bud and stem end. Cores were taken from the remaining intact tuber perpendicular to the longitudinal axis of the tuber through the native periderm. A 15 mm cork borer was used to take two cores; one from the bud and stem end of each tuber (Table A.1). The core was trimmed to 30 mm in

length with no more than 5 mm of the native periderm being trimmed off one end. The fresh weight of each core was recorded (Sartorius Quintix Scale, Bohemia, NY. Model 612-1S) and cores were placed in a wire mesh basket (bud and stem end cores randomized) (15.9 cm x 5.8 cm x 6.3 cm) gridded with plastic twine to separate cores. One replicate consisted of four cores from two tubers; 5 replicates per treatment. The baskets were placed on top of sponges saturated with 1300 mL of water in a plastic tub measuring 33.0 cm x 20.3 cm x 10.2 cm (5 baskets per tub). The baskets were elevated above the sponges by placing plastic pipettes between the sponge and the basket to avoid direct contact with the saturated sponges. Baskets were covered in damp cheese cloth and the plastic tub lid was placed over the top of the baskets with an approximate gap of 1 cm between the lid and top of the tub to ensure airflow into the tub.

Tubs with cores were placed in incubators (Fisher Scientific Isotemp Undercounter BOD Refrigerated Incubators, Fisher Scientific Waltham, MA. Model 146E 115V) set at one of the three treatment temperatures (7.2°C, 12.8°C, 18.3°C) for up to 20 days. Humidifiers (SPT Personal Humidifiers, China, Model SU-1051B) were placed in the incubator to maintain 95% relative humidity inside the tub. Temperature and relative humidity were monitored and recorded in each incubator and tub using multiple instruments due to the inherent difficulty of measuring relative humidity and temperature in the system. The incubator thermometer, glass thermometers, and data loggers (HOBO UX100 data loggers Onset, Bourne, MA. Model UX100-003, Kestrel DROP D2, Kielsen-Kellerman, Boothwayn, PA) were used in each incubator. The instruments and manufacturer specifications are presented in Table 2. At each of the curing intervals, cores were removed from the

incubator and placed in a separate wire mesh basket. In experiment 2, a 'Core Visual Appearance' rating was recorded for each core. Ratings were based on visual observation of cores described in Table 3. Cores at each curing interval were transferred to a drying oven (Modern Lab Equipment Company New York, NY. Model 125-SS) to undergo forced desiccation at 65°C (Knowles et al. 1982). The weight of the cores was recorded every 30 minutes for 120 minutes. Wound healing units were calculated by the resistance to weight loss method described by Kumar and Knowles (2003). Wound healing units were computed as the inverse of the slope of weight loss over the 120 minute desiccation period; wound healing units describe the amount of time it takes to lose 1% of the wound healed weight of the cores, or the resistance to weight loss of cured cores. Wound healing units will be the designated units used in this document, however, resistance to weight loss (min/%) would be applicable to describe this method of measuring wound healing.

Table 2. Instruments used to measure temperature and relative humidity within incubators used to cure cores of Russet Burbank, Ranger Russet and Clearwater Russet potatoes.

Parameter Measured	Name of Instrument	Manufacturer of Instrument	Manufacturer Specifications
Temperature	HOBO	Onset Company	+/-0.21°C
Temperature	Kestrel	Nielsen-Kellerman	+/-0.5°C
Temperature	Incubator	Fisher Scientific	+/- 0.2°C stability +/-1.0°C uniformity
Temperature	Glass Thermometer	Fisher Scientific	+/-1.5°C
Relative Humidity	HOBO	Onset Company	+/-5.0%
Relative Humidity	Kestrel	Nielsen-Kellerman	+/-2.0%

In addition to the complete data set, data was omitted from analysis in experiment 1 if the weight loss during the desiccation period was unusually higher than the average

and/or if a visual observation of decay was noted to which the high weight loss could be attributed. This was done to eliminate variability in resistance to weight loss due to decay. In experiment 2, cores which were given a 'Core Visual Appearance Rating' of 3 (Table 3), were omitted in data analysis to eliminate variability due to observable decay.

Table 3. Potato core visual appearance rating scale used prior to forced desiccation.

Core Visual Appearance Rating	Visual Observation
0	No discoloration or apparent disease present on core; core is firm.
1	Slight or mild discoloration or pathogenic growth on core; core is firm.
2	Moderate to heavy discoloration or pathogenic growth on core; core is firm.
3	Heavy discoloration and/or pathogenic growth on core; core is no longer firm; decay of core has occurred.

Statistical Methods

Four cores comprised one replicate for wound healing ability analysis and five replicates per treatment and a randomized complete block design was used. Wound healing units were calculated by generating regression lines for the weight loss (response variable) over time (independent variable) for each rep of treatment (curing interval/ temperature combination). The slope of the regression line was used if the regression was significant at $p \leq 0.05$. Wound healing units were calculated from the regression slope as the inverse of the slope. An adjustment was calculated from the standard deviation of the

slopes as the inverse of the standard deviation. An analysis of variance was performed. The adjustment previously calculated from the inverse of the standard deviation was used to adjust the estimations based on accuracy of the slopes used for computing wound healing units. Least-square means tests for comparisons among temperature, curing time and experiments were considered significant at $P \leq 0.05$ when the model was significant ($P \leq 0.5$). SAS Version 9.4 was used for all data analysis (SAS Institute Inc., Cary, NC).

Microscopy Analysis of Suberin Deposition

Cores cured in the same treatments and sampling dates as described above were used to analyze suberin deposition using auto fluorescence microscopy technique. Freehand cross-sections, 15 mm diameter, ≥ 1 mm thick, were taken from cores to acquire a disc of potato tissue that was mounted in glycerin according to Brundrett et al. (1991). Discs were examined for auto fluorescence at 5, 10, 15 and 20 days as described by Nolte et al. (2011) under a Carl Zeiss Standard Illumination Microscope (Carl Zeiss Jena, Germany. Model 910112) phase UV microscope for auto-fluorescence to indicate the presence of suberin in cell walls. A control was added in experiment 2, consisting of fresh cored and sliced tissue. The number of suberized cells was counted and the depth of the suberin layer was measured with an eyepiece micrometer under fluorescent light at 80x magnification. Pictures of representative sections were taken using a Canon Rebel T4i EOS 650D DSLR camera (Canon U.S.S, Inc., Melville, NY.) mounted with an Amscope Camera Adapter for Microscope lens (Amscope, Irvine, CA.) at 20x.

Statistical Methods

One core comprised one replicate for microscopy analysis. Eight replicates per treatment were used in experiment 1, while five replicates were used in experiment 2. Analysis of variance was performed utilizing SAS (GLMM). Least-square means tests for comparisons among temperature and curing time were considered significant at P=0.05 when the model was significant (P≤0.05). SAS Version 9.4 was used for all data analysis (SAS Institute Inc., Cary, NC).

Study 2: The impacts of curing temperatures on Russet Burbank, Ranger Russet and Clearwater Russet potatoes and the effect on long term storability and processing quality characteristics

At harvest, approximately 500 kg of tubers per cultivar were stored for processing quality assessments in plastic mesh boxes (60.4 cm x 42.7 cm x 31.1 cm) and approximately 60 kg of tubers were stored for weight loss evaluation in mesh bags (43.2 cm x 33.0 cm Associated Bag Company, Wisconsin). Table 4 outlines the tuber curing treatments of 7.2°C, 12.8°C, or 18.3°C (95% relative humidity (RH)) for 14 days (4 replicates/treatment). Ramping up or down began on October 8, 2014 (0.3°C/day 95% RH) until the final holding temperature of 8.9°C (95% RH) was reached. Chlorpropham (CIPC; Sprout Nip 7A, Loveland Products, Inc., Colorado) sprout inhibitor was thermally applied November 25, 2014 at 22 ppm.

Table 4. Potato tuber curing treatments for processing quality assessments and weight loss evaluation in the 2014-15 study. All treatments maintained 95% relative humidity throughout the duration of the study.

Harvest Date	Cultivar[1]	Curing Temperature (°C)	Days of Curing	Curing End Date	Ramp Rate (°C/Day)	Days of Ramp	Ramping End Date	Final Holding Temperature (°C)
9/23/2014	RB	7.2	14	10/8/2014	+0.3	5	10/13/2014	8.9
9/23/2014	RB	12.8	14	10/8/2014	-0.3	13	10/27/2014	8.9
9/23/2014	RB	18.3	14	10/8/2014	-0.3	33	11/10/2014	8.9
9/23/2014	RR	7.2	14	10/8/2014	+0.3	5	10/13/2014	8.9
9/23/2014	RR	12.8	14	10/8/2014	-0.3	13	10/27/2014	8.9
9/23/2014	RR	18.3	14	10/8/2014	-0.3	33	11/10/2014	8.9
9/23/2014	CW	7.2	14	10/8/2014	+0.3	5	10/13/2014	8.9
9/23/2014	CW	12.8	14	10/8/2014	-0.3	13	10/27/2014	8.9
9/23/2014	CW	18.3	14	10/8/2014	-0.3	33	11/10/2014	8.9

[1]RB=Russet Burbank; RR=Ranger Russet; CW=Clearwater Russet

Processing Quality Assessment

At harvest, specific gravity of four replicates was measured on approximately 4.5 kg of randomly selected tubers via the weight in air/weight in water method of Schippers (1976). Processing quality was assessed by evaluating fry color and quality, as described below, and potato tuber glucose and sucrose concentrations using the sugar analysis of Sowokinos et al. (2000) with modifications. Processing quality was determined from a ten-tuber sample (4 replicates/treatment) at 2, 14, 48, 134, 203, and 237 days after harvest. The sampling schedule for processing quality assessment is described in Table 5.

Table 5. Sampling date, days after harvest and description of date for processing quality assessment.

Date	Days after Harvest	Description of Date
09/25/2014	2	At harvest
10/08/2014	15	After curing
11/11/2014	49	After ramping
02/04/2015	139	February
4/14/2015	203	April
05/18/2015	237	End of Storage

Sugar and Fry Quality Analysis

Washed tubers were cut using a Keen Kut Shoe Stringer French fry cutter. Tuber tissue (200 g) collected from the center of the ten tubers was macerated in an Acme Juicerator (Acme Equipment, Spring Hill, FL). During processing, tuber tissue was combined with 150 mL of sodium-phosphate buffer (0.05 M, pH 7.5) for a final homogenate volume of 275 mL. Glucose and sucrose concentrations were determined using a YSI model 2700

Analyzer (Yellow Springs Instrument Co., Inc., Yellow Springs, OH) and expressed on a percent fresh weight basis.

One fried plank (3.0 cm x 0.8 cm) from each of the ten tubers used in the sugar extraction procedure was used for fry color determination (10 strips per replicate). A mean of the fry planks was used for fry color analysis per replication. Strips were fried in canola oil at 190.6°C for 3.5 minutes. Fry color was determined within 3 minutes using a model 577 Photovolt Reflection Meter (model 577, Photovolt Instruments Inc., Minneapolis, MN). A green filter was used and calibrated using a black-cavity standard as 0.0% reflectance and a white plaque (Cat. No. 26-570-08) as 99.9% reflectance. Measurements were taken on the bud and stem ends of each strip. A relationship between USDA fry color and photovolt reflectance as measured by this particular meter and methodology was previously established. A USDA fry color rating 1 was equal to a 44.0 or greater reflectance rating, a USDA 2 rating ranged from 44.0 to 35.0 reflectance rating, a USDA 3 rating ranged from 35.0 to 26.0 reflectance reading, and a USDA 4 rating was less than 26.0 reflectance rating (Kincaid et al. 1993). The lower the reflectance measurement, the darker the fry color.

Statistical Methods

A ten-tuber subsample comprised one replicate for sugar and fry color analysis; four replicates per treatment were analyzed. Analysis of variance was performed utilizing SAS (GLM). Means were separated by LSD at α=0.05. Multiple comparisons were evaluated using Fisher's LSD.

Weight Loss and Disease Incidence

Tuber samples, approximately 4.5 kg (4 replicates per treatment) were stored in mesh bags (43.2 cm x 33.0 cm Associated Bag Company, Wisconsin) in the KREC storage bins for 212 days. Curing treatments were the same as processing quality assessment and described in Table 4. Initial sample bag weight was recorded on September 9, 2014 and final weight was recorded on April 4, 2015. Sample bag weight was recorded weekly for the first 50 days of storage and then monthly. Percent weight loss was calculated. After the final weight was recorded, disease incidence was recorded on one replicate per treatment by the number of tubers with disease visually present divided by the total number of tubers.

Statistical Methods

One (4.5 kg) sample comprised one replicate for weight loss analysis and four replicates per treatment. Analysis of variance was performed using SAS (GLM). Least-square means tests for comparisons among curing temperature and cultivar were considered significant at $P \leq 0.05$ when the model was significant ($P \leq 0.05$). SAS Version 9.4 was used for all data analysis (SAS Institute Inc., Cary, NC).

Study 3: Using commercial storages to understand cultivar and temperature influence on weight loss of stored potatoes grown in Southern Idaho

In 2013, two RB commercial storages were sampled for weight loss. Tubers were randomly selected off the conveyors into mesh sample bags weighing 13-18 kg and placed in the storage as tubers were being loaded into the storage bay at harvest. Samples were distributed evenly throughout the pile in groups of three. Two samples were embedded

within the pile and a third bag was placed on top of the pile. Total sample bag weight was recorded. Pulp temperature, general tuber condition, presence of decay and outdoor environmental conditions were recorded throughout sampling. Samples were collected when the commercial grower unloaded the storage; weight was recorded and amount of decay assessed. Percent weight loss was calculated. Some samples were lost during unloading and are not included in the results. Table 6 provides a description and details of commercial storages sampled in 2013.

In addition to samples placed in commercial storages in 2013, matched samples were stored at the University of Idaho Kimberly Research and Extension Center (KREC) in Kimberly, Idaho. Tubers were randomly selected off the conveyors of the commercial operations as described above, into mesh sample bags weighing approximately 5 kg. Total sample bag weight was recorded on site of commercial storage operation. Samples were transported to KREC and cured at 12.8°C for 14 days then ramped 0.03°C per day until the holding temperature of 8.8°C was reached. Ramping took a total of 14 days. Total end weight of KREC stored samples were recorded and amount of decay was assessed when the matching grower storage was unloaded.

In 2014, one RB, one RR and two CW commercial storages were sampled for weight loss. Mesh sample bags of tubers weighing 13-18 kg were placed in storage as tubers were being loaded into the storage bay at harvest. Table 6 provides a description and details of commercial storages sampled in 2014. Sample weight and tuber condition were recorded as stated above. Samples were distributed evenly throughout the pile in groups of three. Two samples of the three-group samples were embedded within the pile and a third

sample was placed on the top of the pile. Samples were collected when the commercial grower unloaded the storage; weight was recorded and amount of decay assessed. Percent weight loss was calculated.

Statistical Methods

One sample comprised one replicate for weight loss analysis. Refer to Table 6 "Number of Samples Recovered" for number of replicates per storage used in the analysis. Analysis of variance was performed using SAS GLM. Least-square means tests for comparisons among in pile and on top of pile samples were considered significant at $P \leq 0.05$ when the model was significant ($P \leq 0.05$). SAS Version 9.4 was used for all data analysis (SAS Institute Inc., Cary, NC).

Table 6. Description and details of potato commercial storages sampled in 2013 and 2014 in Southern Idaho.

Storage year	Storage	Cultivar	Size of storage (MT)	Type of storage	Harvest date range	Set holding temperature °C/set RH[1]	Days of curing and ramping	Number of samples placed	Number of samples recovered	Unload date range	Total days in storage
2013-2014	A	RB	5,442	Slant wall	10/1/13-10/3/13	8.9 (95%)	63	31	31	5/27/14-6/12/14	254
2013-2014	B	RB	6,100	Slant wall	9/24/13-9/27/13	8.9 (95%)	65	32	20[2]	6/16/14-6/23/14	272
2014-2015	C	RB	6,100	Slant wall	10/3/14-10/7/14	Unknown	Unknown	30	21[2]	6/26/2015-7/09/2015	279
2014-2015	D	RR	5,442	Slant wall	9/15/14-9/22/14	8.9 (95%)	Unknown	30	27[2]	10/21/14-10/27/14	42
2014-2015	E	CW	5,442	Slant wall	9/9/14-9/10/14	8.9 (95%)	75	18	17[2]	6/18/15-6/26/15	290
2014-2015	F	CW	6,803	Curvette	10/9/2014	8.9 (95%)	56	10	8[2]	6/15/15-6/17/15	251

[1]Relative Humidity
[2] Number of recovered samples is lower than the initial due to loss in recovering

Accumulated Heat Units

Accumulated Heat Units were calculated for all three studies. Daily heat units were calculated as follows:

$$Heat\ Unit = \left[\frac{Tmax+Tmin}{2}\right] - Tbase$$

where T-max is the daily maximum temperature, T-min is the daily minimum temperature, and T-base is the base temperature (McMaster 1997). Heat units were accumulated by summing the heat units of each day. A T-base of 0˚C was used to calculate heat units. This base was used to account for any wound healing that may occur at low temperatures (Artschwager 1927).

Statistical Methods

Regression analysis was performed using SAS (version 9.4; SAS Institute Inc., Cary, NC) on experiment 1 and 2 wound healing units separately for each cultivar using a cubic model over accumulated heat units. The cubic model was $y = B_0 + B_1x + B_2x^2 + B_3x^3$.

RESULTS

Study 1: Effects of curing temperature and time on wound healing of Russet Burbank, Ranger Russet and Clearwater Russet

Russet Burbank

Wound Healing Units

Russet Burbank (RB) wound healing units (WHU) calculated from experiment 1 and experiment 2 were significantly different so data was not combined in the analysis. The data presented below consists of all cores including those with observable decay. In addition to these results, WHU data was analyzed by omitting any cores that were noted to be severely decayed in experiment 1 (Figure A.1) or cores that received a 'Core Visual Appearance Rating' of 3 (Table 2; Figure A.2) in experiment 2, and also omitting cores noted with any decay in experiment 1 (Figure A.3) and with a 'Core Visual Appearance Rating' of 2 and 3 (Table 3; Figure A.4) in experiment 2 in order to account for WHU that may be undetectable due to decay of cores. The results of the decay-omitted data did not appear to change WHU trends as seen in Figures 1 and 2.

Experiment 1

Figure 1 displays the WHU for Russet Burbank in experiment 1. After 5 days, regardless of curing temperature, WHU were not significantly different than the control. WHU of cores cured at 7.2°C were significantly higher (6.1) than the control (5.2) only after 15 days of curing; these cores were slow to wound heal. At 10 and 15 days of curing, each increase in temperature resulted in a significantly higher amount of WHU of the cores. WHU of cores cured at 18.3°C for 15 days and WHU cured at 12.8°C for 20 days were not significantly different, suggesting a 5 day lag in wound healing ability when the curing

temperature decreased from 18.3°C to 12.8°C. At 20 days of curing, cores cured at 18.3°C had significantly lower WHU than those cured for 15 days at 18.3°C due to the presence of decay in the cores.

Experiment 2

Although significantly different, results in experiment 2 (Figure 2) showed similar trends to experiment 1 results (Figure 1); in general, wound healing was slower and WHU were lower in cores from experiment 2 compared to experiment 1. Similar to the results obtained in experiment 1, none of the curing temperatures in experiment 2 resulted in significant wound healing compared to the control after 5 days of curing and WHU of cores cured at 7.2°C (5.2) were only significantly different from the control (4.8) after 15 days of curing, however, WHU of cores cured for 15 days at 7.2°C were not significantly different from WHU of cores cured at 7.2°C for 5 days. At 10, 15, and 20 days of curing, each increase in temperature resulted in a significantly higher amount of WHU of the cores. WHU of cores cured at 18.3°C did not increase after 15 days of curing, suggesting the completion of wound healing. Less decay of the cores was observed than in experiment 1. Wound healing of cores from the 12.8°C curing temperature lagged 5 days behind the 18.3°C curing temperature, similar to experiment 1, but after 20 days of curing, the WHU of cores cured at 12.8°C remained significantly lower than the WHU of cores cured for 15 and 20 days at 18.3°C.

Accumulated heat units

Accumulated heat units (AHU) were calculated for the curing interval/temperature combinations to plot RB experiment 1 and experiment 2 WHU (Figure 3). Both experiment

1 and experiment 2 were combined for the regression analysis. WHU as described by AHU exhibited a cubic trend for RB. The equation for the regression line fit to the data was: $WHU=5.31-(3.87e^{-2})AHU+(5.45e^{-4})AHU^2-(1.1e^{-6})AHU^3$. ($P<.0001$, $R^2=0.86$). According to the regression analysis, the maximum WHU were achieved at 304 AHU. The control treatment of freshly cored tissue was considered the minimum WHU. The AHU at which WHU began to rise above this minimum was 86 AHU.

Microscopy

Experiment 1

At 5, 10, 15 and 20 days of curing, each 5.5°C increase in temperature resulted in a significantly higher number of auto fluorescing cells (AFC; Figure 4). A similar response occurred in the depth of AFC with increasing curing temperature (Figure 5). Both the number and depth of AFC at 7.2°C was significantly less than the two warmer temperatures (Figure 4, Figure 5). The depth of AFC in cores cured at 12.8°C for 20 days (382 µm) was not significantly different than the depth of AFC in cores cured at 18.3°C for 20 days (345 µm, Figure 5). At day 20 of curing, AFC depth at 18.3°C (345 µm) was significantly less than the AFC depth at 15 days curing at 18.3°C (406 µm; Figure 5). The number of AFC in cores cured at 18.3°C did not increase after 15 days of curing (2.5 cells, Figure 4).

Experiment 2

Figure 6 presents the number of AFC in experiment 2 and Figure 7 presents the depth of cells AFC in experiment 2. The number and depth of AFC at the curing temperature of 7.2°C was not significantly different from the control after 5 days of curing, but was significantly less than the warmer curing temperatures of 12.8°C and 18.3°C at this

time. The number and AFC depth in cores cured at 7.2°C continued to be significantly less than the warmer curing temperatures at each of the curing intervals (Figure 6). Suberization was stagnant for both AFC number (Figure 6) and depth (Figure 7) in cores cured at the cooler temperature of 7.2°C between 10 (0.7 cells, 117 µm) and 15 days (0.7 cells, 130 µm). This same pattern also occurred at the warmer temperatures. At the curing temperature of 12.8°C, the number (0.7 cells) and depth (43 µm) of AFC in cured cores was significantly less than the number and depth of AFC in cores cured at 18.3°C (1.1 cells, 111 µm) at 5 days of curing. The number and depth of AFC significantly increased in cores from both warmer temperatures between 5 and 10 days, but at 10 days cores from the two temperatures did not significantly differ from each other and the depth and number of cells with suberization were equal. The number of AFC did not change from 10 to 15 days when cores were cured at 12.8°C, but significantly increased from 15 to 20 days at this temperature. Suberization was static between 10 and 15 days at 12.8°C. The depth of AFC significantly decreased from 10 to 15 days for both curing temperatures 12.8°C and 18.3°C, confirming that no suberization was occurring at these temperature between 10 and 15 days. The number of AFC for 18.3°C cured cores continued to significantly increase at each curing interval. At the final curing interval of 20 days, the number of AFC was not significantly different between cores from the two warmer temperatures. Both at the 12.8°C and 18.3°C curing temperatures, AFC depth increased from 15 to 20 days, at which time 12.8°C curing resulted in significantly greater depth of AFC (455 µm) than the 18.3°C (364 µm) curing temperature.

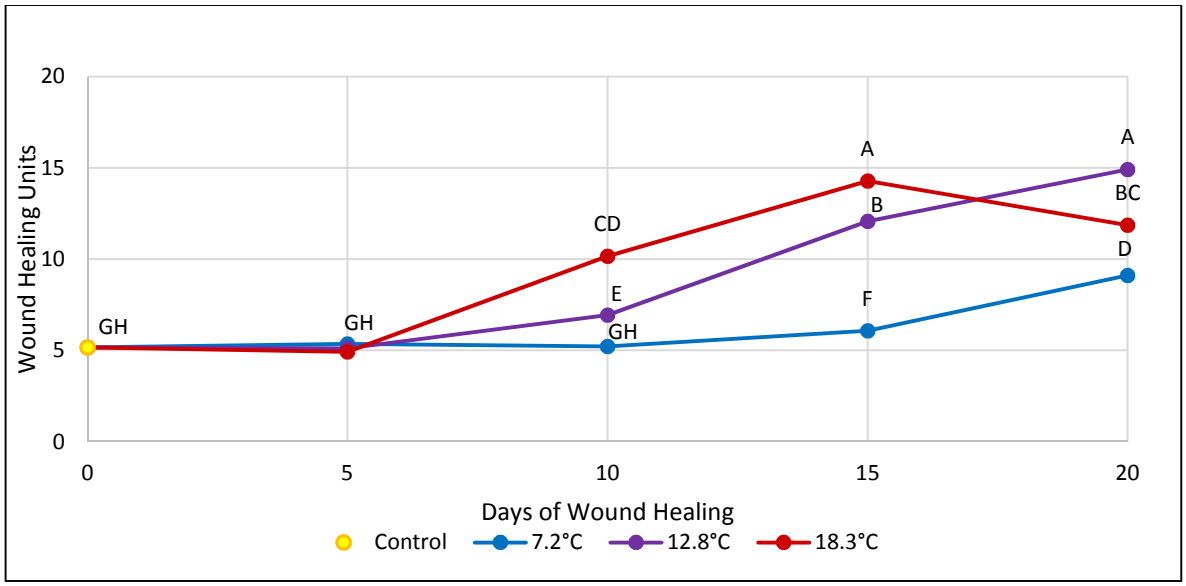

Figure 1. Wound healing units of Russet Burbank potato cores cured at 7.2°C, 12.8°C or 18.3°C for 0, 5, 10, 15, or 20 days in 2014-15 experiment 1. A control consisted of freshly cored tissue. At each curing interval, cores were force desiccated (65°C, 120 minutes) and percent weight loss recorded. Wound healing units were calculated as inverse of slope of the weight loss line. Different letters indicate significant differences at P≤0.05.

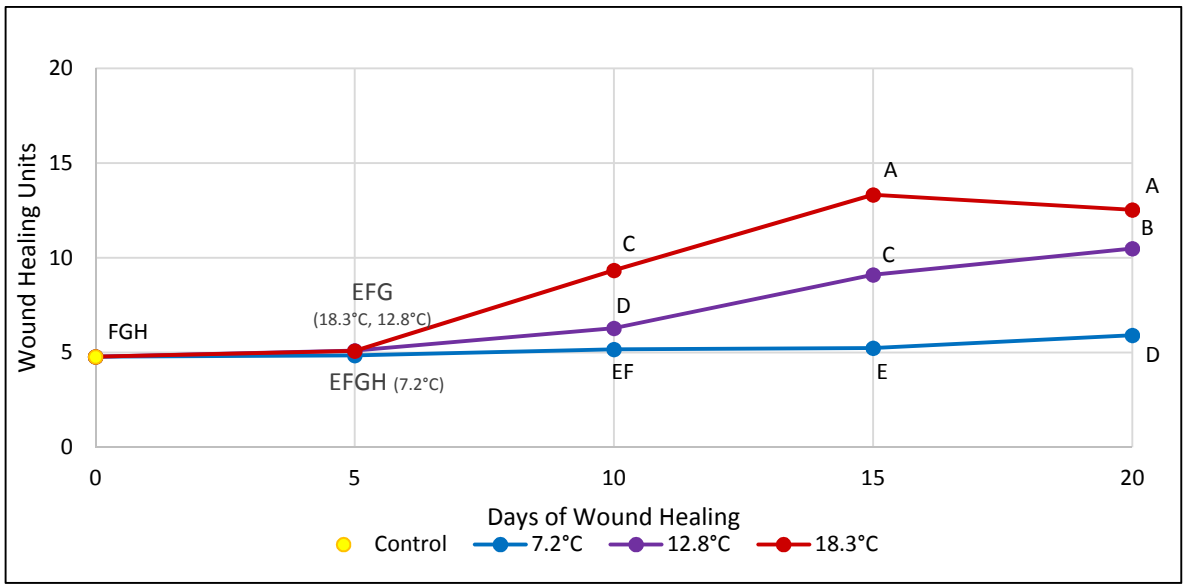

Figure 2. Wound healing units of Russet Burbank potato cores cured at 7.2°C, 12.8°C or 18.3°C for 0, 5, 10, 15, or 20 days in 2014-15 experiment 2. A control consisted of freshly cored tissue. At each curing interval, cores were force desiccated (65°C, 120 minutes) and percent weight loss recorded. Wound healing units were calculated as inverse of slope of the weight loss line. Different letters indicate significant differences at P≤0.05.

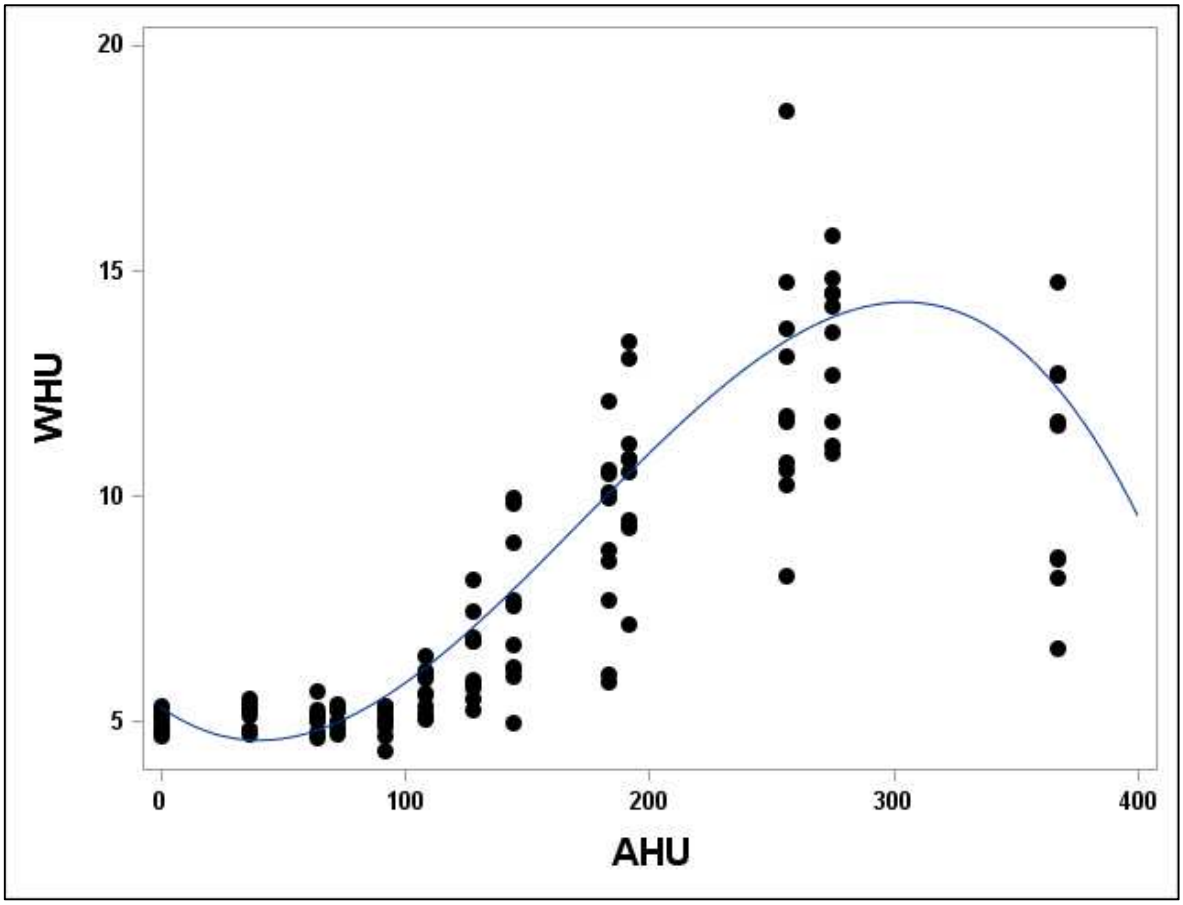

Figure 3. Wound healing units (WHU) of Russet Burbank potato cores. Cores were cured at 7.2°C, 12.8°C or 18.3°C for 0, 5, 10, 15, or 20 days in 2014-15 experiment 1 and experiment 2. Accumulated heat units (AHU; base temperature = 0°C) were calculated for each temperature/day combination. ($P \leq 0.0001$, $R^2=0.86$). $WHU=5.31-(3.87e^{-2})AHU+(5.45e^{-4})AHU^2-(1.1e^{-6})AHU^3$

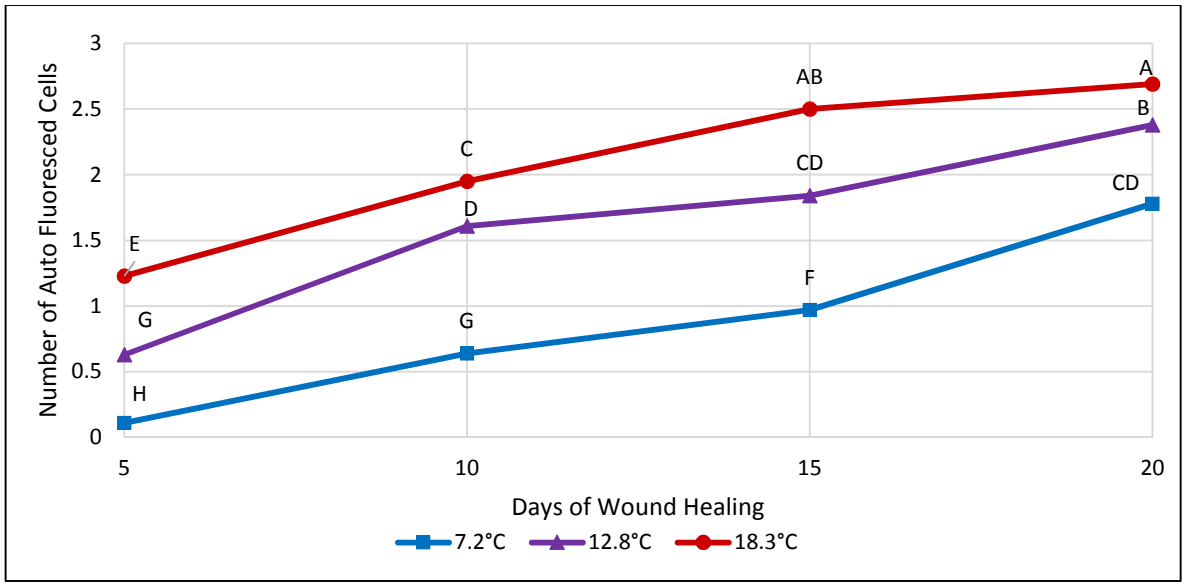

Figure 4. Number of auto fluoresced cells in Russet Burbank potato cores cured at 7.2°C, 12.8°C or 18.3°C for 0, 5, 10, 15, or 20 days in 2014-15 experiment 1. Different letters indicate significant differences at P≤0.05.

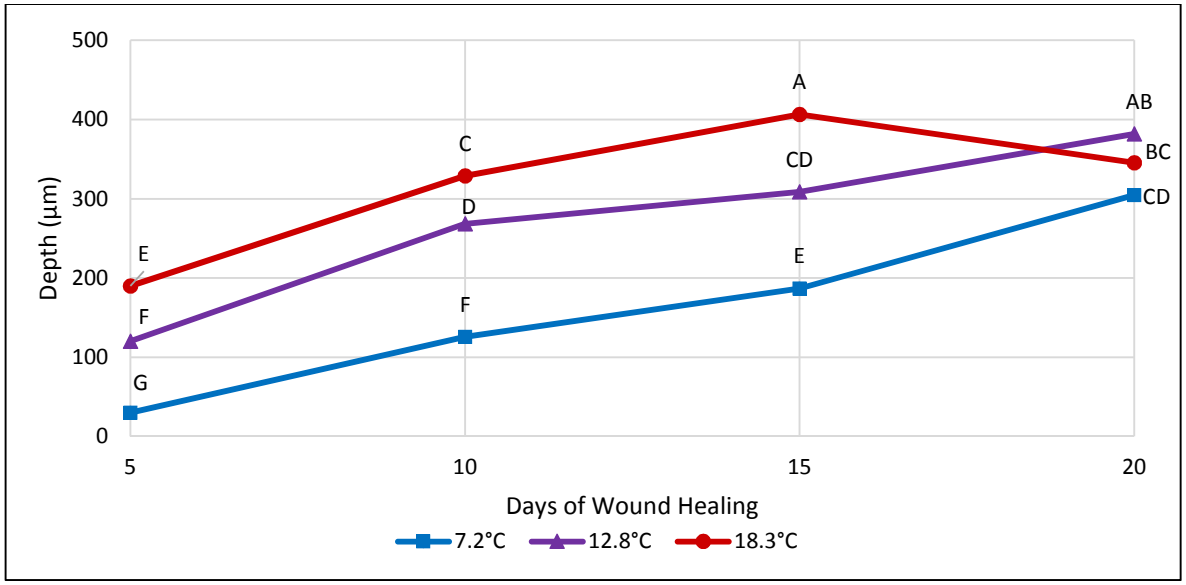

Figure 5. Depth of auto fluoresced cells in Russet Burbank potato cores cured at 7.2°C, 12.8°C or 18.3°C for 5, 10, 15, or 20 days in 2014-15 experiment 1. Different letters indicate significant differences at P≤0.05.

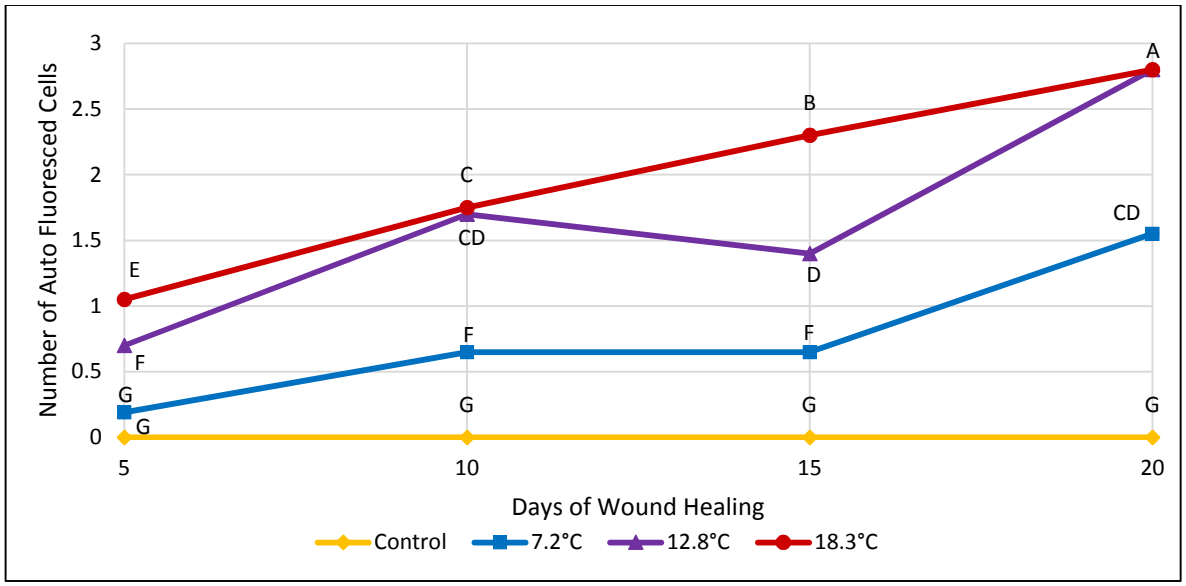

Figure 6. Number of auto fluoresced cells in Russet Burbank potato cores cured at 7.2°C, 12.8°C or 18.3°C for 0, 5, 10, 15, or 20 days in 2014-15 experiment 2. Control consisted of freshly cored tissue. Different letters indicate significant differences at P≤0.05.

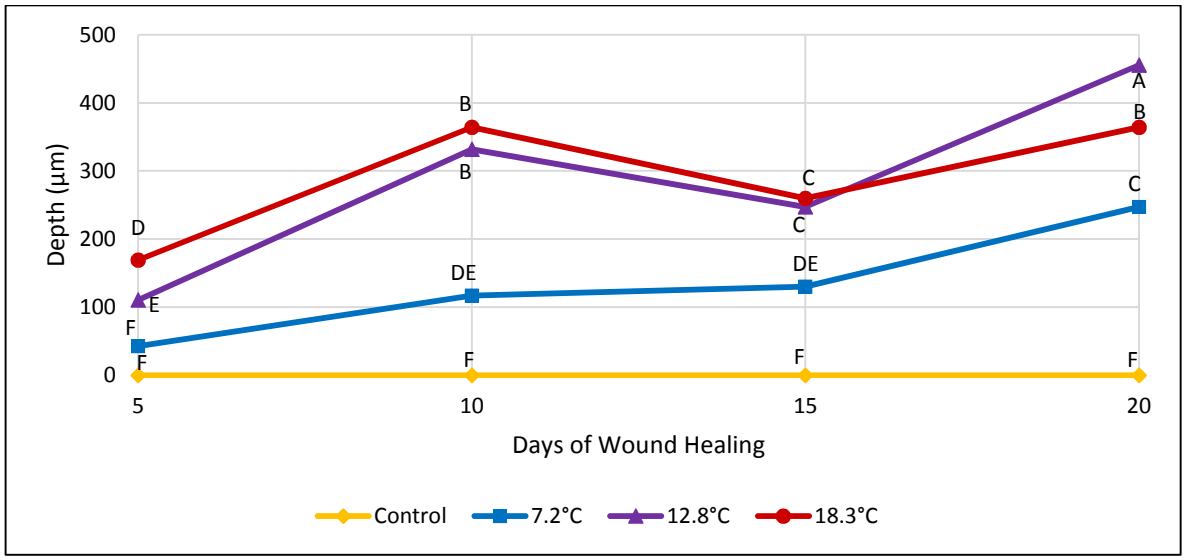

Figure 7. Depth of auto fluoresced cells in Russet Burbank potato cores cured at the temperature of 7.2°C, 12.8°C or 18.3°C for 0, 5, 10, 15, or 20 days in 2014-15 experiment 2. Control consisted of freshly cored tissue. Different letters indicate significant differences at P≤0.05.

Ranger Russet

Wound Healing Units

Ranger Russet WHU calculated from experiment 1 and experiment 2 were significantly different so data was not combined in the analysis. The data presented below consists of all cores including those with observable decay. Additionally, WHU data was analyzed by omitting any cores that were noted to be severely decayed in experiment 1 (Figure A.5) or cores that received a 'Core Visual Appearance Rating' of 3 (Table 3; Figure A.6) in experiment 2, and also omitting cores noted with any decay in experiment 1 (Figure A.7) and with a 'Core Visual Appearance Rating' of 2 and 3 (Table 3; Figure A.8) in experiment 2 in order to account for WHU that may be undetectable due to decay of cores. The results of the decay-omitted data did not appear to change WHU trends seen in Figure 8 and Figure 9.

Experiment 1

WHU for Ranger Russet tubers at the low curing temperature of 7.2°C was significantly lower than the two warmer curing temperatures for the entire 20 days of curing and were not significantly different from the control (Figure 8). WHU of cores cured at 12.8°C were not significantly different compared to the control until 15 days of curing, indicating the lack of wound healing even at this intermediate curing temperature. At 15 days of curing, WHU were equal for the two warmer curing temperatures and at 20 days of curing the WHU for 12.8°C cured cores significantly surpassed WHU from cores at the warmer curing temperature of 18.3°C. At 10 days of curing at 18.3°C, WHU were significantly higher (7.9) than the curing temperatures of 12.8°C (5.0) and 7.2°C (4.6), after

which 18.3°C cured cores did not wound heal anymore; decay was observed in the warmer temperature of 18.3°C after day 10. WHU were greatest for Ranger Russet after 20 days of curing at 12.8°C (9.7).

Experiment 2

Similar to the results obtained in experiment 1, the 7.2°C curing temperature did not result in any additional WHU compared to the control until 15 days of curing in experiment 2 (Figure 9). At 20 days, WHU was significantly higher at 7.2°C curing temperature (6.9) than the control (4.9). At 15 days of curing, cores cured at 12.8°C had a WHU significantly higher (8.5) than the control (4.9) and at 10 days of curing WHU for cores cured at 18.3°C was significantly higher (6.9) than the control (4.9). Also at 15 days, each 10 degree increase in temperature resulted in a significantly higher WHU, while at 20 days, only the 5.6°C increase in temperature from 7.2°C (6.9) to 12.8°C (12.2) resulted in significantly higher WHU. WHU was significantly higher for the curing temperature of 18.3°C at 10 (6.9) and 15 days (10.1) of curing compared to the curing temperature of 12.8°C (5.3, 8.5) and 7.2°C (4.8, 5.3) at 10 and 15 days, respectively. Cores of experiment 2 were quicker to wound heal at 18.3°C, however at 20 days, both the 18.3°C and 12.8°C curing temperatures resulted in maximum WHU.

Accumulated heat units

Accumulated heat units (AHU) were calculated for curing interval/temperature combinations to plot RR experiment 1 and experiment 2 WHU (Figure 10). WHU were best described by a cubic trend for RR. The equation for the regression line fit to the data was: $WHU=5.08-(2.72e^{-2})AHU+(3.31e^{-4})AHU^2-(5.68e^{-7})AHU^3$. ($P\leq.0001$, $R^2=0.79$). The maximum

WHU for RR was reached at 341 AHU. The control treatment of freshly cored tissue was considered the minimum WHU. The AHU at which WHU began to rise above this minimum was 100 AHU.

Microscopy

Experiment 1

Change in the number and depth of AFC for Ranger Russet is presented in Figure 11 and 12. At 5 and 10 days of curing, each 5.5°C increase in temperature resulted in a significantly higher number of AFC. There was no significant increase or decrease in the number of AFC between 10 and 15 days of curing for any of the curing temperatures. There was a significant increase in the number of AFC between 15 days of curing at 7.2°C (1.3 cells) and 20 days of curing at this cooler temperature (1.8 cells). Furthermore, there was no significant difference in number of AFC between 10 days of curing at 12.8°C and 18.3°C and 20 days of curing at these warmer temperatures.

The AFC depth was significantly greater at the warmer curing temperatures of 12.8°C and 18.3°C at 5, 10, and 15 days of curing compared to the curing temperature of 7.2°C, while the two warmer temperatures did not differ in AFC depth over these days. At day 20, depth of AFC of cores cured at 12.8°C (423 µm) was significantly greater than the depth of AFC in cores cured at 18.3°C (317 µm).

Experiment 2

At 5 days of curing, cores at 12.8°C and 18.3°C had a significantly higher number of AFC than cores at 7.2°C (0.8 cells, 0.6 cells) and the control (0.0 cells, Figure 13). The results for AFC depth at 5 days of curing followed this same pattern with the warmer

temperatures having significantly greater depth than the lower temperature and the control (Figure 14). At the next sampling day, 10 days of curing, cores had a significantly increased number of AFC (Figure 13) and depth (Figure 14) of AFC as temperature increased by 5.5°C. Cores showed no significant difference in the number of AFC (Figure 13) or depth of AFC (Figure 14) after 15 days of curing at 12.8°C and 18.3°C; these two curing temperatures resulted in greater depth (364 µm, 338 µm) and number (2.3 cells, 2.5 cells) of AFC when compared to the 7.2°C (156 µm, 0.9 cells) curing temperature and the control (0 µm, 0.0 cells) at this day (Figure 13; Figure 14). The number of AFC was significantly greater when cores were cured at 18.3°C for 20 days (2.9 cells) than at any other curing time and temperature (Figure 13). There was no significant change in depth of AFC from 15 days of curing to 20 days in cores cured at 12.8°C and 18.3°C (Figure 14).

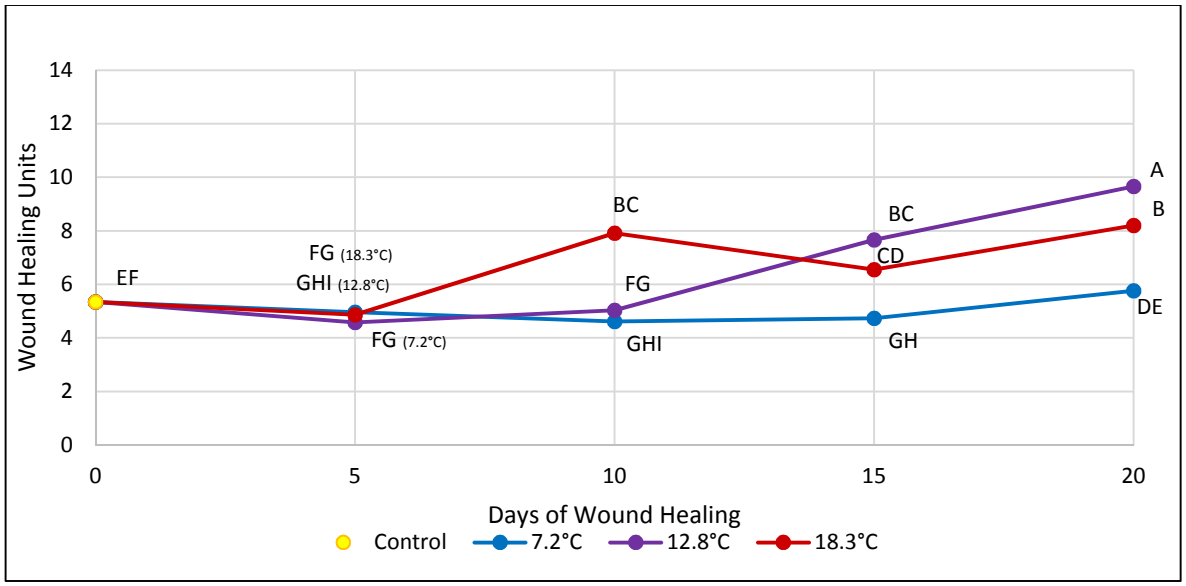

Figure 8. Wound healing units of Ranger Russet potato cores cured at 7.2°C, 12.8°C or 18.3°C for 0, 5, 10, 15, or 20 days in 2014-15 experiment 1. A control consisted of freshly cored tissue. At each curing interval, cores were force desiccated (65°C, 120 minutes) and percent weight loss recorded. Wound healing units were calculated as inverse of slope of the weight loss line. Different letters indicate significant differences at P≤0.05.

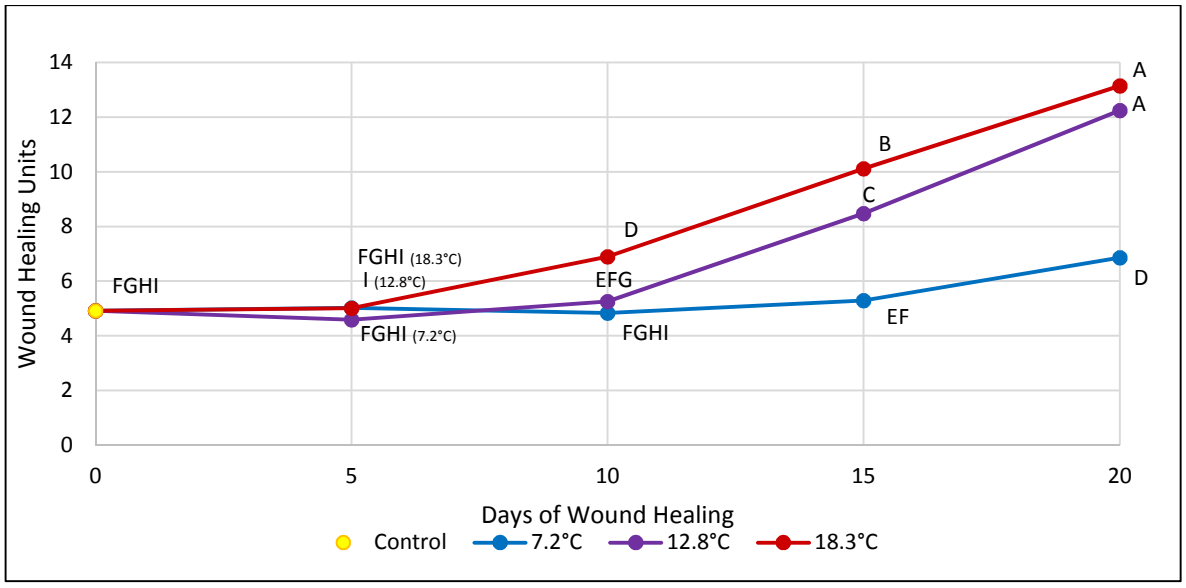

Figure 9. Wound healing units of Ranger Russet potato cores cured at 7.2°C, 12.8°C or 18.3°C for 0, 5, 10, 15, or 20 days in 2014-15 experiment 2. A control consisted of freshly cored tissue. At each curing interval, cores were force desiccated (65°C, 120 minutes) and percent weight loss recorded. Wound healing units were calculated as inverse of slope of the weight loss line. Different letters indicate significant differences at P≤0.05.

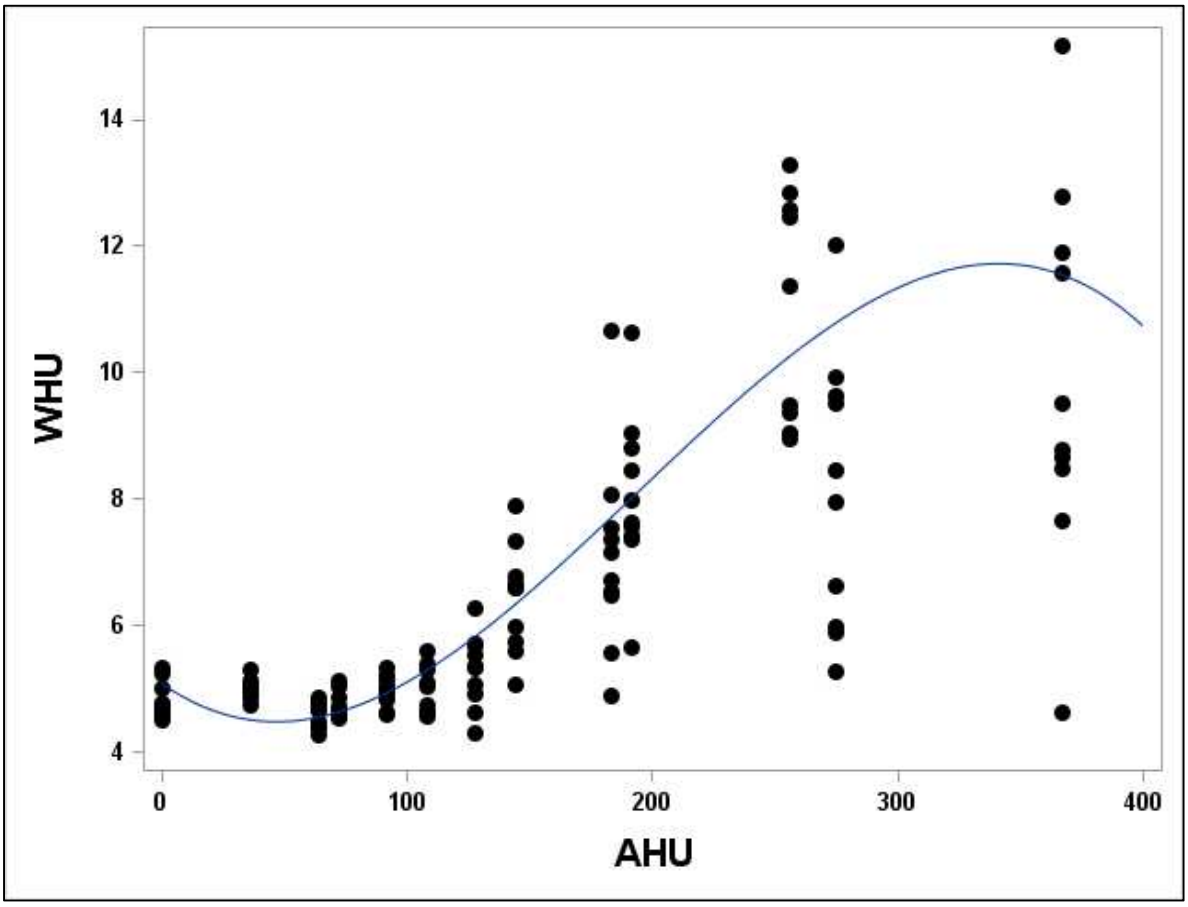

Figure 10. Wound healing units (WHU) of Ranger Russet potato cores. Cores were cured at 7.2°C, 12.8°C or 18.3°C for 0, 5, 10, 15, or 20 days in 2014-15 experiment 1 and experiment 2. Accumulated heat units (AHU; base temperature = 0°C) were calculated for each temperature/day combination. ($P \leq 0.0001$, $R^2=0.79$). $WHU=5.08-(2.72e^{-2})AHU+(3.31e^{-4})AHU^2-(5.68e^{-7})AHU^3$

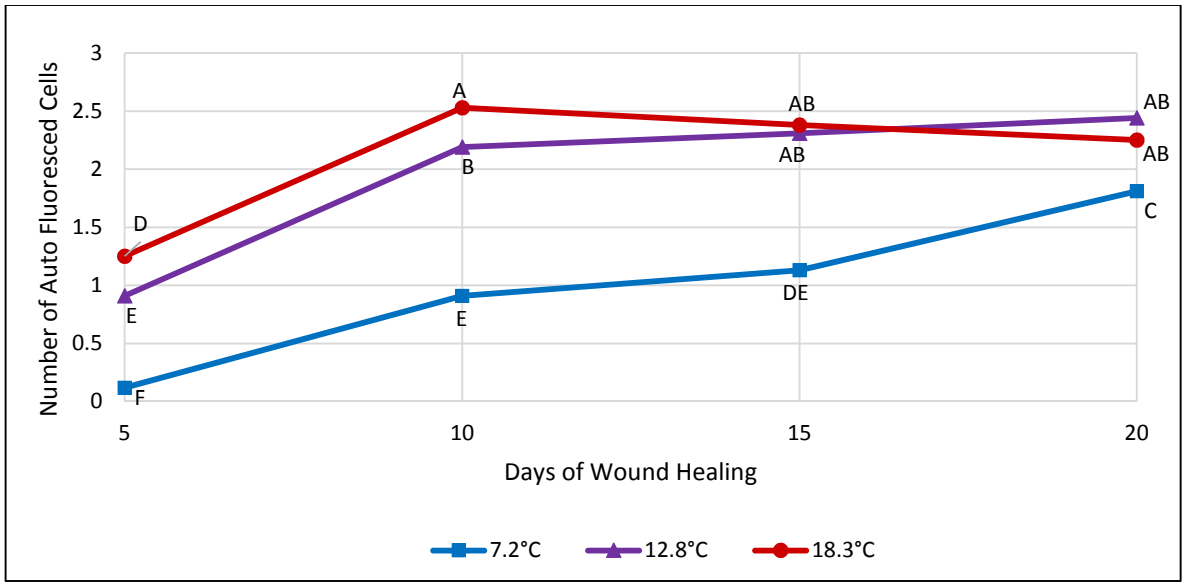

Figure 11. Number of auto fluoresced cells in Ranger Russet potato cores cured at 7.2°C, 12.8°C or 18.3°C for 0, 5, 10, 15, or 20 days in 2014-15 experiment 1. Different letters indicate significant differences at P≤0.05.

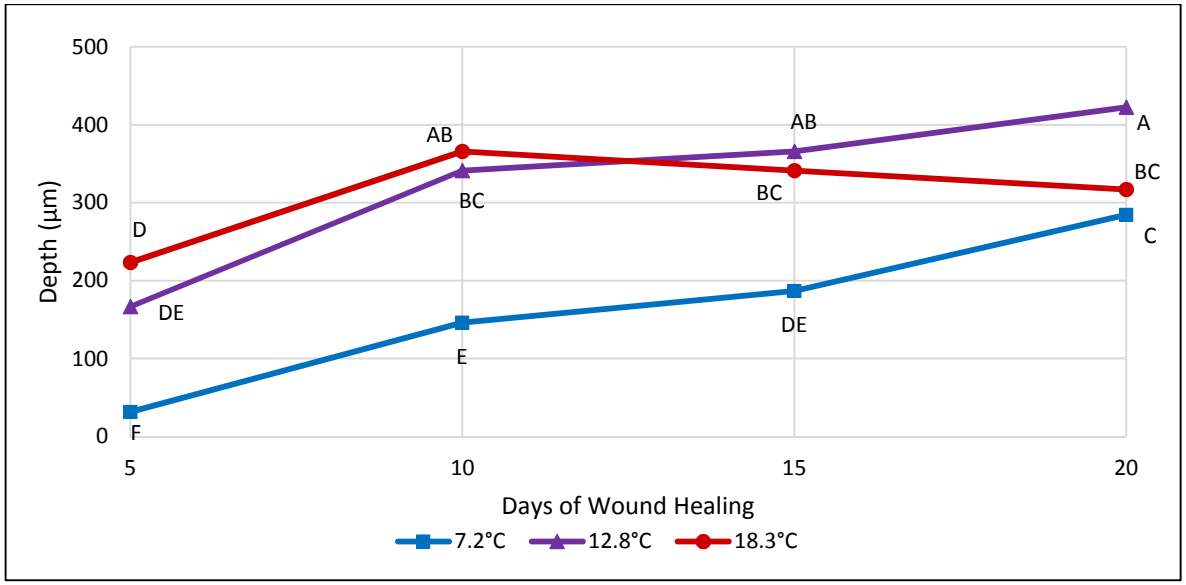

Figure 12. Depth of auto fluoresced cells in Ranger Russet potato cores cured at 7.2°C, 12.8°C or 18.3°C for 0, 5, 10, 15, or 20 days in 2014-15 experiment 1. Different letters indicate significant differences at P≤0.05.

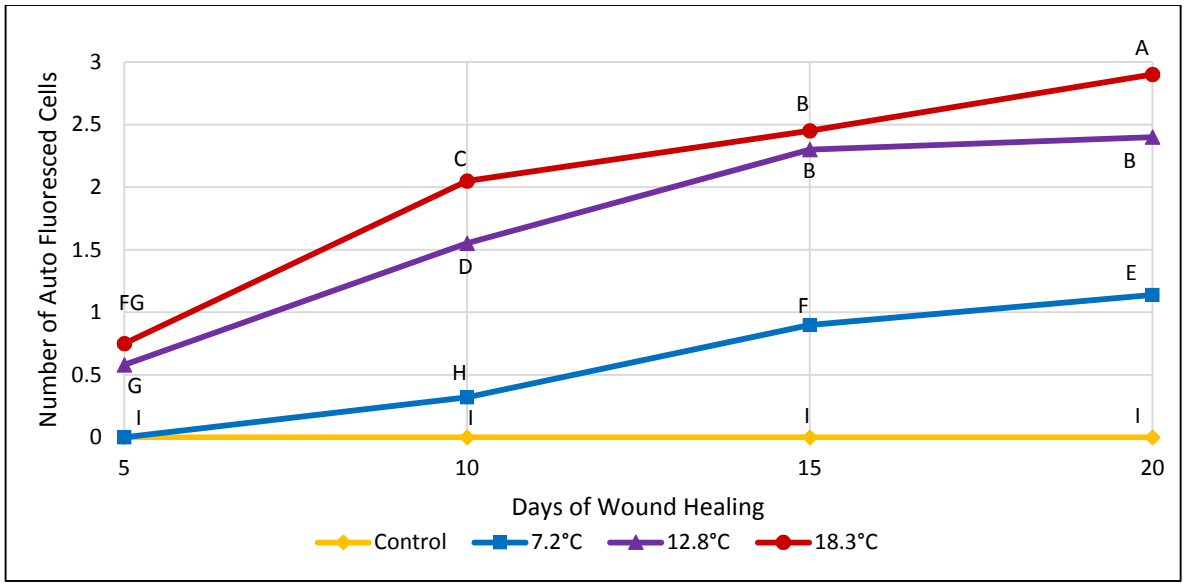

Figure 13. Number of auto fluoresced cells in Ranger Russet potato cores cured at 7.2°C, 12.8°C or 18.3°C for 0, 5, 10, 15, or 20 days in 2014-15 experiment 2. Control consisted of freshly cored tissue. Different letters indicate significant differences at P≤0.05.

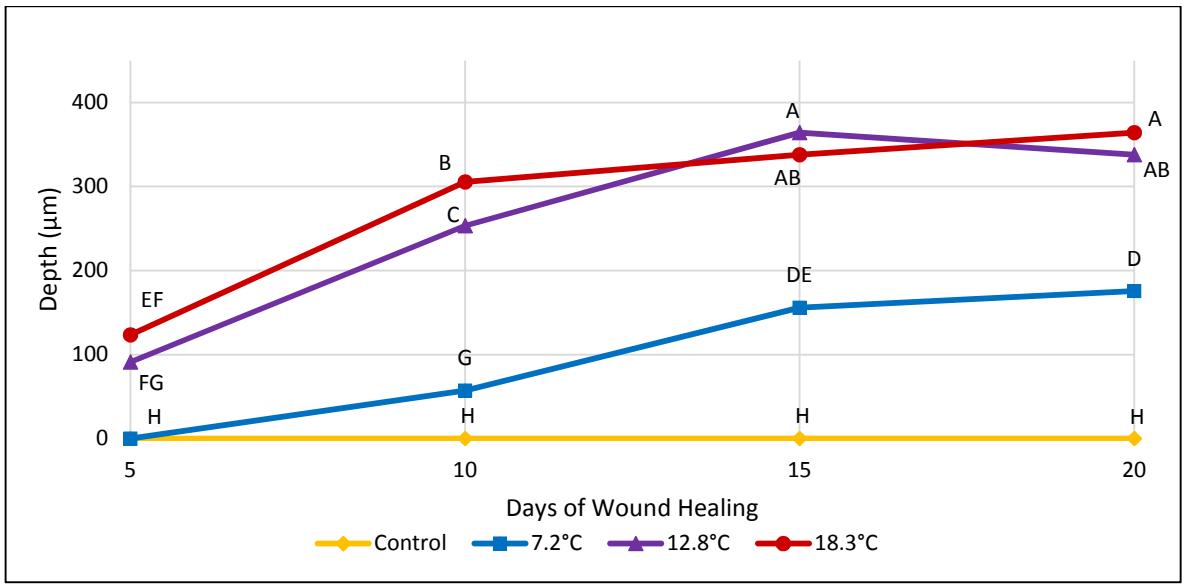

Figure 14. Depth of cells auto fluoresced in Ranger Russet potato cores cured at 7.2°C, 12.8°C or 18.3°C for 0, 5, 10, 15, or 20 days in 2014-15 experiment 2. Control consisted of freshly cored tissue. Different letters indicate significant differences at P≤0.05.

Clearwater Russet

Wound Healing Units

Clearwater Russet (CW) wound healing units (WHU) calculated from experiment 1 and experiment 2 were significantly different so data was not combined in the analysis. The data presented below consists of data of all cores, including those with observable decay. Additionally, WHU data was analyzed by omitting any cores that were noted to be severely decayed in experiment 1 (Figure A.9) or cores that received a 'Core Visual Appearance Rating' of 3 (Table 3; Figure A.10) in experiment 2, and also omitting cores noted with any decay in experiment 1 (Figure A.11) and with a 'Core Visual Appearance Rating' of 2 and 3 (Table 3; Figure A.12) in experiment 2 in order to account for WHU that may be undetectable due to decay of cores. The results of the decay-omitted data did not appear to change WHU trends as seen in Figure 15 and Figure 16.

Experiment 1

Figure 15 presents the WHU of CW experiment 1. The WHU of cores from the curing temperature of 7.2°C was not significantly different from the control core WHU even at 20 days of curing. WHU were significantly higher for cores at the curing temperature of 12.8°C (5.2, 6.8) compared to cores at the curing temperature of 7.2°C (4.4, 4.9) only at 15 and 20 days of curing, respectively. The WHU were significantly higher for cores at 18.3°C curing temperature at 10, 15, and 20 days of curing (6.4, 8.0, 8.9, respectively) compared to cores at 12.8°C curing (4.8, 5.2, 6.8) and 7.2°C curing (5.0, 4.4, 4.9) temperatures. The warmest curing temperature favored wound healing in CW, but WHU did not significantly

increase after 15 days. The lower temperatures inhibited wound healing, up to 15 days at the 12.8°C curing temperature and even longer in cores cured at 7.2°C.

Experiment 2

Figure 16 illustrates the WHU of CW in experiment 2. At 5 and 10 days of curing, 18.3°C curing temperature resulted in significantly higher WHU (6.0) of cores than WHU of cores at 12.8°C (5.6) and 7.2°C (5.4). A similar trend for cores from the 12.8°C curing temperature was seen in experiment 2 as in experiment 1 where WHU were significantly higher at the curing temperature of 12.8°C (5.2, 6.8) compared to the curing temperature of 7.2°C (4.4, 4.9) only at 15 and 20 days of curing, respectively. Unlike experiment 1, WHU of cores cured at 12.8°C for 20 days (10.5) in experiment 2 were significantly higher than any other treatment and sampling days. Cores cured at 18.3°C had significantly higher WHU (9.2) than those cured at 12.8°C (7.5) or 7.2°C (5.4) after 15 days, however, 20 days of curing at 18.3°C did not result in a significant increase in WHU after 15 days. Decay of cores was observed at the warmest curing temperature after 15 days of curing.

Accumulated heat units

Accumulated heat units (AHU) were calculated for curing interval/temperature combinations to plot CW experiment 1 and experiment 2 WHU against AHU (Figure 17). The CW WHU as related to AHU exhibited a cubic trend regression. The equation for the regression line fit to the data is $WHU=5.61-(1.76e^{-2})AHU+(1.72e^{-4})AHU^2-(2.63e^{-7})AHU^3$. ($P<.0001$, $R^2=0.62$). The maximum WHU for CW occurred at 377 AHU. The control treatment of freshly cored tissue was considered the minimum WHU. The AHU at which WHU began to rise above this minimum was 128 AHU.

Microscopy

Experiment 1

Changes in the number and depth of AFC for CW are shown in Figures 18 and 19. Cores cured at 7.2°C had the least number and depth of AFC compared to cores cured at the warmer temperatures of 12.8°C and 18.3°C at all sampling dates. Between day 10 and 15, suberization did not significantly change at all three curing temperatures. The 7.2°C curing temperature resulted in significantly greater number and depth of AFC after 20 days of curing compared to the shorter curing intervals at the same temperature. Cores cured at 12.8°C had significantly greater number and depth of AFC than cores cured at 7.2°C for all curing intervals. At 20 days of curing, the number of AFC in cores cured at 12.8°C (2.3 cells) were not significantly different from the number of AFC in cores cured at 18.3°C (2.4 cells; Figure 18). Cores cured at 18.3°C had significantly higher number of AFC at 5 and 10 days (1.7 cells, 2.3 cells, respectively) of curing than those cured at 12.8°C (1.0 cells, 1.5 cells) and 7.2°C (0.3 cells, 0.8 cells) at 5 and 10 days (Figure 18).

The depth of AFC in cores cured for 5 days was significantly greater as temperature increased by 5.5°C (Figure 19). Cores cured at 7.2°C for 10 days did not significantly differ in depth of AFC (146 μm) from cores cured at 12.8°C (158 μm) for 5 days (Figure 19); likewise, cores cured at 12.8°C (244 μm) for 10 days did not significantly differ in depth of AFC from cores cured at 18.3°C (276 μm) for 5 days. Cores cured for 20 days had significantly greater depth of AFC when cured at 12.8°C and 7.2°C compared to the depth of AFC in cores cured for 5, 10, or 15 days (Figure 19). The depth of AFC in cores cured at 18.3°C for 20 days did not significantly differ compared to 10 days of curing (Figure 19).

Experiment 2

The number of AFC (Figure 20) and the depth of AFC (Figure 21) were significantly higher in cores cured at 12.8°C and 18.3°C compared to cores cured at 7.2°C and the control. At 5 days of curing, the 7.2°C (0.2 cells, 22 µm) curing temperature did not differ in number or depth of AFC from the control (0.0 cells, 0 µm). For the curing temperature of 7.2°C, each additional 5 days of curing resulted in a significantly greater number of AFC (Figure 20) and depth of AFC (Figure 21) from 10 until 20 days of curing. The number of AFC in cores cured at 18.3°C (0.7 cells) was significantly higher than those cured at 12.8°C (0.5 cells) for 5 days (Figure 20). The number of AFC (Figure 20) and depth of AFC (Figure 21) were significantly greater from 5 (0.5 cells, 98 µm) to 15 days (1.9 cells, 319 µm) of curing when cores were cured at 12.8°C. Cores cured at 18.3°C had significantly greater number and depth of AFC at 10 days curing compared to 5 days curing; the number of AFC (Figure 20) and depth of AFC (Figure 21) did not significantly change from 10 to 20 days of curing at this temperature.

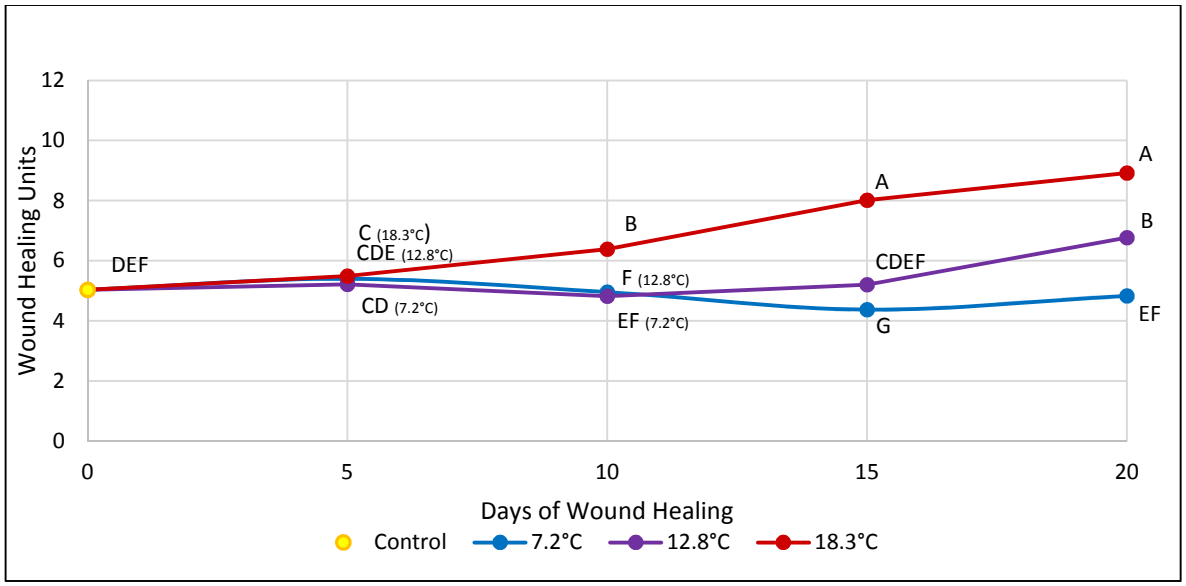

Figure 15. Wound healing units of Clearwater Russet potato cores cured at 7.2°C, 12.8°C or 18.3°C for 0, 5, 10, 15, or 20 days in 2014-15 experiment 1. A control consisted of freshly cored tissue. At each curing interval, cores were force desiccated (65°C, 120 minutes) and percent weight loss recorded. Wound healing units were calculated as inverse of slope of the weight loss line. Different letters indicate significant differences at P≤0.05.

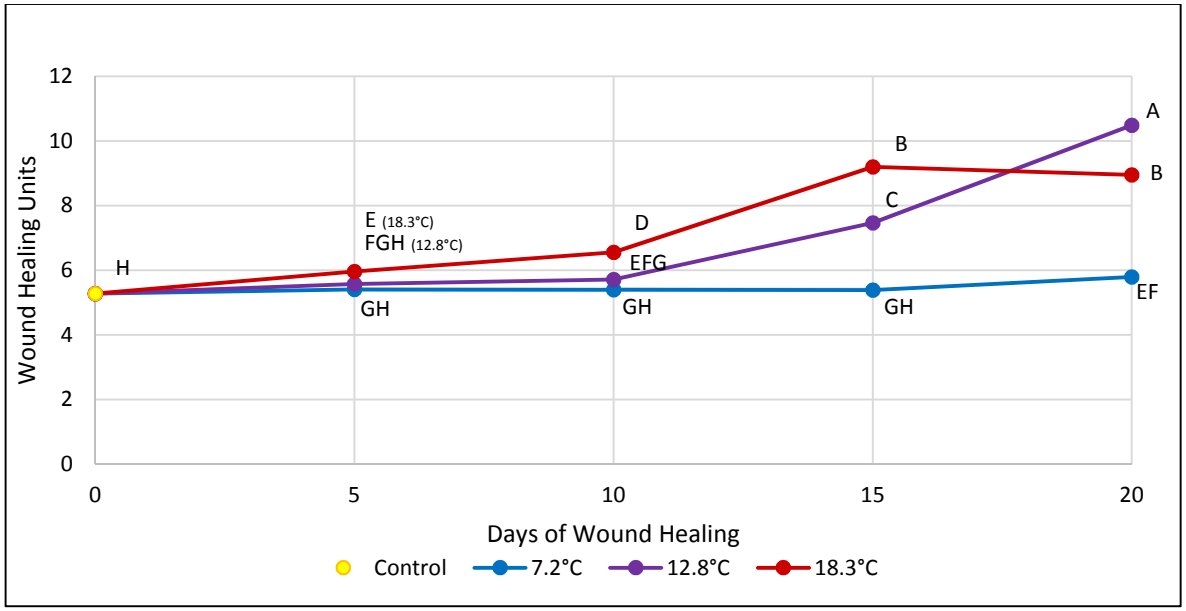

Figure 16. Wound healing units of Clearwater Russet potato cores cured at 7.2°C, 12.8°C or 18.3°C for 0, 5, 10, 15, or 20 days in 2014-15 experiment 2. A control consisted of freshly cored tissue. At each curing interval, cores were force desiccated (65°C, 120 minutes) and percent weight loss recorded. Wound healing units were calculated as inverse of slope of the weight loss line. Different letters indicate significant differences at P≤0.05.

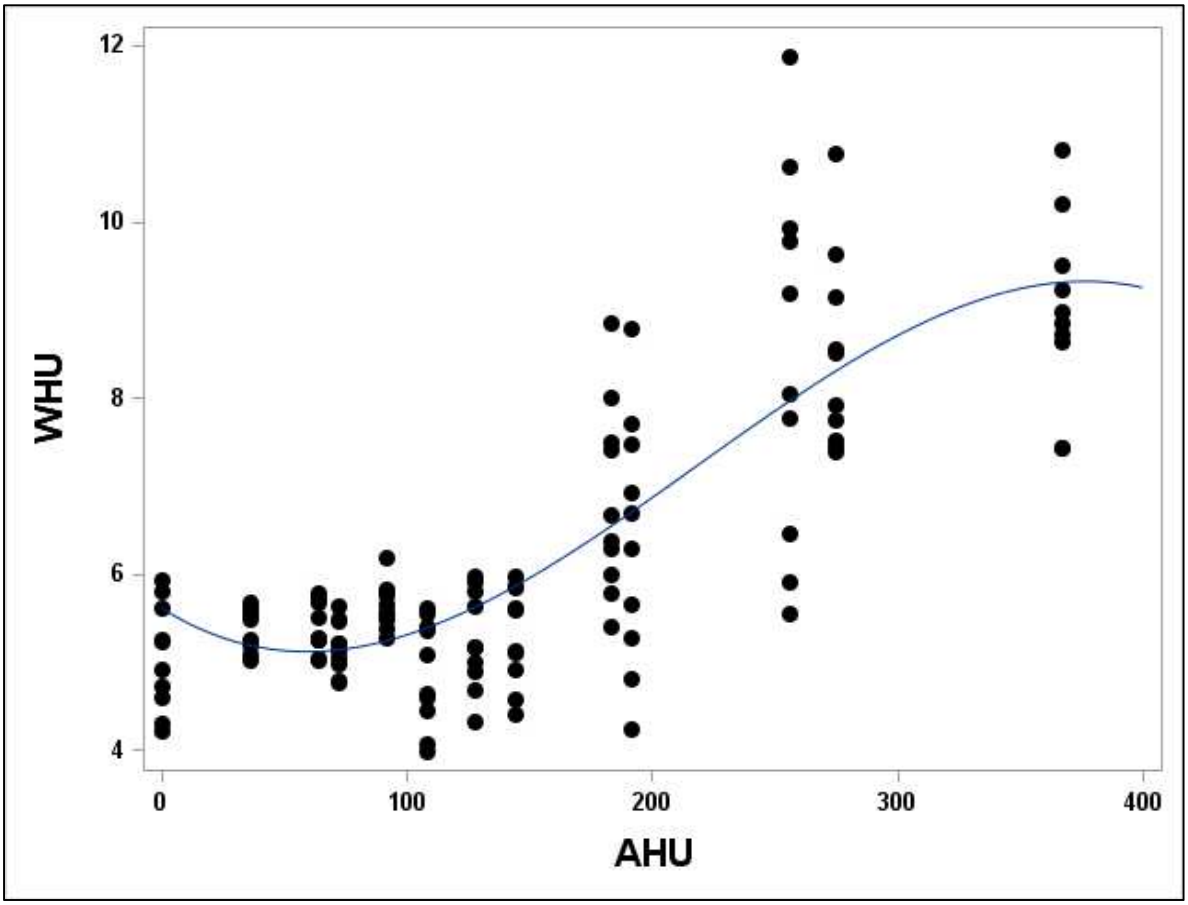

Figure 17. Wound healing units (WHU) as related to accumulated heat units (AHU; base temperatures = 0°C) of Clearwater Russet potato cores. Cores were cured at 7.2°C, 12.8°C or 18.3°C for 0, 5, 10, 15, or 20 days in 2014-15 experiment 1 and experiment 2. AHU were calculated for each temperature/day combination. ($P<0.0001$, $R^2=0.62$). $WHU=5.61-(1.76e^{-2})AHU+(1.72e^{-4})AHU^2-(2.63e^{-7})AHU^3$

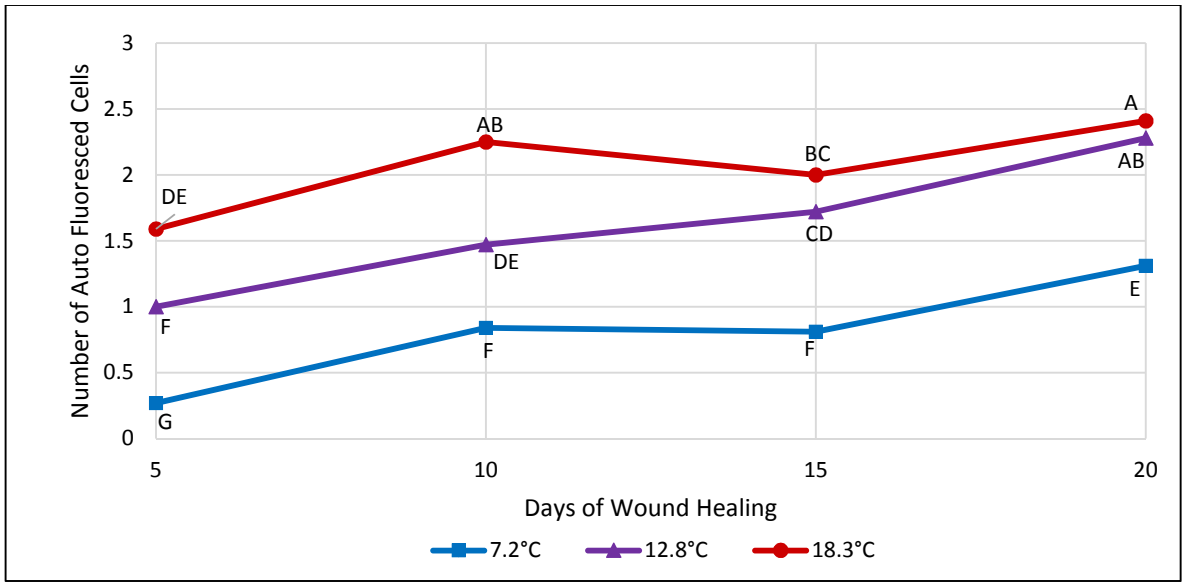

Figure 18. Number of auto fluoresced cells in Clearwater Russet potato cores cured at 7.2°C, 12.8°C or 18.3°C for 0, 5, 10, 15, or 20 days in 2014-15 experiment 1. Different letters indicate significant differences at P≤0.05.

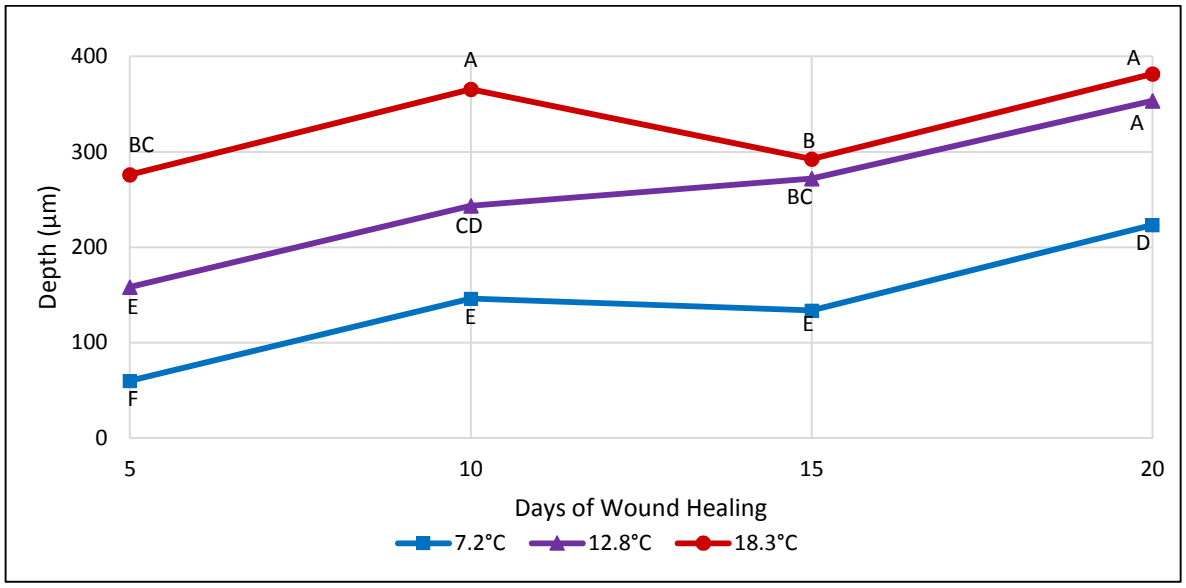

Figure 19. Depth of auto fluoresced cells in Clearwater Russet potato cores cured at 7.2°C, 12.8°C or 18.3°C for 0, 5, 10, 15, or 20 days in 2014-15 experiment 1. Different letters indicate significant differences at P≤0.05.

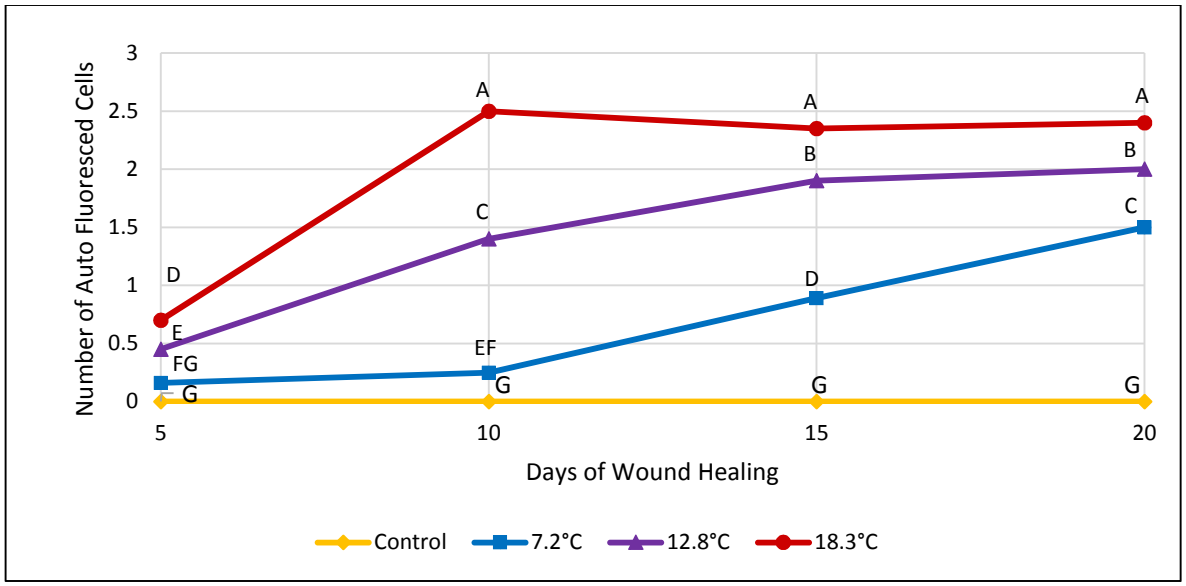

Figure 20. Number of auto fluoresced cells in Clearwater Russet potato cores cured at 7.2°C, 12.8°C or 18.3°C for 0, 5, 10, 15, or 20 days in 2014-15 experiment 2. Control consisted of freshly cored tissue. Different letters indicate significant differences atP≤0.05.

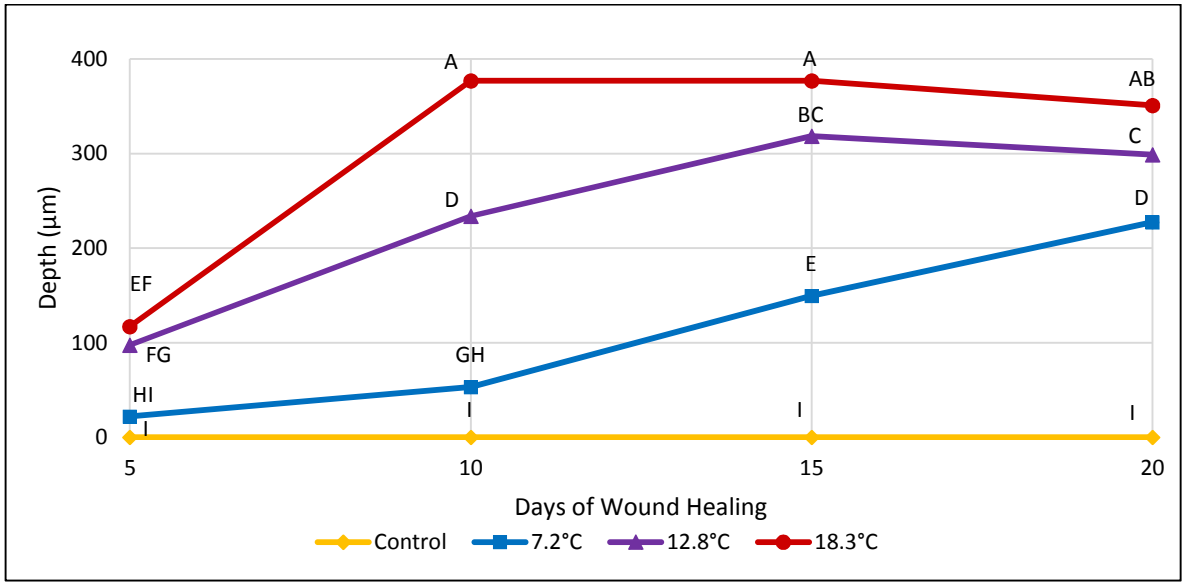

Figure 21. Depth of auto fluoresced cells in Clearwater Russet potato cores cured at 7.2°C, 12.8°C or 18.3°C for 0, 5, 10, 15, or 20 days in 2014-15 experiment 2. Control consisted of freshly cored tissue. Different letters indicate significant differences at P≤0.05.

Study 2: Impacts of curing temperature on processing quality and long term storability of Russet Burbank, Ranger Russet and Clearwater Russet potatoes

At harvest quality characteristics, overall weight loss and post-storage disease incidence were compared to make broad generalizations among the cultivars. Processing quality and weight loss results are also presented separately by cultivar in order to highlight differences between storage treatments for each cultivar and to identify cultivar-specific management practices.

Processing Quality at Harvest: Comparison of all Three Cultivars

Specific gravity, which is an indicator of dry matter and starch content, was significantly higher (P=.0013) in the cultivars Clearwater Russet (CW; 1.093) and Ranger Russet (RR; 1.087) compared to Russet Burbank (RB; 1.072) at harvest. Processing quality assessment at harvest indicated higher processing quality for CW compared to RR and RB. Sugar levels were significantly different between cultivars (glucose, P=0.0283; sucrose, P=0.0023); glucose levels were 40% higher in RB compared to CW, which had the lowest sugar level. At harvest RR glucose level was not significantly different from RB or CW, however, sucrose levels in RR was 58% higher than the average sucrose level of RB and CW. Fry color at harvest was also significant by cultivar for basal end fry color only (P=0.0022); CW had the lightest fry color at 55.4% reflectance and RB had the darkest fry color at 44.6% reflectance. RR had fry color (50.0 % reflectance) between CW and RB.

Weight Loss: Comparison of all Three Cultivars

RB tubers had significantly less weight loss after 148 days (5.2%) in storage compared to CW (6.3%) tubers regardless of curing temperature (P=0.0005). Averaged over all three cultivars, tubers cured at 18.3°C lost more weight (6.3%; P>0.0001) than those cured at

7.2°C (5.5%) or 12.8°C (5.0%) at 148 DAH; the lower two curing temperatures did not result in significant different weight loss from each other. When weight loss was analyzed over time, there was no interaction of cultivar, days after harvest, and temperature. Table A.2 and A.3 provide the P-values for incremental weight loss effects and accumulated weight loss effects, respectively.

Disease Incidence at End of Storage: Comparison of all Three Cultivars

Disease incidence was calculated at the end of storage (237 DAH) for one replicate of each treatment due to the presence of observable decay in the weight loss samples; means were not calculated. Clearwater Russet (CW) and Ranger Russet (RR) appeared to have the highest incidence of disease when tubers were cured at 7.2°C compared to tubers cured at the warmer temperatures 12.8°C and 18.3°C (Table 7). Conversely, RB had no disease incidence in tubers cured at 7.2°C and the highest incidence of disease in RB tubers occurred when tubers were cured at 18.3°C. In each cultivar, 12.8°C curing resulted in intermediate disease incidence.

Table 7. Disease incidence of Russet Burbank (RB), Ranger Russet (RR), and Clearwater Russet (CW) tubers. Tubers were cured at 7.2°C, 12.8°C or 18.3°C for 14 days then ramped +/- 0.3°C/day until the holding temperature of 8.9°C was reached. Tubers were held at 8.9°C until 237 days after harvest. Values for one replicate only.

CULTIVAR	CURING TEMPERATURE (°C)	DISEASE INCIDENCE (%)
RB	7.2	0.0
RB	12.8	5.6
RB	18.3	7.7
RR	7.2	13.3
RR	12.8	6.7
RR	18.3	6.3
CW	7.2	46.7
CW	12.8	21.7
CW	18.3	36.0

Russet Burbank

Fry Color in Storage

Changes in processing quality of RB tubers during storage after a low temperature curing period were significant (Table 8). Fry color was unacceptably dark (USDA rating ≥ 3; Kincaid et al. 1993) throughout storage when tubers were cured for 14 days at 7.2°C. RB tubers cured at 12.8°C and 18.3°C had non-uniform fry color, with especially dark fry color in the basal ends, also known as sugar ends. Using the basal end fry color as the best indicator for fry color (Kincaid et al. 1993), RB tubers cured at the warmer temperature of 18.3°C had significantly darker fry color after curing than freshly harvested tubers; fry color improved after ramping and remained light throughout storage. RB cured at 12.8°C and 7.2°C had significantly darker fry color than freshly harvested tubers and fry color remained unacceptably dark throughout storage. Fry color of tubers cured at 18.3°C were

significantly lighter compared to fry color of tubers cured at 12.8°C and 7.2°C until 203 days after harvest (DAH), after which, fry color of tubers cured at this warmer temperature were not different from fry color of tubers cured at 12.8°C. RB tubers cured at 12.8°C had significantly lighter fry color than tubers cured at 7.2°C throughout storage. At the 7.2°C curing temperature, fry color was significantly darker than the two warmer temperatures through the end of storage.

Sucrose and Glucose Concentrations in Storage

Sucrose and glucose levels of RB tubers cured at 7.2°C, 12.8°C or 18.3°C are presented in Table 8. Glucose levels of RB cured at 7.2°C increased over six-fold from harvest to 49 days after harvest (DAH), well after the temperature ramping was completed (Table 4). This significant increase in the reducing sugar (RS) glucose is responsible for the dark fry color observed in RB tubers cured at this low temperature (Marquez and Anon 1986); RB glucose levels began to decline after 49 DAH until 203 DAH, after which glucose levels did not change. The pattern of sucrose concentrations were similar to that of glucose in RB cured at 7.2°C; sucrose levels increased significantly by 0.042% fresh weight (FWT) between harvest and 15 DAH, and then declined significantly from 15 DAH to 49 DAH, from which point the sucrose level did not significantly change. The low curing temperature also resulted in significantly higher levels of glucose at each sampling date when compared to glucose levels in tubers cured at the warmer temperatures of 12.8°C and 18.3°C.

Glucose levels were significantly lower in tubers cured at the warmest temperature of 18.3°C at 49 DAH and 139 DAH compared to glucose levels in tubers cured at the lower

two temperatures of 12.8°C and 7.2°C; at all other sampling dates, there was no significant difference between glucose levels of tubers cured at 12.8°C and 18.3°C.

Weight Loss

Incremental percent weight loss of RB tubers cured at 7.2°C, 12.8°C or 18.3°C are presented in Table 9 and the accumulated weight loss of RB tubers cured at the same temperatures are presented in Table 10. Weight loss at 176 and 205 DAH were not included in the analysis due to potential impact of visible sprouting of tubers at these later dates. The accumulated weight loss in RB tubers cured at 7.2, 12.8 or 18.3 was not significantly different between temperatures at any time in storage (Table 10). Percent weight loss significantly accumulated over the storage period in tubers cured at different temperatures (Table 10). RB tubers cured in all three storage temperatures lost the greatest amount of weight in the first 7 days of storage (Table 9). The least amount of incremental weight loss occurred by 49 DAH (7 weeks; Table 9); 49 DAH was concurrent with the end of ramping for RB tubers cured at 18.3°C. Weight loss began to increase after 49 DAH and then decreased significantly between 88 and 119 DAH followed by a rise in weight loss once again to the end of storage (148 DAH; Table 10).

Ranger Russet

Fry Color in Storage

Changes in processing quality of RR tubers during storage after a low temperature curing period were significant (Table 11). Fry color of RR tubers cured at 7.2°C darkened significantly after tubers were cured for 14 days compared to the fry color at harvest, as did fry color in tubers cured at the two warmer temperatures 12.8°C and 18.3°C. Apical end

fry color of tubers cured at 7.2°C lightened significantly at each subsequent sampling date. The basal end fry color of the 7.2°C tubers were dark and did not significantly change from 2 to 139 DAH, after which fry color became significantly lighter at each sampling date. Fry color of tubers cured at 12.8°C and 18.3°C was acceptable (USDA rating of 1 or 2; Kincaid et al. 1993) throughout storage in the apical end; however, the basal end fry color resulted in USDA ratings ≥3 later in storage (139 and 237 DAH). Using the basal end fry color as the best indicator for fry color (Kincaid et al. 1993), tubers cured at the two warmer temperatures had significantly lighter fry color compared to the 7.2°C curing temperature throughout storage. Those tubers cured at 18.3°C did not consistently have lighter basal end fry color compared to tubers cured at 12.8°C, therefore processing quality of RR tubers was not dependably better when tubers were cured at 18.3°C compared to tubers cured at 12.8°C.

Sucrose and Glucose Concentrations in Storage

The level of glucose in RR was significantly impacted by curing temperature and time in storage (Table 11). Tubers cured at 7.2°C had significantly higher concentrations of glucose, 8.6 times more, after tubers were cured for 14 days compared to glucose levels at harvest. The high, unacceptable levels of glucose remained in tubers cured at 7.2°C through ramping until the end of storage; even though levels significantly decreased, industry acceptance levels were never met. Glucose levels remained significantly higher in tubers cured at 7.2°C compared to the two warmer curing temperatures until 203 DAH, after which there was no difference in glucose levels, most likely due to sprouting that occurred in tubers by 237 DAH. Glucose levels in tubers cured at 12.8°C and 18.3°C did not differ

after the curing period (15 DAH). Tubers cured at 12.8°C had higher glucose levels than tubers cured at 18.3°C from 49 DAH to 203 DAH. The warmest curing temperature resulted in significantly lower glucose levels after ramping (49 DAH) until 203 DAH compared to the other curing temperatures; the glucose levels of these warmer cured tubers increased significantly over time, indicating deterioration in processing quality in long term storage with this cultivar.

Tubers cured at 7.2°C had significantly higher levels of sucrose compared to the warmer curing temperatures at 15 days; sucrose levels in tubers cured at this 7.2°C temperature decreased significantly over the storage period. Sucrose levels of tubers cured at 12.8°C significantly decreased throughout storage. Sucrose levels contrasted with the trend of glucose levels in tubers cured at 18.3°C and decreased over time in tubers cured at the warmest curing temperature.

Weight Loss

The curing temperature of 7.2°C resulted in the lowest percent weight lost each month in the early part of storage, but began losing significantly more weight each month towards the end of storage compared to tubers at the 18.3°C curing temperature (Table 9). Furthermore, tubers cured at 12.8°C lost significantly less weight than the 7.2°C and 18.3°C curing temperature early in storage, but more weight was lost each month in the 12.8°C cured tubers later in storage compared to tubers cured at 7.2°C and 18.3°C (Table 9). Similarly to RB, RR tubers lost the most amount of weight in the first 7 days of storage (Table 9). All three curing temperatures resulted in RR tubers accumulating a significant amount of weight lost from harvest until the end of storage (148 DAH; Table 10). The

accumulated weight loss of RR tubers cured at 18.3°C was significantly higher than of tubers cured at 7.2°C and 18.3°C throughout the entire storage period.

Clearwater Russet

Fry Color in Storage

Table 12 contains the results for Clearwater Russet fry color. Basal end fry color of CW tubers cured at 7.2°C was significantly darker and unacceptable after tubers were cured for 14 days and fry color remained dark and unacceptable throughout storage (up to 237 days). Tubers cured at 7.2°C had significantly darker fry color compared to the two warmer curing temperatures throughout the entire storage period. CW tubers cured at 12.8°C were also significantly darker after curing compared to harvest and remained darker than harvest fry color throughout storage. Although, fry color was at an acceptable level on the USDA rating scale throughout storage when cured at 12.8°C; apical end fry color never differed from harvest apical end fry color throughout storage when cured at 12.8°C. Tubers cured at the warmest temperature of 18.3°C had excellent fry color of USDA rating 1 throughout storage. Basal end fry color first declined after curing (15 DAH) then improved in storage, from curing to end of storage (237 DAH), for CW tubers cured at 7.2, 12.8, and 18.3°C.

Sucrose and Glucose Concentrations in Storage

Glucose concentrations significantly increased after tubers were cured at 7.2°C, resulting in dark fry color and then decreased throughout time in storage; glucose levels were significantly higher in tubers cured at 7.2°C compared to tubers cured at 12.8°C and 18.3°C until 203 DAH, after which there was no significant difference between curing

temperatures (Table 12). Glucose concentrations were higher in tubers cured at 12.8°C compared to levels in tubers cured at 18.3°C but only at 15, 139, and 203 DAH. The curing temperature of 18.3°C resulted in glucose levels that were the same as harvest glucose levels throughout the entire storage period. Tuber glucose levels in tubers cured at 12.8°C did not change in storage from harvest to end of storage, 237 DAH, while sucrose levels significantly decreased. Sucrose levels in tubers cured at 18.3°C significantly decreased throughout storage from harvest levels (Table 12). Sucrose levels decreased from harvest to the end of storage in tubers cured at 7.2°C.

Weight Loss

Clearwater Russet tubers cured at 7.2°C had significantly higher weight loss than tubers cured at 12.8°C until 119 DAH, when accumulated weight loss was not significantly different in tubers cured at the various temperatures (Table 10). The warmest curing temperature of 18.3°C resulted in the greatest weight loss in tubers of any curing temperature until 119 DAH (Table 10). As in the other two cultivars, percent weight loss in the first 7 days of storage was significantly higher than the weight lost between any other sampling dates (Table 9). Early in storage, up to 42 DAH, weight lost each month was significantly greater in tubers cured at 7.2°C than tubers cured at 12.8°C. The weight lost each month was significantly higher in tubers cured at 18.3°C than at 7.2°C and 12.8°C until 49 DAH. After 49 DAH, there was no significant difference in the amount of weight lost each month for tubers cured at any of the temperatures.

Table 8. Processing quality (sucrose, glucose, and fry color) of Russet Burbank (RB) tubers stored at the Potato Storage Research Facility at the Kimberly Research and Extension Center in Kimberly, Idaho in 2014-2015. Tubers were cured at 7.2°C, 12.8°C or 18.3°C for 14 days (95% Relative Humidity) then ramped +/- 0.3°C/day until the holding temperature of 8.9°C was reached. Tubers were held at 8.9°C until 237 days after harvest.

Cultivar	Curing Temperature (°C)	Days After Harvest (DAH) 2[1]	15	49	139	203	237	
		Sucrose (% FWT[2])						DAH LSD 0.050
RB	7.2	0.132	0.174	0.089	0.072	0.055	0.044	0.032
RB	12.8		0.102	0.084	0.085	0.060	0.047	0.014
RB	18.3		0.087	0.077	0.081	0.058	0.054	0.010
Treatment LSD 0.05			0.02	NS	NS	NS	NS	
Treatment x DAH: P<0.0001								
		Glucose (% FWT)						DAH LSD 0.050
RB	7.2	0.038	0.221	0.255	0.204	0.134	0.122	0.028
RB	12.8		0.056	0.071	0.083	0.066	0.055	NS
RB	18.3		0.047	0.035	0.060	0.046	0.058	NS
Treatment LSD 0.05			0.032	0.021	0.015	0.032	0.034	
Treatment x DAH: P<0.0001								
		Apical End Reflectance (%)						DAH LSD 0.05
RB	7.2	53.8	35.5	30.1	45.0	46.2	50.7	5.6
RB	12.8		47.8	47.8	47.2	49.1	50.2	NS
RB	18.3		49.0	50.4	48.1	50.0	51.2	3.3
Treatment LSD 0.05			6.4	4.6	NS	NS	NS	
Treatment x DAH: P<0.0001								
		Basal End Reflectance (%)						DAH LSD 0.05
RB	7.2	44.6	11.3	12.5	16.8	25.8	21.8	5.1
RB	12.8		27.8	28.1	24.8	27.5	30.7	6.0
RB	18.3		30.1	35.9	35.2	34.0	34.6	5.5
Treatment LSD 0.05			6.9	6.9	4.8	NS	6.0	
Treatment x DAH: P<0.0001								

[1]2 DAH sample used freshly harvested tubers. Tubers were not placed in a curing treatment at this time.
[1]FWT = fresh weight

Table 9. Incremental percent weight loss of Russet Burbank (RB), Ranger Russet (RR), and Clearwater Russet (CW) throughout storage. Tubers were held at the Potato Storage Research Building at the Kimberly Research and Extension Center in Kimberly, Idaho in 2014-2015. Tubers were cured at 7.2°C, 12.8°C or 18.3°C for 14 days (95% relative humidity) then ramped +/- 0.3°C/day until the holding temperature of 8.9°C was reached. Tubers were held at 8.9°C until 205 days after harvest.

Cultivar	Curing Temperature (°C)	Days After Harvest (DAH)											DAH LSD 0.05	176[1]	205[1]
		7	14	21	28	35	42	49	56	88	119	148			
		% Weight Loss													
RB	7.2	2.10	0.62	0.59	0.23	0.18	0.14	0.01	0.08	0.54	0.26	0.42	0.16	0.35	0.95
RB	12.8	2.24	0.35	0.42	0.16	0.15	0.18	0.02	0.13	0.66	0.25	0.45	0.13	0.87	0.58
RB	18.3	2.51	0.68	0.62	0.20	0.24	0.21	0.04	0.16	0.47	0.18	0.37	0.15	0.13	0.58
Treatment LSD 0.05		NS	0.16	NS	NS	NS	0.05	NS	NS	0.10	NS	NS			
RR	7.2	1.85	0.60	0.60	0.26	0.17	0.15	0.01	0.10	0.62	0.34	0.44	0.10	0.54	1.13
RR	12.8	2.01	0.35	0.34	0.13	0.10	0.13	0.05	0.16	0.71	0.30	0.60	0.13	0.55	1.06
RR	18.3	2.84	0.89	0.66	0.35	0.30	0.25	0.15	0.08	0.48	0.20	0.39	0.11	0.34	0.66
Treatment LSD 0.05		0.40	0.07	0.08	0.05	0.04	NS	NS	NS	0.07	0.05	0.04			
CW	7.2	1.99	0.63	0.68	0.34	0.28	0.14	0.02	0.15	0.93	0.60	0.83	0.18	0.85	1.33
CW	12.8	1.96	0.33	0.49	0.16	0.17	0.19	0.01	0.15	0.95	0.47	0.67	0.13	0.68	0.98
CW	18.3	2.55	0.88	0.72	0.43	0.39	0.36	0.15	0.11	0.66	0.30	0.62	0.14	0.37	0.72
Treatment LSD 0.05		0.32	0.12	NS	0.07	0.11	0.13	0.05	NS	NS	NS	NS			

[1]Tubers started sprouting between 148 DAH and 176 DAH. To exclude the influence sprouting on weight loss, the weight loss calculated for 176 and 205 DAH were not included in the statistical analysis, but means for these sampling dates are presented.

Table 10. Accumulated percent weight loss of Russet Burbank (RB), Ranger Russet (RR), and Clearwater Russet (CW) over time in storage. Tubers were held at the Potato Storage Research Building at the Kimberly Research and Extension Center in Kimberly, Idaho in 2014-2015. Tubers were cured at 7.2°C, 12.8°C or 18.3°C for 14 days (95% Relative Humidity) then ramped +/- 0.3°C/day until the holding temperature of 8.9°C was reached. Tubers were held at 8.9°C until 205 days after harvest.

Cultivar	Curing Temperature (°C)	Days After Harvest (DAH)											DAH LSD 0.05	176[1]	205[1]
		7	14	21	28	35	42	49	56	88	119	148			
		% Weight Loss													
RB	7.2	2.10	2.70	3.27	3.49	3.66	3.80	3.80	3.88	4.40	4.64	5.04	0.22	5.40	6.29
RB	12.8	2.24	2.59	2.99	3.15	3.30	3.47	3.49	3.61	4.24	4.49	4.92	0.19	5.80	6.39
RB	18.3	2.51	3.17	3.78	3.97	4.20	4.41	4.44	4.60	5.04	5.21	5.56	0.18	5.70	6.29
Treatment NS															
RR	7.2	1.85	2.44	3.03	3.28	3.45	3.59	3.59	3.69	4.28	4.61	5.02	0.08	5.58	6.73
RR	12.8	2.02	2.36	2.69	2.81	2.91	3.04	3.08	3.23	3.92	4.21	4.77	0.12	5.33	6.42
RR	18.3	2.84	3.70	4.33	4.66	4.95	5.19	5.33	5.39	5.84	6.04	6.40	0.09	6.74	7.40
Treatment LSD 0.05		0.40	0.46	0.49	0.53	0.53	0.52	0.61	0.61	0.64	0.66	0.68			
CW	7.2	1.99	2.60	3.26	3.59	3.85	3.98	3.99	4.14	5.03	5.60	6.38	0.48	7.23	8.56
CW	12.8	1.96	2.28	2.76	2.92	3.08	3.26	3.26	3.41	4.32	4.77	5.41	0.17	6.11	7.10
CW	18.3	2.55	3.39	4.09	4.50	4.87	5.21	5.35	5.46	6.08	6.37	7.00	0.20	7.32	8.04
Treatment LSD 0.05		0.32	0.38	0.51	0.51	0.56	0.56	0.54	0.57	0.75	NS	NS			

[1]Tubers started sprouting between 148 DAH and 176 DAH. To exclude the influence sprouting on weight loss, the weight loss calculated for 176 and 205 DAH were not included in the statistical analysis, but means for these sampling dates are presented.

Table 11. Processing quality (sucrose, glucose, and fry color) of Ranger Russet (RR) tubers stored at the Potato Storage Research Facility at the Kimberly Research and Extension Center in Kimberly, Idaho in 2014-2015. Tubers were cured at 7.2°C, 12.8°C or 18.3°C for 14 days (95% Relative Humidity) then ramped +/- 0.3°C/day until the holding temperature of 8.9°C was reached. Tubers were held at 8.9°C until 237 days after harvest.

Cultivar	Curing Temperature (°C)	Days After Harvest (DAH) 2[1]	15	49	139	203	237	
		Sucrose (% FWT[2])						DAH LSD 0.050
RR	7.2	0.223	0.161	0.082	0.070	0.054	0.039	0.026
RR	12.8		0.134	0.100	0.094	0.061	0.048	0.017
RR	18.3		0.126	0.100	0.097	0.066	0.047	0.016
Treatment LSD 0.05			0.023	NS	0.017	NS	NS	
Treatment x DAH: P<0.0001								
		Glucose (% FWT)						DAH LSD 0.050
RR	7.2	0.033	0.284	0.275	0.233	0.180	0.154	0.059
RR	12.8		0.049	0.064	0.093	0.095	0.085	0.030
RR	18.3		0.025	0.033	0.059	0.059	0.103	0.020
Treatment LSD 0.05			0.038	0.028	0.025	0.042	NS	
Treatment x DAH: P<0.0001								
		Apical End Reflectance (%)						DAH LSD 0.05
RR	7.2	52.0	23.7	27.0	35.1	41.8	46.4	2.6
RR	12.8		43.4	45.3	43.0	43.7	44.9	5.0
RR	18.3		49.3	50.9	48.8	50.1	49.5	NS
Treatment LSD 0.05			5.6	3.7	4.5	3.7	NS	
Treatment x DAH: P<0.0001								
		Basal End Reflectance (%)						DAH LSD 0.05
RR	7.2	50.0	13.7	16.1	18.5	24.1	27.9	3.5
RR	12.8		37.6	38.0	34.4	35.1	32.5	5.7
RR	18.3		43.6	45.1	38.1	41.0	37.0	3.9
Treatment LSD 0.05			7.2	3.1	4.0	3.3	5.4	
Treatment x DAH: P<0.0001								

[1]2 DAH sample used freshly harvested tubers. Tubers were not placed in a curing treatment at this time.

[2]FWT = fresh weight

Table 12. Processing quality (sucrose, glucose, and fry color) of Clearwater Russet (CW) tubers stored at the Potato Storage Research Facility at the Kimberly Research and Extension Center in Kimberly, Idaho in 2014-2015. Tubers were cured at 7.2°C, 12.8°C or 18.3°C for 14 days (95% Relative Humidity) then ramped +/- 0.3°C/day until the holding temperature of 8.9°C was reached. Tubers were held at 8.9°C until 237 days after harvest.

Cultivar	Curing Temperature (°C)	Days After Harvest (DAH) 2[1]	15	49	139	203	237	
		Sucrose (% FWT[2])						DAH LSD 0.05
CW	7.2	0.151	0.152	0.055	0.042	0.038	0.043	0.026
CW	12.8		0.095	0.062	0.044	0.035	0.039	0.010
CW	18.3		0.091	0.056	0.050	0.046	0.049	0.010
Treatment LSD 0.05			0.016	NS	NS	0.008	NS	
Treatment x DAH: P<0.0001								
		Glucose (% FWT)						DAH LSD 0.05
CW	7.2	0.027	0.279	0.267	0.147	0.117	0.122	0.050
CW	12.8		0.061	0.052	0.049	0.041	0.072	NS
CW	18.3		0.023	0.023	0.024	0.024	0.040	NS
Treatment LSD 0.05			0.032	0.045	0.013	0.012	NS	
Treatment x DAH: P<0.0001								
		Apical End Reflectance (%)						DAH LSD 0.05
CW	7.2	57.5	31.0	39.1	56.5	54.6	58.0	3.9
CW	12.8		51.9	55.0	55.9	57.5	60.1	NS
CW	18.3		54.7	56.5	57.1	59.9	60.7	NS
Treatment LSD 0.05			5.4	5.1	NS	NS	NS	
Treatment x DAH: P<0.0001								
		Basal End Reflectance (%)						DAH LSD 0.05
CW	7.2	55.4	13.1	18.5	25.0	32.3	35.3	5.4
CW	12.8		38.9	38.4	43.4	46.0	48.8	5.7
CW	18.3		45.8	46.5	51.1	54.6	53.7	3.9
Treatment LSD 0.05			4.3	7.1	4.6	8	5.5	
Treatment x DAH: P<0.0001								

[1]2 DAH sample used freshly harvested tubers. Tubers were not placed in a curing treatment at this time.
[2]FWT = fresh weight

Study 3: Using commercial storages to understand cultivar and temperature influence on weight loss of stored potatoes grown in Southern Idaho

Table 13 provides details of the commercial storages sampled in 2013 and 2014 with the total days in storage and mean percent weight loss results. Table 14 provides the accumulated heat units calculated for the curing and ramping regimens for commercial storage A, B, E, F, and the KREC stored commercial grower samples.

Russet Burbank

Average percent weight loss for storage A was 8.4% after 254 days in storage (Figure 22). Weight loss of bags from storage A varied from a low of 5.5% to a high of 15.4% (Figure 22). Samples harvested September 24, 25, and 26, 2013 experienced lower weight loss (7.5%) than samples harvested on September 27, 2013 (11.3, Figure 22). Tubers sampled on September 27 were noted to be wet and the weather was noted as cold and wet. It was noted that tubers displaying symptoms of pink rot (causal agent *Phytophthora erythroseptica*) were more numerous on September 27. At the end of storage, samples harvested on September 24 and 25 were in good condition, samples harvested on September 26 showed some decay and pressure bruise, but samples from September 27 had obvious decay and complete breakdown, sprouting, and pressure bruise.

Harvest and placing of sampling bags for storage B occurred on October 1 and October 3, 2013. Weight loss varied from 3.9% to 40.6% (Figure 23) for storage B. Average weight loss for samples harvested on October 1 was 5.2% (Figure 23) while average weight loss for samples harvested on October 3 was 11.2% (Figure 23), double the previous sampling. Many tubers exhibiting symptoms of pink rot were observed at harvest on

October 3. These later samples included a significant amount of decay. The average weight loss in storage B was 9.9% after 272 days in storage (Figure 23).

In storage A, average weight loss of samples stored on top of the pile was 10.2%, and not significantly different than 9.8% weight loss of samples placed within the pile (Figure 24). In storage B, weight loss of samples stored on the top of the pile (8.6%) was similar to weight loss of samples placed in the pile (8.5%; Figure 24).

In 2013, matched samples were taken at harvest for storage A and B to be stored at KREC. KREC weight loss tuber samples were recorded respective to the unload date of the matched storage. The total weight loss of samples matching those of storage A was 8.0% (Figure 25) and the weight loss of samples matching those of storage B was 6.6% (Figure 26).

In 2014, average percent weight loss for storage C was 6.3% after 279 days in storage (Figure 27). Harvesting and placement of samples occurred September 3-7, 2014. Average percent weight loss for samples harvested September 3 was 7.7% and pulp temperatures ranged from 4.9°C-10.6°C, average percent weight loss for samples harvested September 6 was 5.7% with the pulp temperature range of 11.3°C-14.3°C, and average percent weight loss for samples harvested September 10 was 5.7% and pulp temperatures ranged from 11.7°C-19.5°C. The presence of pink rot in low amounts were noted for each day.

Average weight loss of samples placed on top of the pile (6.8%; Figure 24) was not significantly different from the average weight loss of samples stored in the pile (5.6%; Figure 24) in storage C.

Ranger Russet

Average percent weight loss for storage D was 3.8% after 42 days in storage (Figure 28). Weight loss averages for each harvest date were 4.3% for September 15, 2014 and 3.1% for September 16, 2014 (Figure 28). Pulp temperatures for September 15 were 16.1°C-20.5°C and pulp temperatures on September 16 were 15.0°C-21.7°C. The weather was clear, and sunny and ambient temperatures ranged from 20.0°C-25.6°C on September 15 and 15.0°C-29.4°C on September 16. Very little tuber decay or debris was present either day. Pythium leak (causal agent *Pythium ultimum*) and pink rot were identifiable diseases in the samples. Tubers brought back to the KREC showed some blackspot bruising. When samples were removed at the end of storage, tuber decay from wet rot had occurred. Greater overall weight loss was observed in tubers harvested on September 15 (4.3%), but greater loss due to decay was observed in tubers harvested on September 16 (3.1%) (Figure 28). Weight loss of samples stored on top of the pile (3.6%) was not statistically different to weight loss of samples stored within the pile (3.7%) (Figure 24).

Clearwater Russet

Average percent weight loss for the storage samples of storage E was 8.1% after approximately 209 days in storage (Figure 29). Weight loss of samples from storage E varied from a low of 5.6% to a high of 11.8%. Harvest and sample bag placement occurred on September 9 and 10, 2014. Slightly higher pulp temperatures were recorded at harvest on September 9 (average 13.9°C) with ambient temperature approximately 21.1°C at the time of sampling. On September 10, ambient temperature was lower, 15.6°C, and pulp temperatures of tubers were slightly lower than the previous day (10.6°C average). Tubers

were skinned from harvest of green-dug potatoes on both days. At harvest early blight was present on the foliage. Lower weight loss (7.7%) occurred in samples harvested on the first day (September 9) than in samples harvested September 10 (8.5%). Samples for storage E were collected June 18 through June 26, 2015; tubers were in storage for approximately 290 days (Table 13). Storage E was an older facility with no refrigeration. At the end of storage, samples harvested September 9 were in good condition with some sprouting while samples harvested on September 10 had some decay and pressure bruise.

Tubers were harvested and samples were placed into storage F on October 9, 2014. Samples for storage F were collected on June 15-17, 2015; tubers were in storage for 251 days (Table 13). Tubers were clean going into storage with only some skinning. Ambient temperature was 21.1°C at the time of sampling and pulp temperatures ranged from 14.0°C-16.5°C. This storage was newly built in 2014 (without refrigeration) and the pile was split with another cultivar Ranger Russet. Weight loss varied from 4.1% to 6.1% (Figure 30). Average weight loss for storage F was 5.2% (Figure 30).

Weight loss of samples stored on top of the pile in storage E (8.8%) were similar to that of samples buried in the pile (7.8%, Figure 24). In storage F, weight loss was 5.0% for samples stored on top of the pile and 5.2% for samples stored within the pile (Figure 24).

Table 13. Description of commercial potato storages and weight loss of samples sampled in 2013 and 2014 in southern Idaho.

Storage year	Storage	Cultivar	Size of storage (MT)	Type of storage	Set holding temperature °C (set RH[1])	Total days in storage	Mean Weight Loss (%)
2013-2014	A	RB	5,442	Slant wall	8.9 (95%)	254	8.4
2013-2014	B	RB	6,100	Slant wall	8.9 (95%)	272	9.4
2014-2015	C	RB	6,100	Slant wall	Unknown	279	6.3
2014-2015	D	RR	5,442	Slant wall	8.9 (95%)	42	3.9
2014-2015	E	CW	5,442	Slant wall	8.9 (95%)	290	8.1
2014-2015	F	CW	6,803	Curvette	8.9 (95%)	251	5.2

[1]Relative Humidity

Table 14. Table of accumulated heat units (AHU; base temperature = 0°C) calculated for curing and ramping regimens for three commercial storages in Idaho and University of Idaho Kimberly Research and Extension Center (KREC). AHUs are calculated at first day of harvest through curing and ramping to holding temperature (8.9°C). (RB=Russet Burbank, CW=Clearwater Russet)

	STORAGE				
DAYS	A	B	E	F	KREC
	RB	RB	CW	CW	RB
			AHU		
1	14	12	13	16	13
2	25	27	26	32	26
3	36	42	38	46	38
4	49	55	51	59	51
5	62	66	64	73	64
6	75	76	77	87	77
7	88	88	89	101	89
8	101	101	102	116	102
9	115	113	115	129	115
10	128	126	128	143	128
11	141	139	140	157	141
12	155	153	153	171	153
13	168	167	165	184	166
14	181	180	177	198	179
15	194	194	189	212	192
16	207	207	201	226	204
17	220	221	213	240	216
18	233	234	225	253	228
19	246	247	237	266	239
20	259	259	248	279	251
21	272	271	260	291	262
22	285	283	271	304	272
23	299	296	282	317	283
24	312	309	293	329	293
25	326	322	304	342	303
26	339	335	315	354	312
27	352	349	326	366	322
28	365	362	337	379	331
29	378	376	347	391	
30	391	389	358	403	
31	404	402	368	414	
32	417	415	378	426	
33	429	428	388	438	
34	442	441	398	449	

35	454	454	408	461
36	467	466	418	472
37	479	479	428	483
38	491	491	437	494
39	503	504	447	505
40	515	516	456	516
41	527	528	465	527
42	540	540	474	537
43	551	552	483	548
44	563	564		558
45	575	576		569
46	587	587		579
47	599	598		589
48	611	609		600
49	623	621		610
50	635	632		620
51	646	643		630
52	658	654		640
53	669	665		649
54	680	676		659
55	692	687		669
56	703	698		678
57	713	709		
58	724	720		
59	734	731		
60	745	742		
61	755	752		
62	765	762		
63	774	772		
64	784	782		
65		793		
66		804		
67		815		

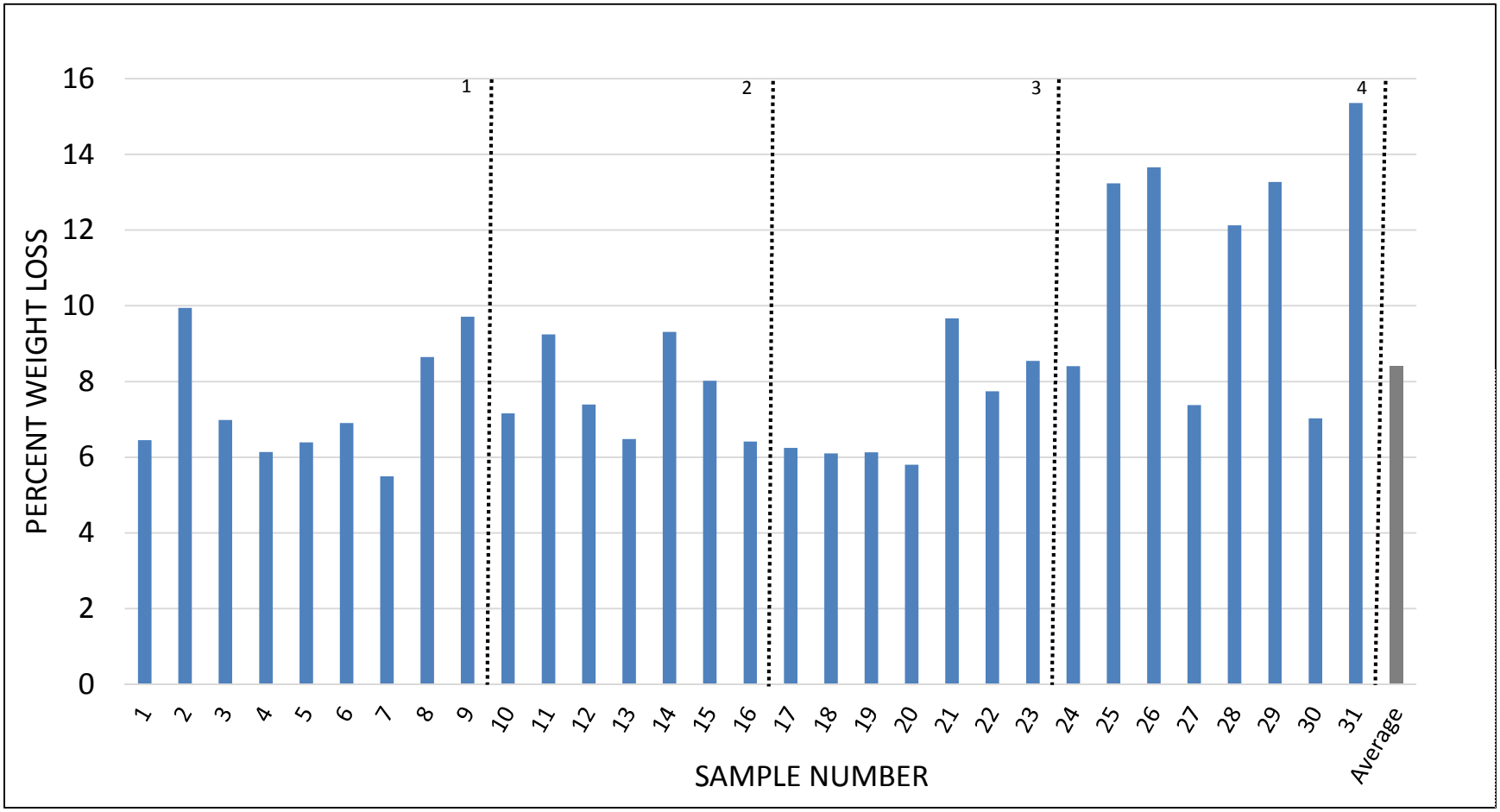

Figure 22. Percent weight loss of Russet Burbank samples from storage A in 2013-4 after 254 days in storage. [1] Samples 1-9 tubers harvested 9/24/2013. [2]Samples 10-16 tubers harvested 9/25/2014. Pulp temperatures ranged from 8.9°C-11.7°C. [3]Samples 17-23 tubers harvested 9/26/2013. Pulp temperature ranged from 8.9°C-11.1°C. [4]Samples 24-31 tubers harvested 9/27/2013. Pulp temperatures ranged from 8.3°C-13.9°C.

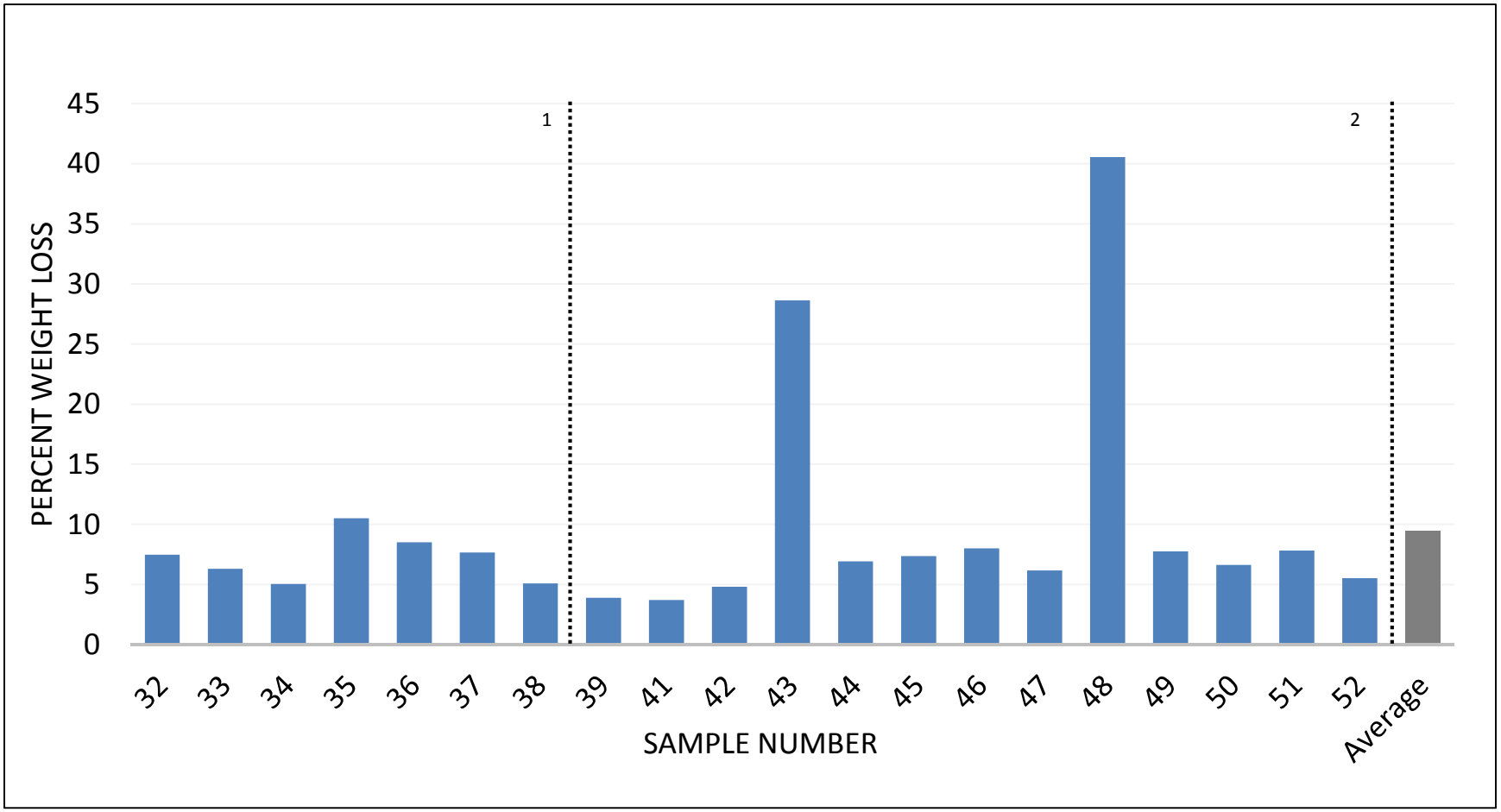

Figure 23. Percent weight loss of Russet Burbank samples from storage B in 2013-1 stored for 272 days. [1] Samples 32-38 tubers harvested 10/01/2013. Pulp temperatures ranged from 10.8°C-12.4°C. [2] Samples 39-52 tubers harvested 10/03/2013. Pulp temperatures ranged from 5.3°C-8.1°C. Presence of pink rot and wet weather noted.

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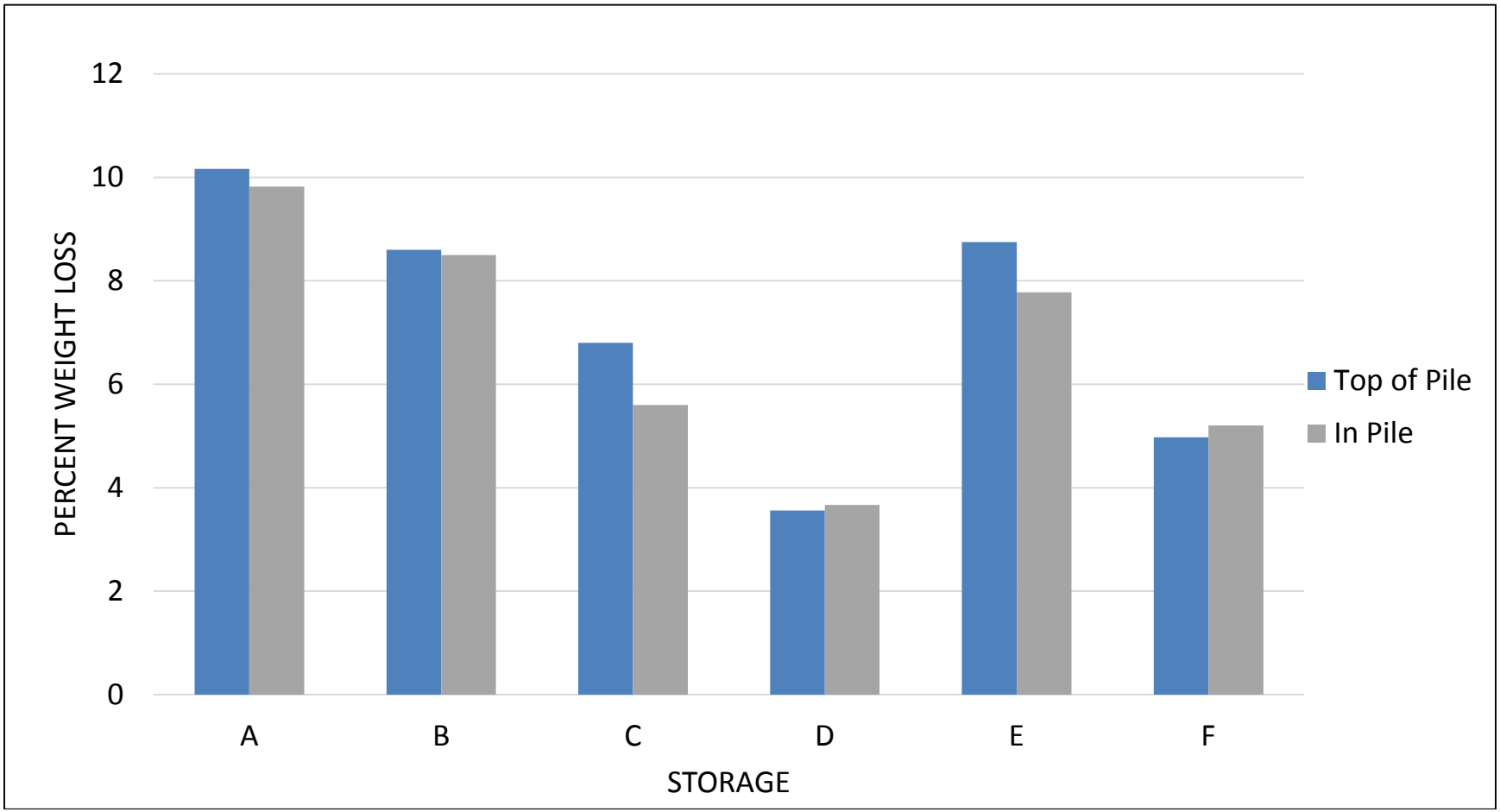

Figure 24. Percent weight loss of potato samples placed on top of commercially stored potato piles designated as "Top of the Pile" and samples embedded within the commercially stored potatoes denoted as "In Pile" in southern Idaho commercial storages in 2013-2014. Placement of samples did not significantly influence weight loss of potatoes (P=0.79).

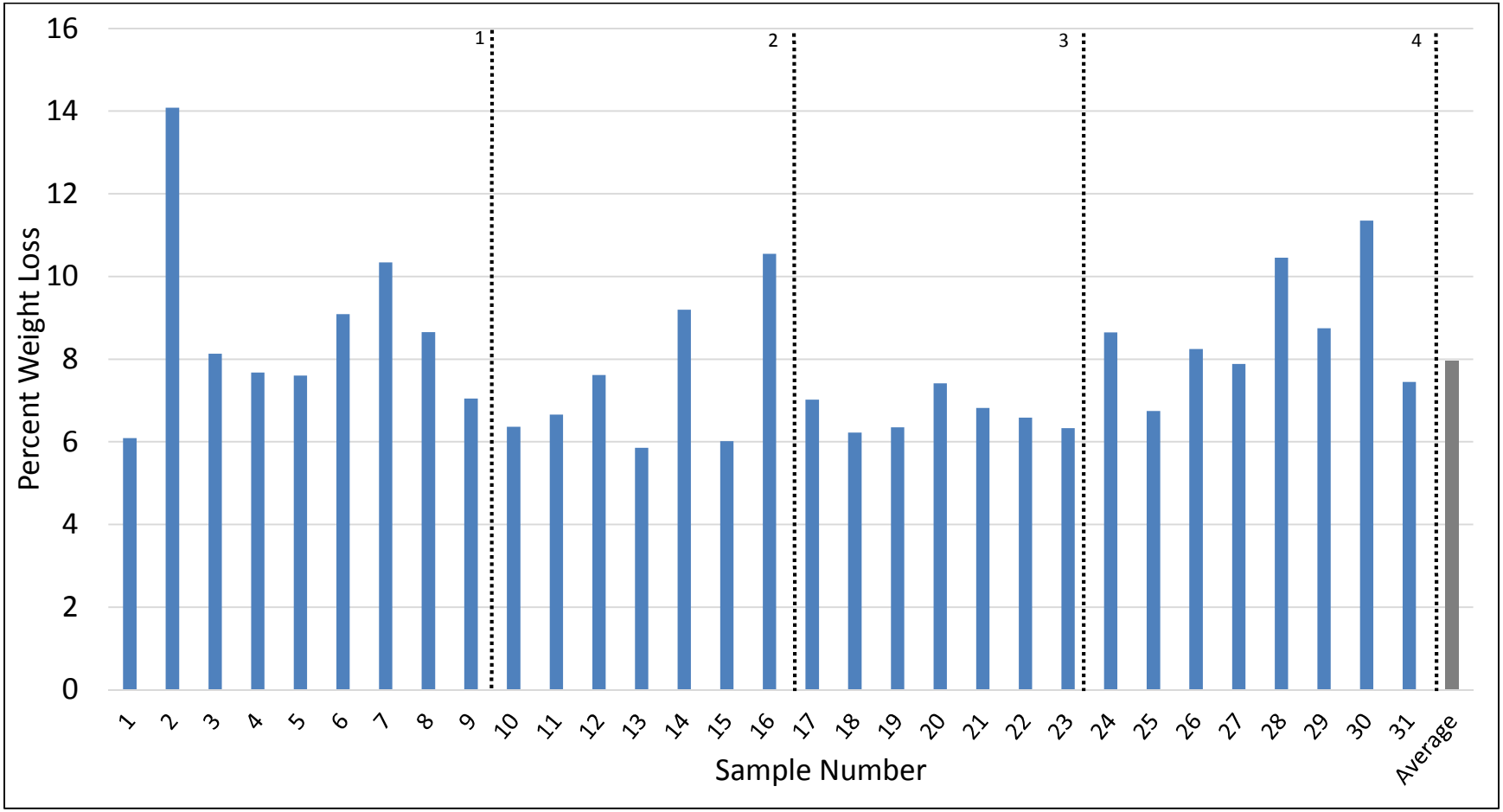

Figure 25. Percent weight loss of Russet Burbank samples from storage A in 2013-4 stored at the University of Idaho Kimberly Research and Extension Center (KREC) in Kimberly, Idaho for 254 days. [1] Samples 1-9 tubers harvested 9/24/2013. [2]Samples 10-16 tubers harvested 9/25/2013. Pulp temperatures ranged from 8.9°C-11.7°C. [3]Samples 17-23 tubers harvested 9/26/2013. Pulp temperature ranged from 8.9°C-11.1°C. [4]Samples 24-31 tubers harvested 9/27/2013. Pulp temperatures ranged from 8.3°C-13.9°C

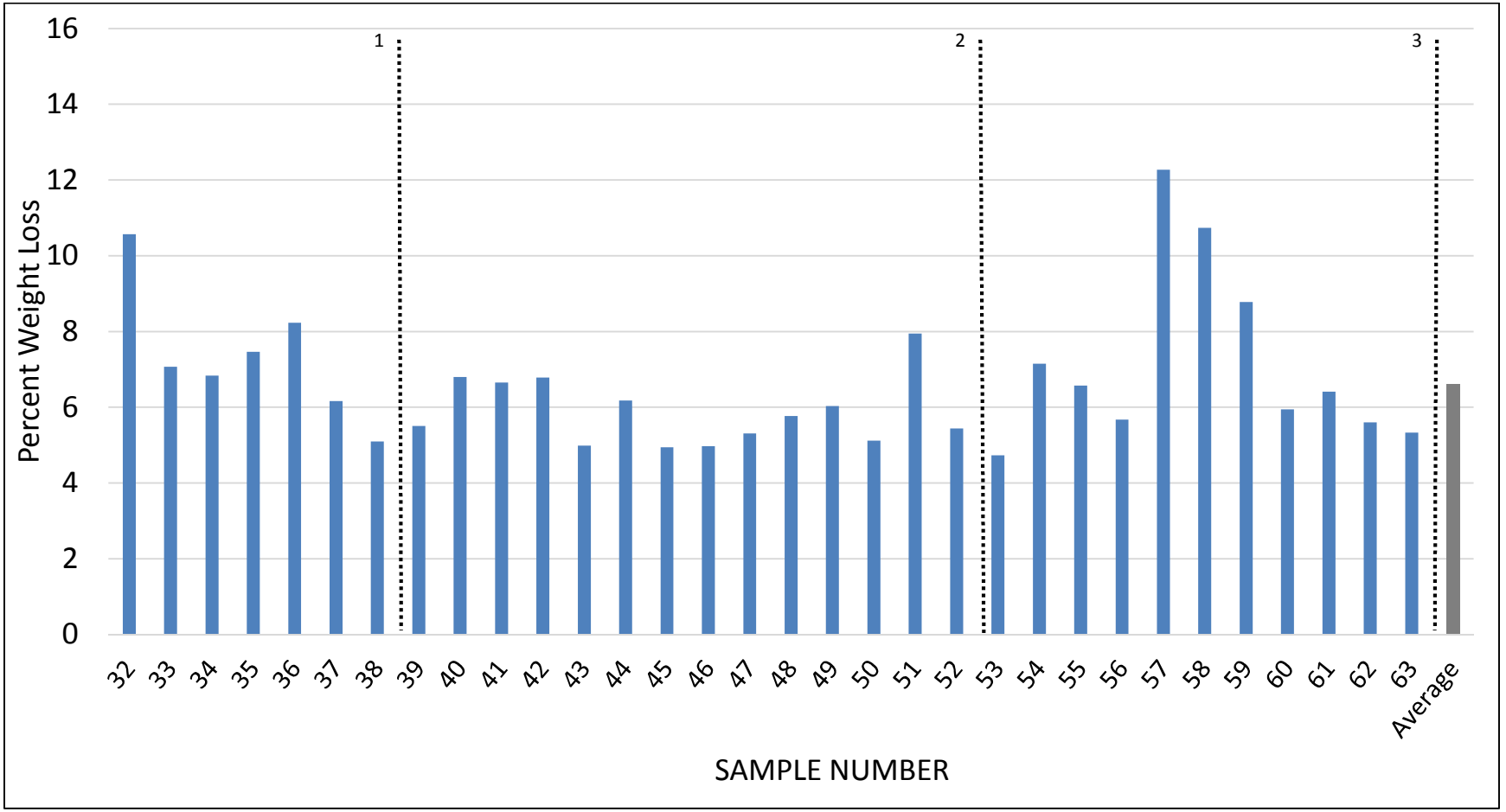

Figure 26. Percent weight loss of Russet Burbank samples from storage B in 2013-4 stored at the University of Idaho Kimberly Research and Extension Center (KREC) in Kimberly, Idaho for 272 days. [1] Samples 32-38 tubers harvested 10/01/2013. Pulp temperatures ranged from 10.8°C-12.4°C. [2] Samples 39-52 tubers harvested 10/03/2013. Pulp temperatures ranged from 5.3°C-8.1°C. Presence of pink rot and wet weather noted. [3]Samples 53-33 were never recovered from the commercial storage pile.

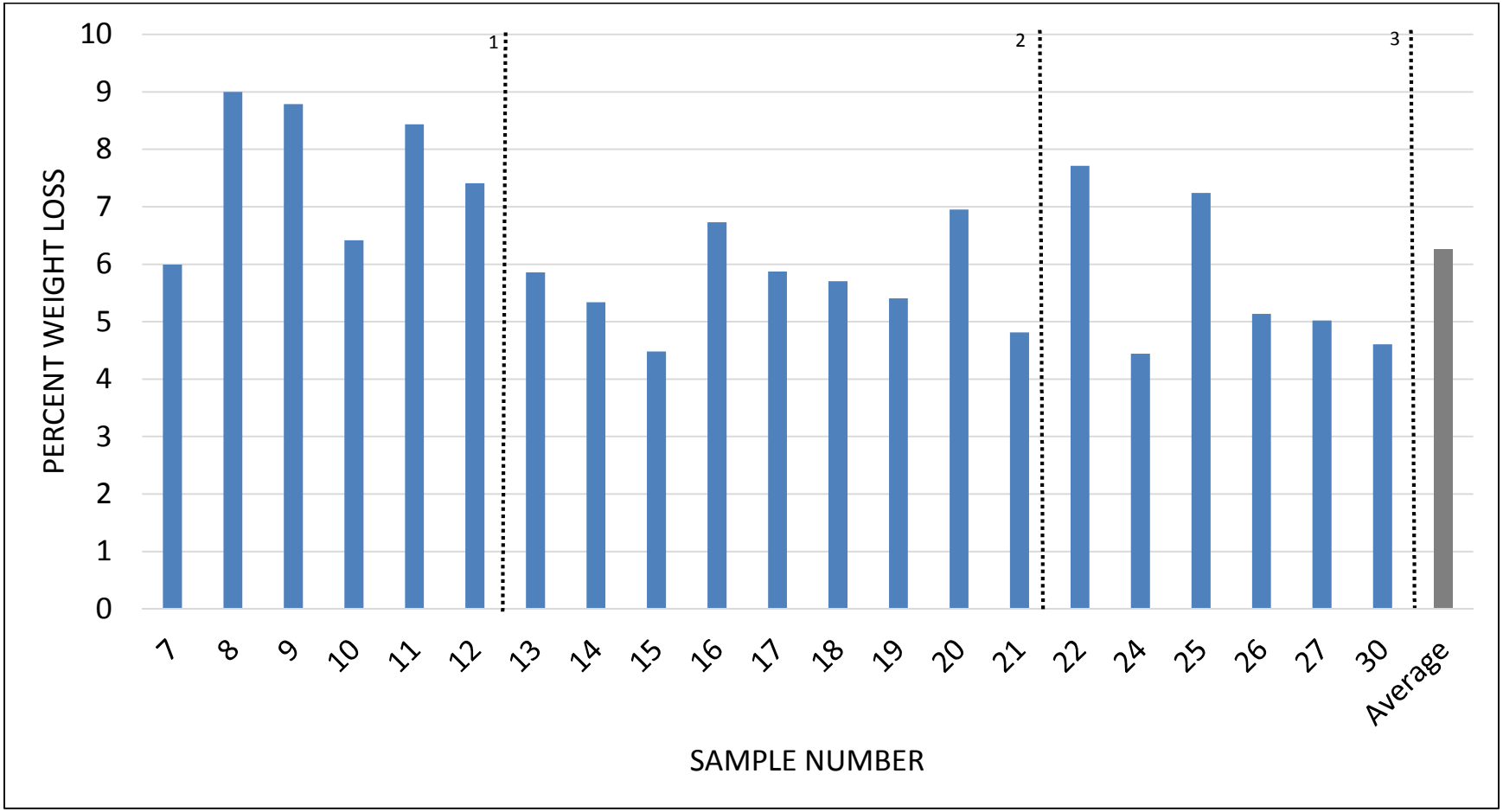

Figure 27. Percent weight loss of Russet Burbank samples from storage C in 2014 stored for 279 days. [1] Samples 7-12 tubers harvested 10/03/2014. Pulp temperatures ranged from 4.9°C-10.6°C. Ambient temperature was 6.1°C. A little bit of rot was noted. [2] Samples 13-21 tubers harvested 10/06/2014. Pulp temperatures ranged from 11.3°C-14.3°C. Ambient temperature was 17.8°C. A little bit of pink rot was noted. [3]Samples 22-30 were harvested 10/7/2014. Pulp temperatures ranged from 11.7°C-19.5°C. Ambient temperature was 22.2°C. A little bit of rot was noted going in to storage.

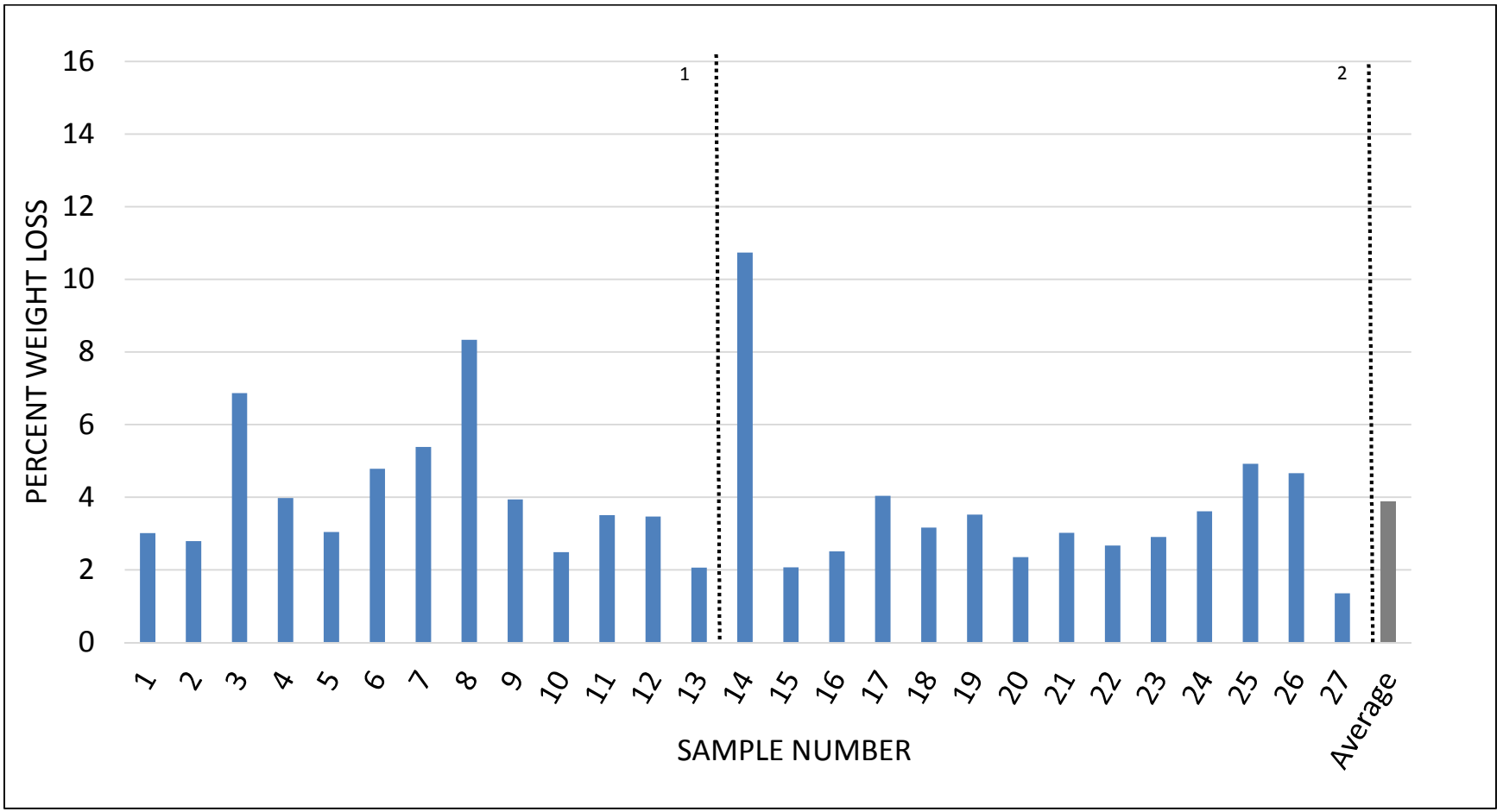

Figure 28. Percent weight loss of Ranger Russet samples from storage D in 2014 stored for 42 days. [1] Samples 1-13 tubers harvested 9/15/2014. Pulp temperatures ranged from 15.6°C-20.1°C. Ambient temperature ranged from 20°C-25.6°C. Very little rot noted at harvest. [2]Samples 14-27 tubers harvested 9/16/2014. Pulp temperatures ranged from 13.9°C-21.7°C. Very little presence of pink rot at harvest and condensation on ceiling was noted. Ambient temperatures ranged from 15°C-21.7°C.

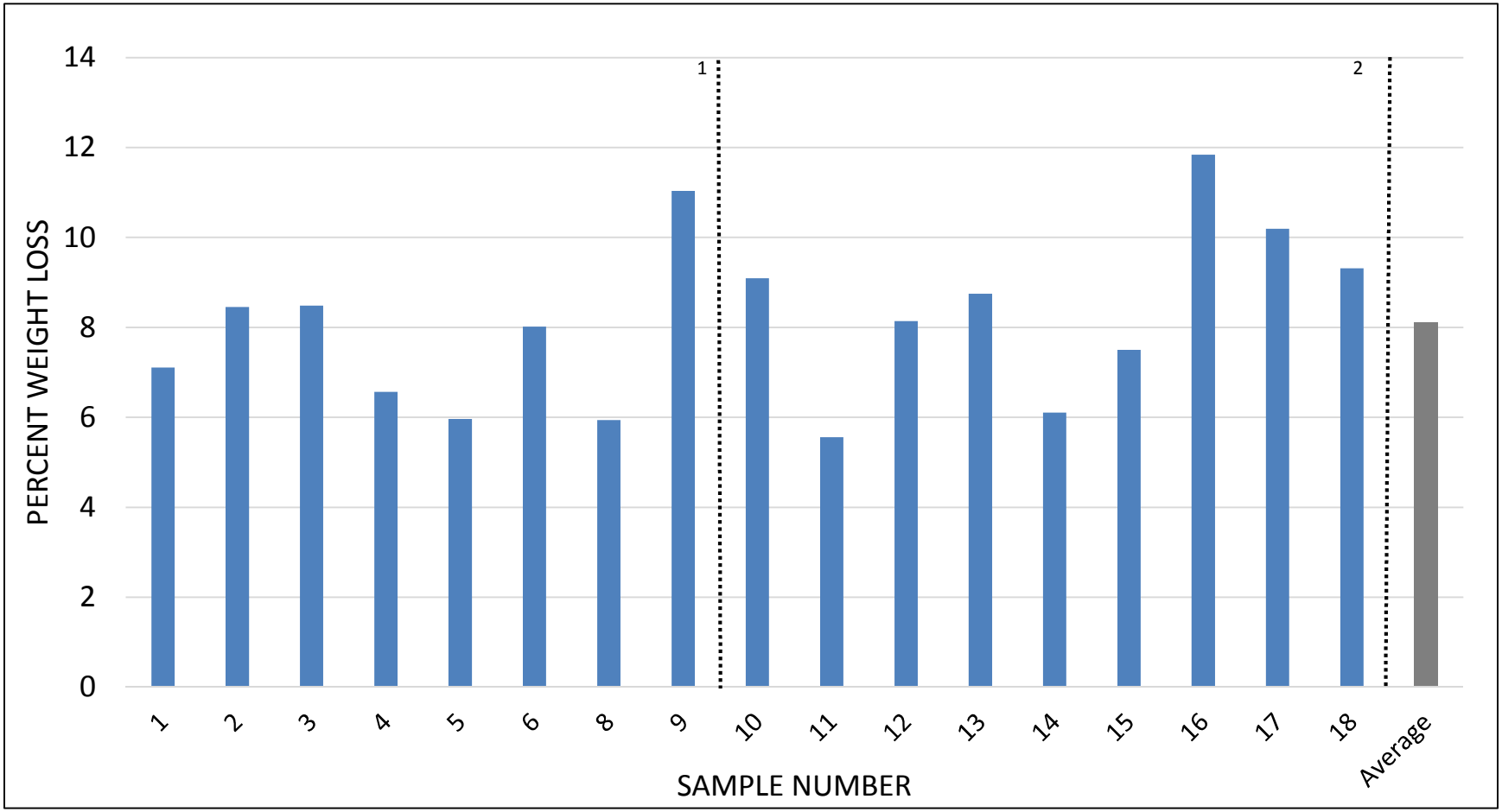

Figure 29. Percent weight loss of Clearwater Russet samples from storage E in 2014-5 stored for 290 days. [1] Samples 1-9 tubers harvested 9/09/2014. Pulp temperatures ranged from 14.1°C-16.3°C. Ambient temperature 21.1°C. [2]Samples 10-18 tubers harvested 9/10/2014. Pulp temperatures ranged from 10.9°C-11.2°C. Ambient temperature 15°C. Both days noted skinning of tubers.

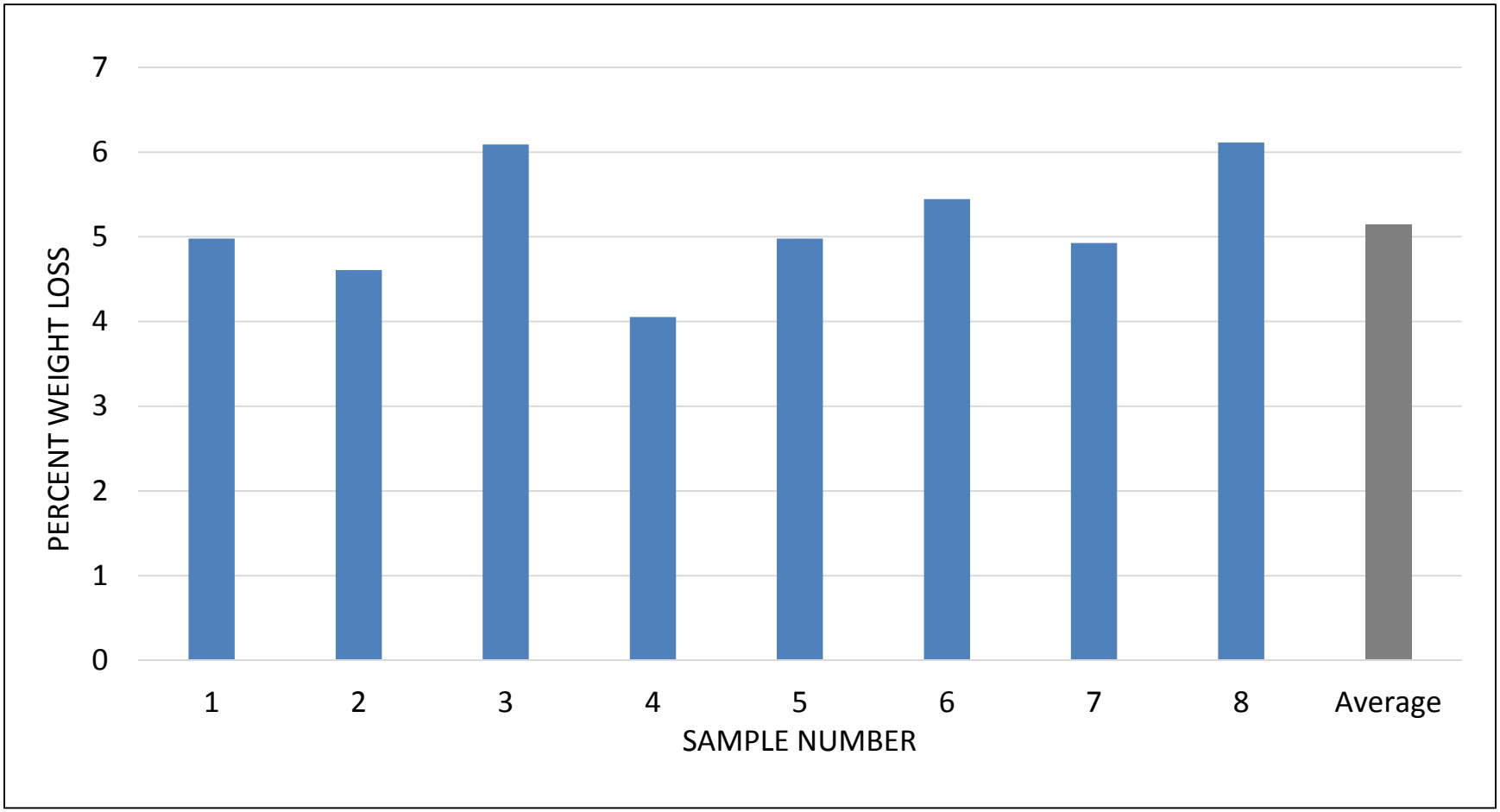

Figure 30. Percent weight loss of Clearwater Russet samples from storage F in 2014-5 stored for 251 days. [1] Samples 1-8 tubers harvested 10/09/2014. Pulp temperatures ranged from 14.0°C-16.5°C. Ambient temperature 21.1°C. Notes of nice skin, no rot, and storage shared with Ranger Russet potatoes.

DISCUSSION

The effects of temperature on wound healing, weight loss, processing quality, and disease were investigated in the popular processing cultivars Russet Burbank (RB) and Ranger Russet (RR) as well as in a newer processing cultivar gaining popularity in the industry, Clearwater Russet (CW). Russet Burbank and RR are the top two processing cultivars in Idaho (NASS 2014c). Clearwater Russet is a processing cultivar that is gaining popularity for having consistently low sugar concentrations (Novy et al. 2010). All three cultivars were included in these studies to evaluate the effects of curing temperature on wound healing, processing quality and storability.

It is important to note the significance of other factors which contribute to the storability of potatoes. Temperature is one variable of many which can greatly influence transpirational water loss in potato tubers during storage; other variables include ventilation and air movement, relative humidity, respiration, the development and/or suppression of sprouting and disease development (Burton et al. 1992). The studies reported herein were done with the purpose of gaining insight on how early storage management recommendations may be modified in the context of temperature alone, but are not made with the intention of neglecting other factors that contribute to storability.

Three curing temperatures were chosen to evaluate the effect of early storage temperatures on wound healing, processing quality and long term storability of potatoes. A high and low temperature of 7.2°C and 18.3°C, respectively, were selected to present extreme early storage temperature conditions, and an intermediate temperature of 12.8°C was selected as typical of the industry standard. The 12.8°C curing temperature falls into

current curing temperature guidelines (10°C-12.8°C) recommended for the potato industry (Kleinkopf and Olsen 2003). The low temperature of 7.2°C is well below the industry curing temperature recommendation, however, it represents a very plausible harvest situation for Northwest potato growers when tubers are harvested later and cool ambient temperatures may lead to cooler tuber pulp temperatures. The 18.3°C temperature was chosen as the warmest temperature to evaluate as it also represents a real-world situation often encountered by Northwest potato growers. Northwest potato harvest is often accompanied by tuber pulp temperatures well above the recommended cut off of 18.0°C (Lambert and Salas 2001, Salas et al. 2000). Core curing intervals, 0, 5, 10, 15, and 20 days, were selected to fall within the current industry recommendation of 14 to 21 days (Kleinkopf and Olsen 2003).

In addition to choosing temperatures Northwest potato growers may experience, early storage temperatures were evaluated for the possible benefits and/or disadvantages on subsequent storability and processing quality. Choosing appropriate curing temperatures for the processing industry entails balancing the maintenance of processing quality while minimizing losses due to disease, respiration and evaporation. Warm and cool temperatures can positively and negatively impact tuber quality and losses. Cooler temperatures minimize weight loss, disease development, sprouting and respiration, but promotes reducing sugar accumulation in tubers (Kleinkopf and Olsen 2003). Low temperature sweetening is not acceptable in the processing industry, therefore, warmer curing temperatures must be utilized in order to meet consumer demands of light fry color. However, weight loss is maximized at warmer temperatures from increased vapor pressure

deficits, senescent sweetening occurs earlier (Burton 1989) and disease development is favored (Kleinkopf and Olsen 2003). Figure A.13 shows the percent of fresh weight Russet Burbank cores lost during the curing intervals and may provide some insight on how greater vapor pressure deficits at the warmer temperatures will increase weight loss. This graph is included in the appendix to show the difference in weight loss of potato tissues cured at the extreme temperatures chosen in this study. The fresh weight lost during curing most definitely should be discussed along with wound periderm, especially when the effects of temperature, or vapor pressure deficits, are of interest.

The resistance to weight loss indicates the level of wound healing and provides an effective method for quantifying wound healing (Knowles 1982, Kumar and Knowles 2003). Tuber tissue free of native periderm provides a tissue sample entirely free of periderm allowing for the measurement of resistance to weight loss which primary suberization and the wound periderm alone provides. While core samples only provide a small scale representation of wound healing, whole tubers cured in research facility bins provide a more accurate depiction of what physiological changes may occur when tubers are subjected to selected curing temperatures. Furthermore, understanding and evaluating the practical application of early storage management in commercial storages were evaluated to capture experiences of growers.

Determining if a curing period of cooler temperatures can provide benefits of lower weight loss and disease development while excluding disadvantages of low processing quality would be beneficial to all sectors of the potato industry. Conversely, understanding if warm curing temperatures can provide the benefit of good processing quality while

minimizing disease development and lowering weight loss would provide better tools for managing processing potato storages. Furthermore, tubers exposed to warmer early storage temperatures cure faster (Thomas 1982), possibly allowing the curing interval to be shortened in order to minimize weight loss and disease development.

To enhance the usability of wound healing units, accumulated heat units (AHU) were applied. AHU combine time and temperature into one point and allows data from different temperatures and times to be placed on the same line, making comparisons between treatments easier. AHU is a practical application of temperature used to monitor physiological growth and is common in the agriculture industry; finding a use for AHU in potato storage management could serve as a useful tool for potato growers.

Young RB and RR tubers (1 and 2 month old tubers, respectively) had more decay in the early core wound healing studies than older tubers (4 and 5 month old tubers, respectively) in later studies, while the presence of decay in the CW cores was higher in older tubers. The increased decay in older CW tuber tissue (6 months) could be due to an age-induced increase in disease susceptibility (Kumar and Knowles 2003, Kumar et al. 2007). RB and RR tubers did not follow this same pattern of greater disease development with older tubers. In the early studies, the inoculum level of pathogens in the RB and RR tubers may have been higher than the inoculum level in the CW tubers, since the CW tubers were examined last (3 months after harvest) in the early studies. If the inoculum level decreased over time, it may explain why the older RB and RR tubers did not have the disease development that RB and RR had in the younger tubers of the early studies, despite the findings that aged tubers have less disease resistance than younger tubers (Bhatia and

Young 1985). Furthermore, wound healing ability was delayed and WHU were lower in later studies compared to earlier studies, supporting the findings in the literature of the decreased ability of tubers to wound heal as they age (Thomson et al. 1995, Kumar and Knowles 2003, Kumar et al. 2007). The studies of Kumar and Knowles 2003 and Kumar et al. 2007 use tubers differing in chronological age of 12 months which is an important note when trying to make conclusions about tuber age and wound heal ability in relation to this study.

The development of disease in the wound healing core study brought forth the idea that disease resistance should be a component to future wound healing studies. The use of WHU in quantifying the wound periderm development is a direct measure of resistance to water loss after wound healing has occurred (Kumar 2003, Lulai 2007). However, WHU do not provide information about the tissue's ability to resist bacterial and fungal infection, an important aspect of tuber wound healing (Lulai 2007).

Russet Burbank

The lack of WHU accumulated in RB at the 7.2°C temperature indicates the lack of wound healing occurring at this cooler temperature even up to 20 days of curing. WHU were higher at the warmer temperature of 18.3°C and therefore consistent with findings in the literature of increased wound healing at warmer temperatures (Thomas 1982). Regardless of tuber age, the warmest curing temperature did not stimulate additional WHU after 15 days of curing, signifying the end of wound periderm development at this temperature. At 12.8°C, WHU continued to increase overtime. However, the WHU at 20 days of curing at 12.8°C was equivalent to WHU at 15 days of curing at 18.3°C, thus

indicating that wound healing was complete at 20 days at 12.8°C. Previous work has shown wound healing to be complete at 21 days at 9.0°C (Knowles et al. 1982). Extending the curing interval past 20 days may be beneficial to see when WHU level off for the intermediate temperature. Wound periderm development was incomplete after 20 days of curing at 7.2°C. Tubers would most likely continue to heal if allowed to cure longer than 20 days, as the WHU significantly increased at each curing interval. Wound healing at 7.2°C would likely continue slowly until WHU became equal to that accumulated at the warmest temperature.

The lack of suberin deposition in RB tissue at lower temperatures is echoed in the whole tuber weight loss results for RB, where total tuber weight loss was not affected by the temperature of curing. Relatively low storage temperatures can reduce weight loss, however, findings in the literature show increased weight loss in tubers cured at temperatures below 7.5°C (Schippers 1971). The equal weight loss in tubers, regardless of curing temperature may have been due to the lack of suberin deposited in the tubers cured at the lower temperatures (Morris et al. 1989) and the higher water vapor pressure deficit (WVPD) and higher rate of respiration at the warmer temperatures (Kays and Paull 2004, Boe et al. 1974, Schippers 1977). If suberin deposition was less, then tubers would lose additional weight due to the absence of a barrier that an adequate closing layer would provide. The weight loss from respiration would be minimal, since colder temperatures reduce the rate of respiration (Boe et al. 1974, Schippers 1977). Tubers cured at the warmer temperatures may lose water due to the higher WVPD and increased respiration

rate (Boe et al. 1974, Schippers 1977), but suberin would be deposited quickly, therefore providing a more effective barrier to water loss (Thomas 1982).

Sacrificing processing quality in order to compensate for weight loss in RB tubers appears not to be a justifiable practice based on this data. Processing quality losses resulting from the lower curing temperature indicated that curing at 7.2°C was not only detrimental to the tubers ability to wound heal, but also to processing quality. The low curing temperature darkened fry color to unacceptable levels in the basal end of RB tubers and this was observed until the end of storage.

Disease incidence in the one replicate of RB tubers was higher in tubers cured at 18.3°C than the other temperatures, as well as in the cores cured at 18.3°C longer than 15 days, indicating the importance of shortening the curing interval to 15 days or less if tubers are held at these warmer temperatures. This may also have application if warm harvest pulp temperatures are experienced. RB tubers with harvest tuber pulp temperatures around 18.3°C will need to be managed to rapidly remove field heat and effectively control the potential development of disease. If disease inoculum is known to be high, it may be advantageous to keep early storage temperatures lower than 18.3°C. Weight loss will not be minimized and processing quality may be sacrificed if a lower curing temperature is selected for disease control. Conversely, if inoculum levels are known to be low, or chemical disease control is strong, curing at a warmer temperature will maintain good processing quality without sacrificing storability in RB.

The RB commercial storages sampled in 2013 exhibited the negative consequences of increased weight loss that cooler pulp temperatures can exacerbate. The last day of

sampling was cooler and wetter than previous days and weight loss of those samples collected that day was elevated. Notes were made of tuber cracking on this cold, wet day; some were the result of shatter bruising, which is one risk of harvesting at cooler temperatures and will contribute to elevated weight loss (Thornton and Bohl 1998). Furthermore, these shatter bruises and cracks provide an entrance for pathogens.

The AHU for the curing and ramping regime of weight loss samples stored at KREC were calculated as well as the AHU for the curing and ramping regime of the two RB commercial storages to note the difference of heat accumulated in early storage (Table 14). Kimberly stored samples accumulated a total of 331 AHU at the end of ramping, while storage A accumulated a total of 784 AHU and storage B accumulated 814 AHU. The difference in the AHU of the commercial storages compared to the KREC stored samples may largely be attributed to the curing interval used and the ramping rate used. KREC tubers were cured at typical industry recommendations for 14 days and ramped at 0.3°C per day. It took a total of 28 days to cure and ramp to the holding temperature at KREC. Storage A was cured for 28 days and storage B was cured for an interval of 32 days; both commercial storages ramped at 0.1°C per day. Storage A took a total of 64 days to cure and ramp to the holding temperature. Storage B took a total of 67 days to cure and ramp the holding temperature.

Even though there was a dramatic difference in AHU between the KREC curing and ramping regime and both commercial storages, the KREC samples matched to storage A and commercial storage A samples lost similar amounts of weight, indicating insignificance in the accumulation of heat units. There was a large difference in KREC samples matched to

storage B and commercial storage B samples, 30% higher weight loss in the commercial storage, indicating that the accumulation of heat units may have influenced weight loss and/or disease development. A more likely explanation for the elevated weight loss in commercial storage B compared to KREC stored samples is the prolonged curing interval and wet weather conditions. Tubers were noted to be wet going into storage which is known to favor disease development (Secor and Gudmestad 1999) and the KREC stored tubers may have dried out quicker since samples were not stored in bulk piles. The impact of humidity and other storage factors contributing to the weight loss of these commercial storages were not investigated. Therefore these conclusions can only speculate on the contribution temperature may have had on total weight loss in relation to other storage conditions. Further research is needed to confirm whether or not AHU of early storage temperatures can be used as a prediction tool to monitor long term storage weight loss.

RB tubers with pulp temperatures near 18.3°C or cured at 18.3°C should not remain at this temperature for longer than 15 days to avoid disease development. Durations of a low temperature near 7.2°C, pulp or curing temperatures, should be avoided to maximize retention of processing quality and storability. The results indicate that tubers with low pulp temperatures should be warmed for curing to avoid negative effects on processing quality and wound healing and supports the current industry recommendation of curing for three weeks at 12.8°C for RB tubers, but brings forth the possibility of negative consequences of any temperatures lower than 12.8°C for curing (2-3 week period).

Ranger Russet

Ranger Russet was similar to RB with minimal wound healing at 7.2°C. Further consequences of the low curing temperature were also seen as elevated glucose levels and dark fry color due to cold induced sweetening (Workman et al. 1979, Richardson et al. 1990, Zrenner et al. 1996). The 7.2°C curing temperature was detrimental to processing quality, favored disease development and reduced wound healing, thus revealing 7.2°C as an unacceptable early storage temperature for RR. This may provide some insight into the effects of cold tuber pulp temperatures at harvest and the effects of low temperatures in RR storage. The short term exposure of RR to 7.2°C (14 days) negatively affected processing quality throughout long term storage. Previous research has shown that even shorter durations of cold temperature, 1 to 2 days will result in deteriorated processing quality in Ranger Russet (Woodell et al. 2004), further implicating the importance of warming RR tubers in storage if harvested with cold pulp temperatures.

Cold harvest temperatures are less frequently an issue in RR for Northwest potato growers, because RR is generally harvested earlier than other cultivars (Pavek et al. 1992). This highlights the issue of warm pulp temperatures and the implications of warm temperatures on processing quality, physiological disorders such as pressure bruise (Mikitzel 2014), increased respiration rate (Burton et al. 1992) and disease development, most notably Pythium leak (Hooker 1981). The warm curing temperature of 18.3°C used in this experiment is a very common occurrence in Northwest RR potato harvest, when temperatures often exceed this temperature. RR wound healed very quickly at the warmest temperature, peaking at 10 days before developing disease, enforcing the

importance of lowering pulp temperatures or curing temperatures below 18.3°C no more than 10 days after harvest. Furthermore, glucose levels of RR cured at 18.3°C increased late in storage implicating the negative consequences of holding RR at warmer early storage temperatures, which may result in the early onset of senescent sweetening (Burton 1989). Additionally, high tuber pulp temperatures at harvest can result in over-maturation of RR in the field, and published data reports susceptibility to sweetening in storage in over-mature RR tubers (Driskill et al. 2007, Knowles et al. 2009). A last concern for an 18.3°C curing temperature for RR is the development of Pythium leak, which RR is very susceptible to (Salas et al. 2003).

The weight loss of RR cured at 12.8°C and below was less than RR cured at the warmest temperature of 18.3°C when tubers were cured for 14 days. Since RR cures faster at 18.3°C than 12.8°C reducing the curing time from 14 days to 10 days may decrease the weight loss of the tubers while still allowing for adequate suberization.

The commercial RR storage monitored for weight loss had high tuber pulp temperatures at harvest, a common occurrence for northwest RR harvest. The average weight loss for the warmest day was actually lower than the average weight loss for the cooler day, however decay was noted more prevalent at the end of storage in samples from the warmest day. One observation made at harvest was condensation on the storage ceiling. The condensation indicated the use of cooler temperatures to reduce the temperature of the incoming tubers, which were very warm. Condensation occurred because the water vapor pressure at the warm temperature of the tubers was much higher than the water vapor pressure of the cool air of the storage (Burton 1992). The storage air

could not hold all of the water the incoming tubers were losing to the storage air, and the excess water condensed on the ceiling of the storage. Wet conditions are known to favor disease development, so the condensation would have favored disease development (Secor and Gudmestad 1999). Furthermore, the elevated pulp temperatures of the tubers would have favored disease development (Secor and Gudmestad 1999, Lui and Kushalappa 2002).

RR cured at 12.8°C must be held for 15 days or more, but no more than 10 days if cured at 18.3°C to ensure adequate wound healing and minimum disease development. This data showed the importance of managing RR harvest pulp temperatures, especially extremely high or low pulp temperatures. Further research is needed to understand the implications of curing RR at 18.3°C on senescent sweetening and whether or not shortened curing periods may be implemented to favor suberization and retard physiological aging.

Clearwater Russet

Consistent with the other two cultivars, CW did not suberize adequately at 7.2°C curing temperatures. Fry color was dark and glucose levels were elevated throughout storage when tubers were cured at this cold temperature. Furthermore, weight loss of tubers cured at 7.2°C was equivalent to those cured at 12.8°C and 18.3° at the end of long term storage, indicating that primary suberization was not adequate enough to prevent water loss at this lower temperature. The lack of suberization in tubers cured at 7.2°C may have been responsible for the elevated disease incidence observed at this temperature as well.

Harvesting CW at temperatures below 12.8°C should be done with caution as a result of this data. Cooler pulp temperatures will affect the wound healing process of CW and may prevent adequate amounts of suberin and wax from being deposited in the cell walls, and thus decreasing storability of this cultivar. However, if cooler pulp temperatures are encountered, warming the CW tubers immediately for a curing period would be necessary to combat processing quality deterioration and decreased storability.

Commercial CW storage weight loss supports the findings that holding CW at warmer temperatures may be beneficial to long term storability of the cultivar; however the impact of additional, unidentified, storage conditions in the CW commercial storages undoubtedly contributed to weight loss. Storage E had greater weight loss than storage F. Storage E was cured for 10 days and storage F was cured for 14 days, both at 12.8°C (95%RH). Storage E had a slightly more aggressive ramping rate, only taking 33 days to reach the holding temperature of 8.9°C. Storage F had a slightly less aggressive ramping rate, taking 42 days to reach the same holding temperature of 8.9°C. From the time of harvest to reaching of the holding temperature was 43 days for storage E and 62 days for storage F. AHU calculated for the curing and ramping regimen for storage E resulted in an AHU of 483 when ramping was completed. AHU calculated for storage F curing and ramping regimen resulted in 678 AHU (Table 14). The higher weight loss in storage E and lower weight loss in storage F raises interest of using AHU as a tool for wound healing and managing weight loss in CW long term storage.

In addition to the AHU of the two CW commercial storages sampled, it is important to discuss the difference in harvest conditions between the two storages, as these factors

were more likely heavier impact factors on overall weight loss. Storage E was harvested earlier than storage F and tubers from storage E were harvested from green vines. Skin set develops best under dead vines (Lulai 2007) and it was evident from the skinned conditions of the tubers that skin set was an issue with the tubers stored in storage E. Lack of skin set can significantly contribute to tuber weight loss (Lulai 2007). Conversely, the tubers stored in storage F were not dug under green foliage. Foliage was removed two weeks prior, an interval large enough to enhance skin set in the tubers (Kempenaar and Struik 2007).

It is documented that CW has lower Fusarium dry rot (*Fusarium sambucinum* or *F. cooerulium*) resistance and higher weight loss in storage than RB (Brandt et al. 2013). Since weight loss at the end of long term storage of CW tubers was not affected by temperature, it may be more beneficial to cure CW at a higher temperature. This data shows the benefits of curing CW at warmer temperatures, even above 12.8°C. The processing quality was good when tubers were cured at 12.8°C, but was even better in the tubers cured at the warmest curing temperature. Further investigation into the impact of curing temperature on disease development is necessary to determine further implications of warm and cold curing temperatures on disease development in CW storage.

Accumulated Heat Units

The use of AHU in potato storage management is still unclear, but this data suggests the possibility of application in the potato industry. The application of AHU to WHU gives a good indication in how cultivars may differ in wound healing ability and also how temperature impacts the wound healing process differently in cultivars. Figures 3, 10 and 17 suggest the three cultivars, RB, RR and CW, greatly differ in their ability to wound heal.

The WHU of RB are much higher than those of RR and CW. Ranger Russet and CW clearly do not have the same resistance to weight loss as RB after equivalent amounts of curing as the WHU unit Y axis on RR doesn't increase above 14 and CW doesn't increase above 12. In comparison, RB WHU reaches 12 WHU at approximately 250 AHU. These graphs indicate the wound healing ability for RB is stronger than RR or CW. Hence, using RB as the basis for wound healing recommendations to cover all cultivars in the potato industry is inappropriate. The reasons why RB has the ability to wound heal as well as it does compared to other cultivars was not evaluated in this study and has yet to be discovered elsewhere. Furthermore, the difference in the wound healing ability of these three cultivars shows that temperature does not affect all cultivars the same during the wound healing process, reinforcing the need for cultivar specific early storage temperature recommendations.

AHU may have a more appropriate use in helping growers manage harvest pulp temperatures, more so than using AHU to determine curing intervals. If potatoes are brought into storage with warm pulp temperatures and ramped down slowly to avoid condensation and sugar accumulation (Bethke 2014), the heat accumulated during this ramping may be equivalent to the heat accumulated if tuber pulp temperatures were ideal and a common curing interval was selected. For example, the AHU for tubers brought in with harvest pulp temperatures of 18.3°C may need to be ramped down to avoid disease development. If ramping occurs at 0.3°C per day, these tubers would reach an AHU equivalent to a curing period of 14 days at 12.8°C (179 AHU, Figure A.14) after 11 days of ramping. After 11 days of ramping, the tubers would only be at 15.3°C. By the time these

tubers reached the 12.8°C curing temperature, they will have accumulated 311 heat units. Furthermore, if these tubers were allowed to continue ramping to an 8.9°C holding temperature, they will have accumulated 462 heat units by the time the temperature reaches the holding point (Figure A.14). The same scenario can be applied to cold temperatures. If tubers are brought to storage with harvest pulp temperatures of 7.2°C and warmed to 12.8°C to cure, AHU would be 200 by the time the tubers reached the curing temperature. A study holding the AHU constant rather than temperature may provide additional insight on the impact of harvest tuber pulp temperatures on early storage management.

To further discuss the use of heat units in the application of AHU in potato early storage management, the curing situations used in this study can be used to demonstrate the accumulation of heat from a curing period plus the additional heat accumulated from the ramping period. Figure A.15 is a graph of the AHU of the three curing regimens of study 2 and illustrates the dramatic difference of AHU between the three curing temperatures (14 days curing) and ramping time (0.3°C/day) required for each temperature to reach the holding temperature of 8.9°C. This graph can also be used as a visual representation of why suberization occurs more quickly at higher temperatures (Thomas 1982); heat will increase enzymatic processes up to a certain point, including the biosynthesis of suberin (Franke and Schreiber 2007).

The use of AHU in potato storage management should be discussed based on the results of the data presented in this document. Temperature is one of the most important

factors in early and long term storage of potatoes and using heat units to quantify temperature could be a useful application for growers.

CONCLUSIONS

There is little benefit, to curing RB, RR or CW at 7.2°C, implicating the importance of managing cold harvest pulp temperatures to facilitate effective wound healing. Short storage intervals of these cultivars resulted in long term negative consequences to processing quality and storability. Curing temperatures near 7.2°C may not provide adequate disease control in storage of potatoes due to the lack of wound healing occurring at this temperature. Furthermore, pulp temperatures near 7.2°C may result in increased weight loss in long term storage. Warmer curing temperatures will help maintain processing quality and favor suberization, however prolonged duration may favor disease development.

Since WHU is the unit for resistance to water loss in the potato tissue, WHU indicate the amount of suberin, wax and phellem layers present in wound healed tissue; waxes providing the primary defense against water loss in wound periderm (Bernards 2002). Further research may provide information on whether different cultivars deposit the same amount of wax in primary suberization, resulting in a difference in WHU between cultivars. Moreover, disease studies which use WHU may provide insight into the process of primary suberization and the differences between cultivars for this process. Does CW deposit the aliphatic components of suberin more slowly than other cultivars such as RB, leading to a higher susceptibility to Fusarium dry rot? Are individual components of suberin influenced by storage conditions differently? Answers to these questions would provide an

explanation of why cultivars differ in resistance to weight loss and pathogen infection and may lead to more specific wound healing recommendations for each cultivar.

The current industry recommendation of curing potatoes at 10°C to 12.8°C for 2 to 3 weeks is most applicable to RB, but may not be appropriate for RR and CW. The large difference in WHU in RB compared to RR and CW suggest that the two latter cultivars may need specific recommendations to favor primary suberization. Further research is needed comparing the WHU of all cultivars. Directly comparing cultivars may provide insight on the differences in storability of cultivars that has remained enigmatic.

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APPENDIX

Table A.1. Wound healing units of bud and stem end cores of three cultivars.

CULTIVAR	CORE LOCATION	[1]WHU	CONFIDENCE INTERVAL
A02062-1TE	Bud	9.92	(7.79, 12.62)
A02062-1TE	Stem	9.59	(7.54, 12.19)
A02507-2LB	Bud	5.30	(4.12, 6.82)
A02507-2LB	Stem	5.24	(4.07, 6.74)
RUSSET BURBANK	Bud	6.23	(4.80, 8.08)
RUSSET BURBANK	Stem	6.54	(5.06, 8.46)

[1]wound healing units

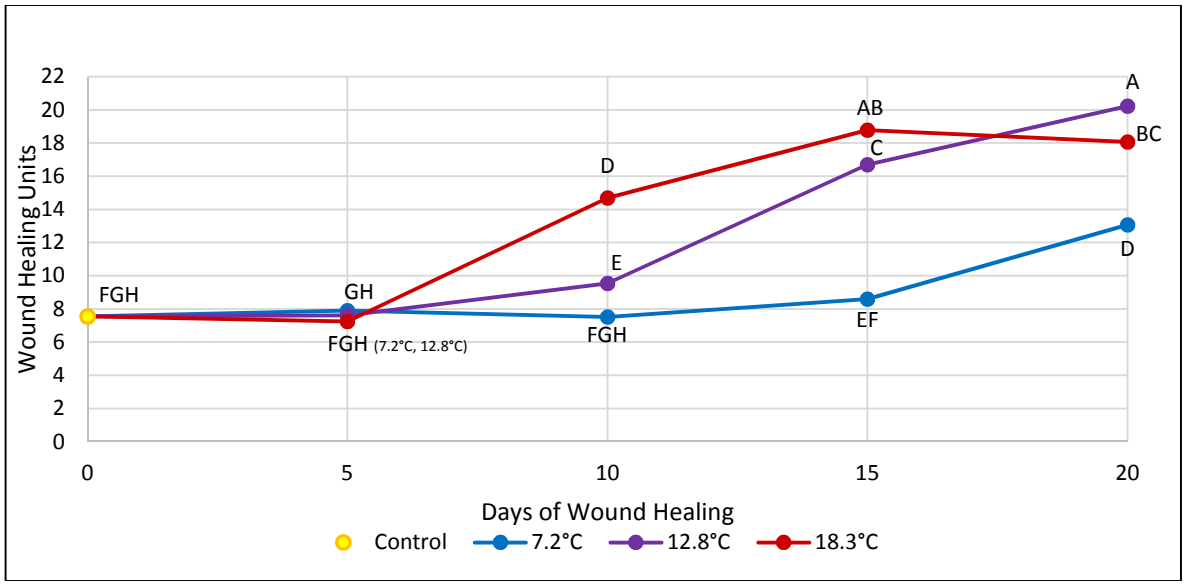

Figure A.1. Wound healing units of Russet Burbank potato cores cured at 7.2°C, 12.8°C or 18.3°C for 0, 5, 10, 15, or 20 days in 2014-15 experiment 1. Some cores with noted decay were omitted. A control consisted of freshly cored tissue. At each curing interval, cores were force desiccated (65°C, 120 minutes) and percent weight loss recorded. Wound healing units were calculated as inverse of slope of the weight loss line. Different letters indicate significant differences atP≤0.05.

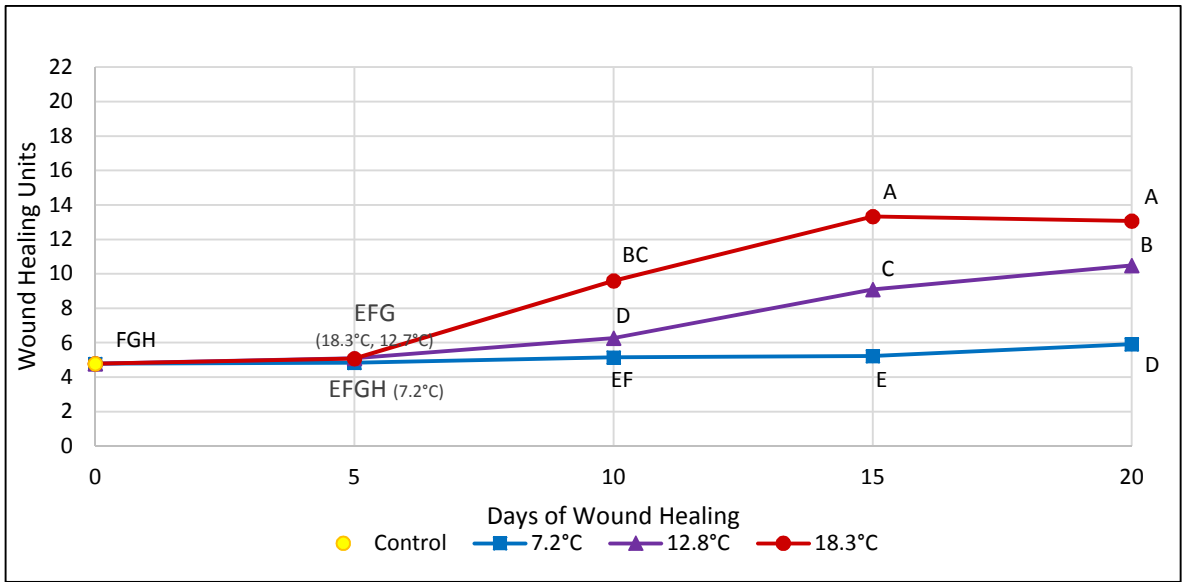

Figure A.2. Wound healing units of Russet Burbank potato cores cured at 7.2°C, 12.8°C or 18.3°C for 0, 5, 10, 15, or 20 days in 2014-15 experiment 2. Cores with a 'Cores Visual Appearance Rating' of 3 (Table 2) were omitted. A control consisted of freshly cored tissue. At each curing interval, cores were force desiccated (65°C, 120 minutes) and percent weight loss recorded. Wound healing units were calculated as inverse of slope of the weight loss line. Different letters indicate significant differences at P≤0.05.

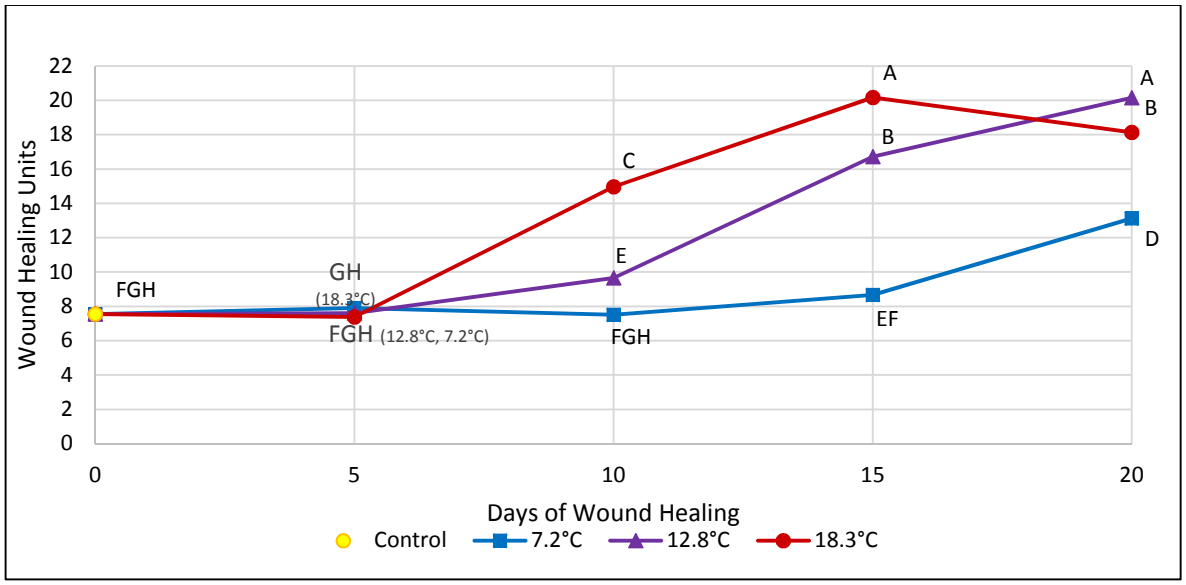

Figure A.3. Wound healing units of Russet Burbank potato cores cured at 7.2°C, 12.8°C or 18.3°C for 0, 5, 10, 15, or 20 days in 2014-15 experiment 1. All cores with noted decay were omitted. A control consisted of freshly cored tissue. At each curing interval, cores were force desiccated (65°C, 120 minutes) and percent weight loss recorded. Wound healing units were calculated as inverse of slope of the weight loss line. Different letters indicate significant differences at P≤0.05.

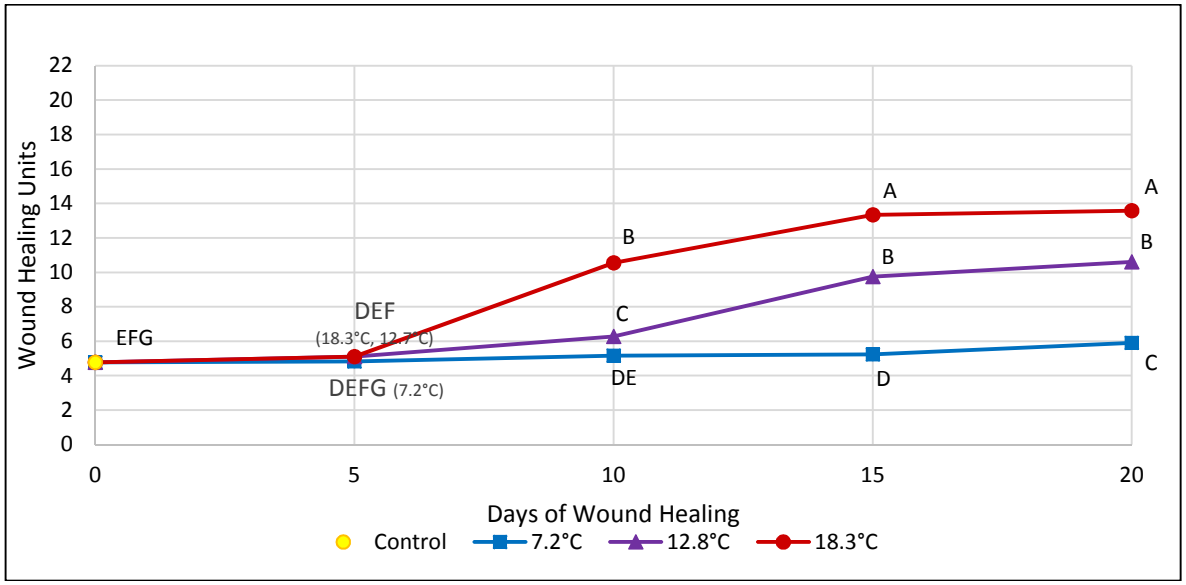

Figure A.4. Wound healing units of Russet Burbank potato cores cured at 7.2°C, 12.8°C or 18.3°C for 0, 5, 10, 15, or 20 days in 2014-15 experiment 2. Cores with a 'Core Visual Appearance Rating of 2 and 3 (Table 2) were omitted. A control consisted of freshly cored tissue. At each curing interval, cores were force desiccated (65°C, 120 minutes) and percent weight loss recorded. Wound healing units were calculated as inverse of slope of the weight loss line. Different letters indicate significant differences at P≤0.05.

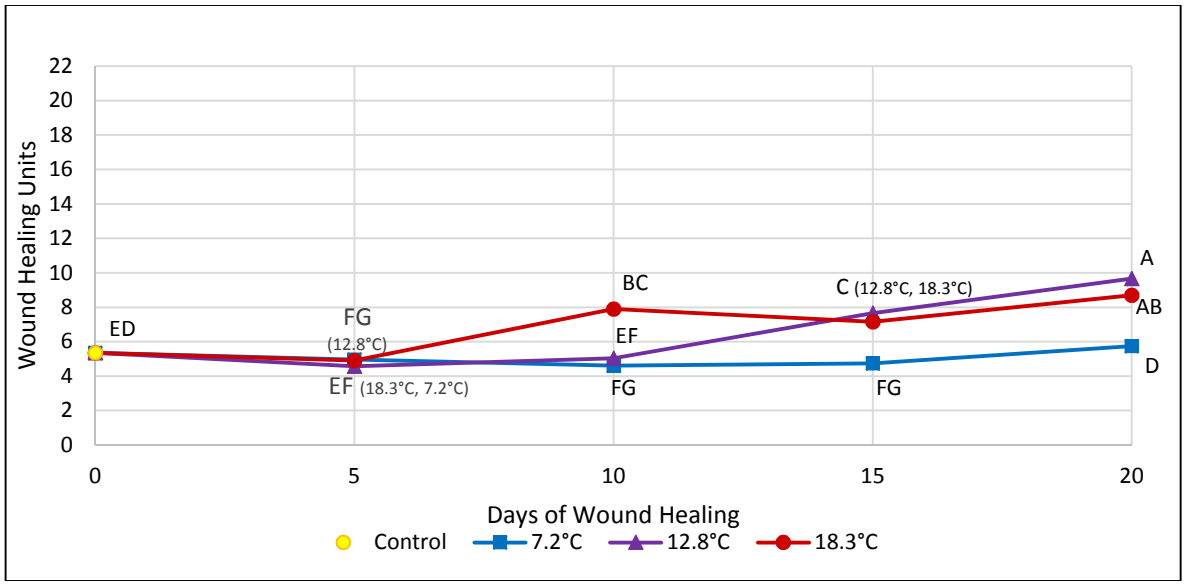

Figure A.5. Wound healing units of Ranger Russet potato cores cured at 7.2°C, 12.8°C or 18.3°C for 0, 5, 10, 15, or 20 days in 2014-15 experiment 1. Some cores with noted decay were omitted. A control consisted of freshly cored tissue. At each curing interval, cores were force desiccated (65°C, 120 minutes) and percent weight loss recorded. Wound healing units were calculated as inverse of slope of the weight loss line. Different letters indicate significant differences at P≤0.05.

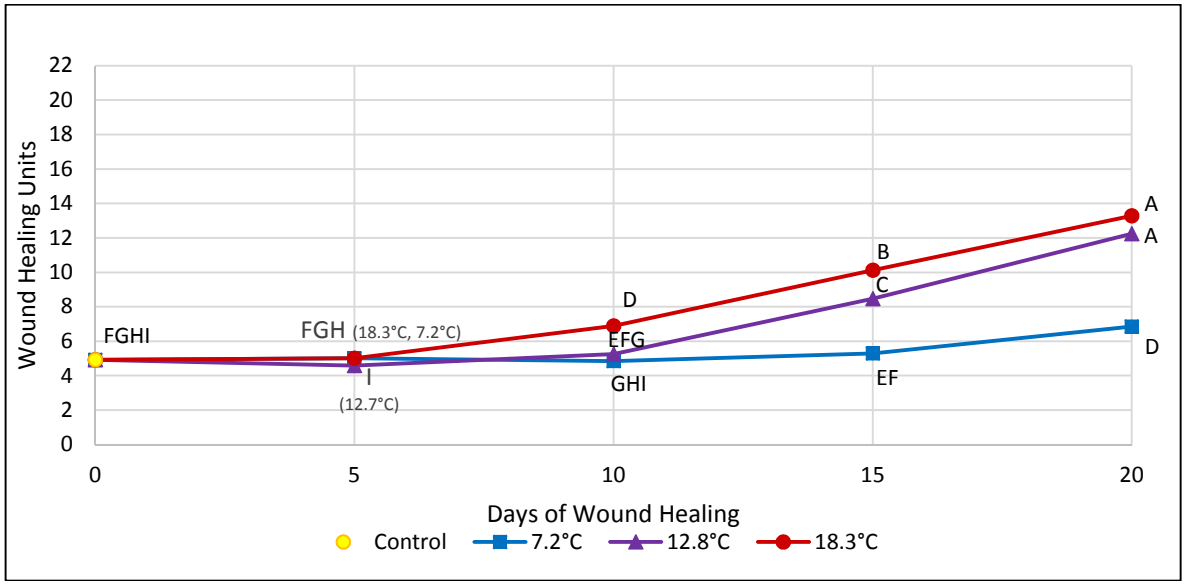

Figure A.6. Wound healing units of Ranger Russet potato cores cured at 7.2°C, 12.8°C or 18.3°C for 0, 5, 10, 15, or 20 days in 2014-15 experiment 2. Cores with a 'Cores Visual Appearance Rating' of 3 (Table 2) were omitted. A control consisted of freshly cored tissue. At each curing interval, cores were force desiccated (65°C, 120 minutes) and percent weight loss recorded. Wound healing units were calculated as inverse of slope of the weight loss line. Different letters indicate significant differences at P≤0.05.

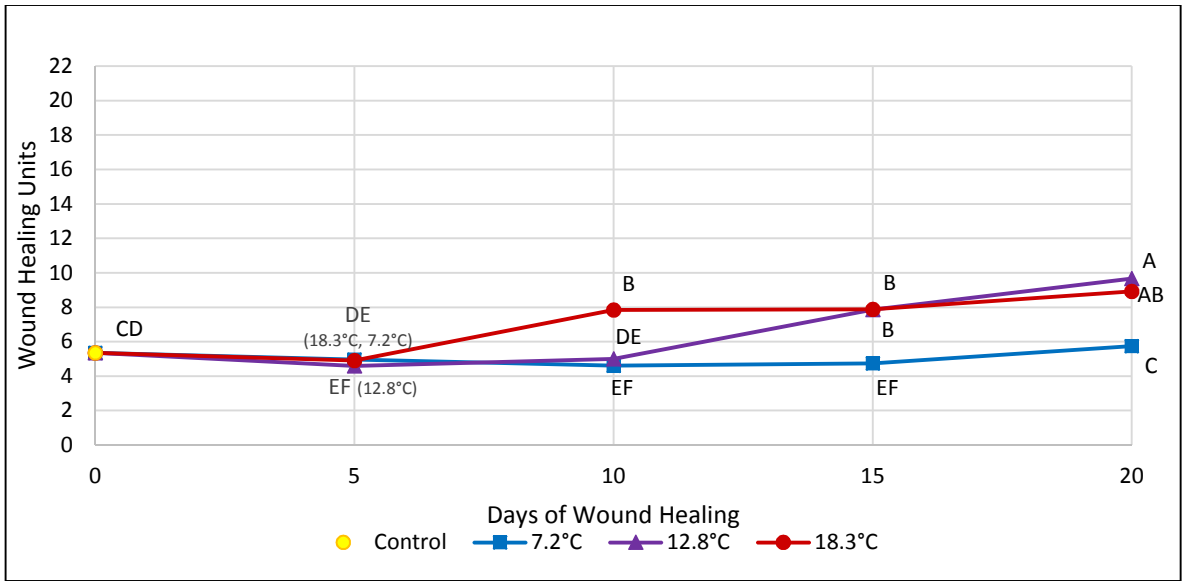

Figure A.7. Wound healing units of Ranger Russet potato cores cured at 7.2°C, 12.8°C or 18.3°C for 0, 5, 10, 15, or 20 days in 2014-15 experiment 1. All cores with noted decay were omitted. A control consisted of freshly cored tissue. At each curing interval, cores were force desiccated (65°C, 120 minutes) and percent weight loss recorded. Wound healing units were calculated as inverse of slope of the weight loss line. Different letters indicate significant differences at P≤0.05.

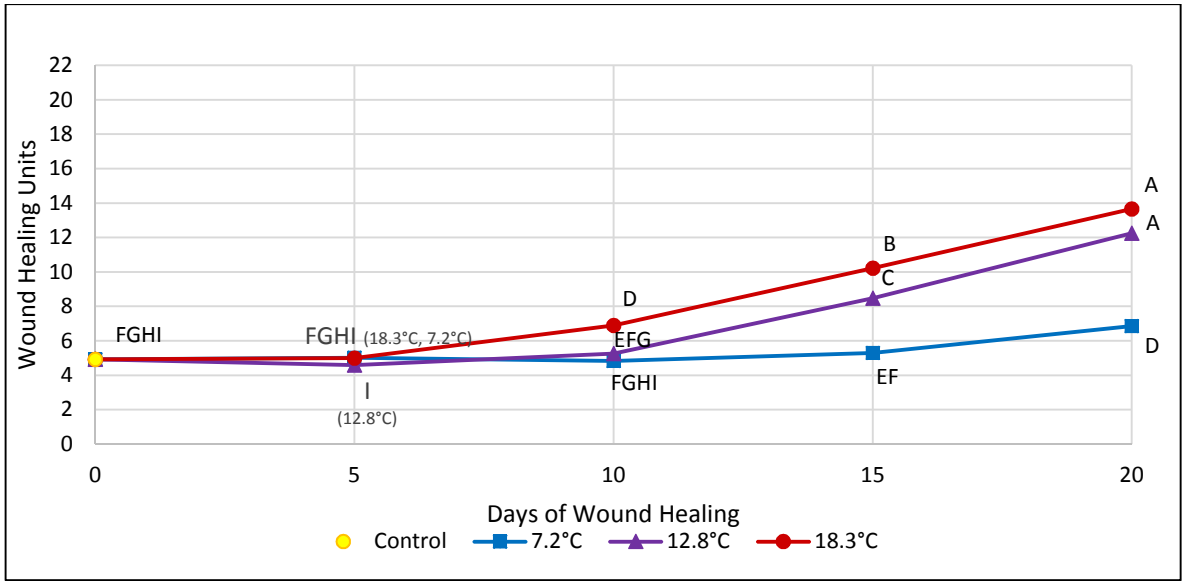

Figure A.8. Wound healing units of Ranger Russet potato cores cured at 7.2°C, 12.8°C or 18.3°C for 0, 5, 10, 15, or 20 days in 2014-15 experiment 2. Cores with a 'Core Visual Appearance Rating of 2 and 3 (Table 2) were omitted. A control consisted of freshly cored tissue. At each curing interval, cores were force desiccated (65°C, 120 minutes) and percent weight loss recorded. Wound healing units were calculated as inverse of slope of the weight loss line. Different letters indicate significant differences at P≤0.05.

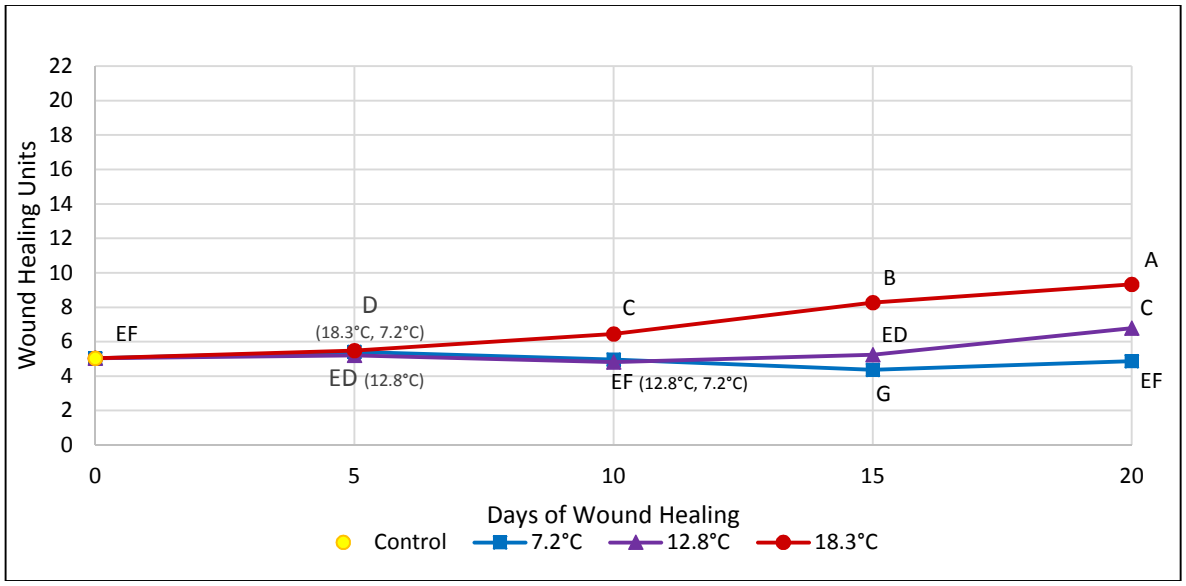

Figure A.9. Wound healing units of Clearwater Russet potato cores cured at 7.2°C, 12.8°C or 18.3°C for 0, 5, 10, 15, or 20 days in 2014-15 experiment 1. Some cores with noted decay were omitted. A control consisted of freshly cored tissue. At each curing interval, cores were force desiccated (65°C, 120 minutes) and percent weight loss recorded. Wound healing units were calculated as inverse of slope of the weight loss line. Different letters indicate significant differences at P≤0.05.

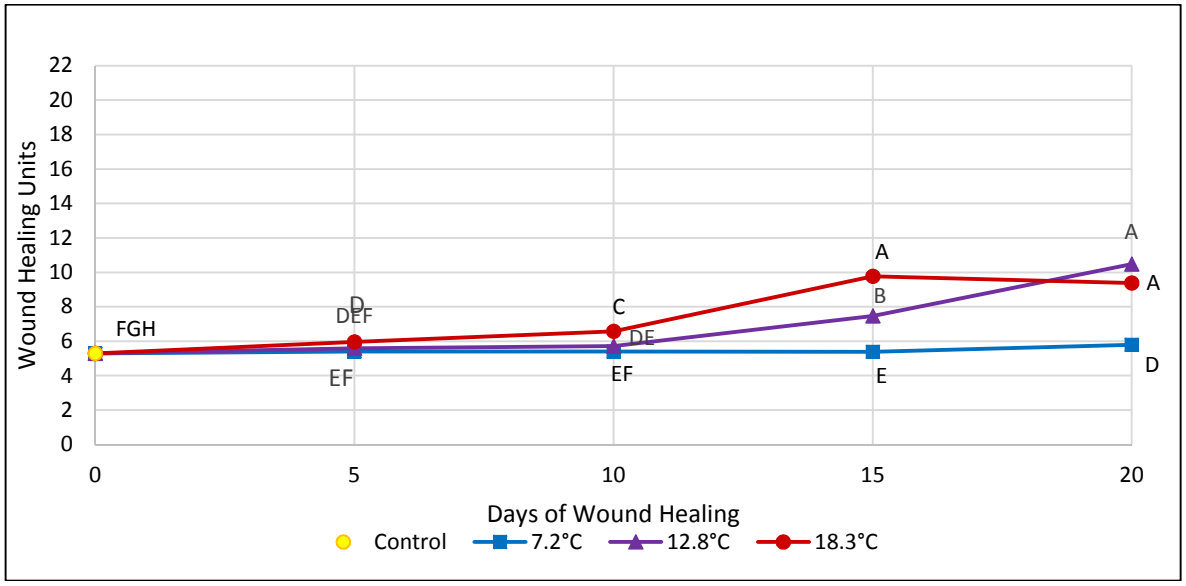

Figure A.10. Wound healing units of Clearwater Russet potato cores cured at 7.2°C, 12.8°C or 18.3°C for 0, 5, 10, 15, or 20 days in 2014-15 experiment 2. Cores with a 'Cores Visual Appearance Rating' of 3 (Table 2) were omitted. A control consisted of freshly cored tissue. At each curing interval, cores were force desiccated (65°C, 120 minutes) and percent weight loss recorded. Wound healing units were calculated as inverse of slope of the weight loss line. Different letters indicate significant differences at P≤0.05.

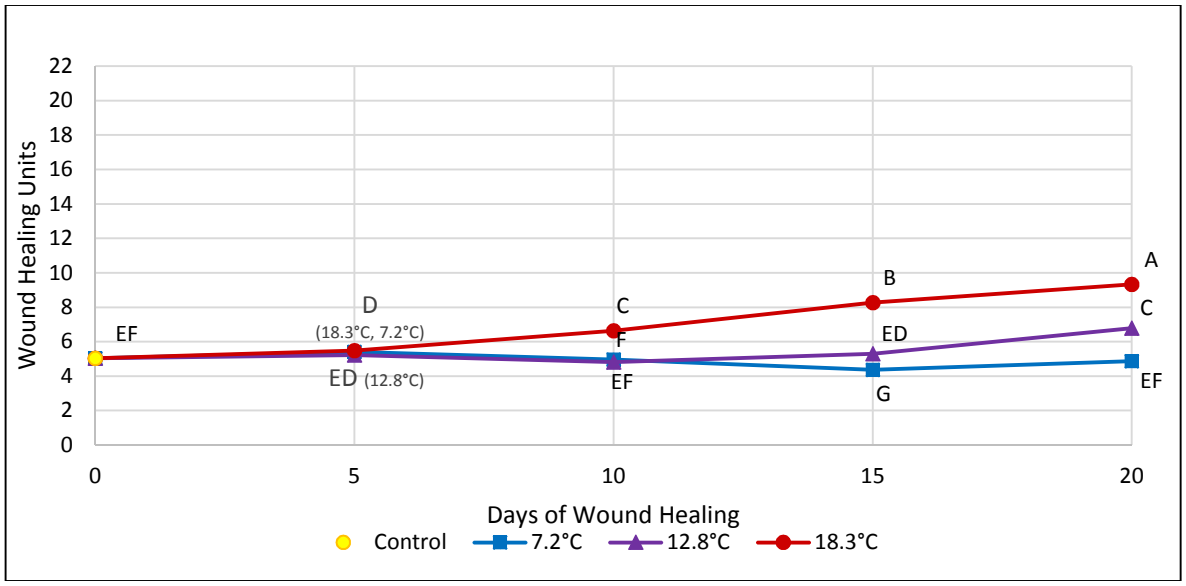

Figure A.11. Wound healing units of Clearwater Russet potato cores cured at 7.2°C, 12.8°C or 18.3°C for 0, 5, 10, 15, or 20 days in 2014-15 experiment 1. All cores with noted decay were omitted. A control consisted of freshly cored tissue. At each curing interval, cores were force desiccated (65°C, 120 minutes) and percent weight loss recorded. Wound healing units were calculated as inverse of slope of the weight loss line. Different letters indicate significant differences at P≤0.05.

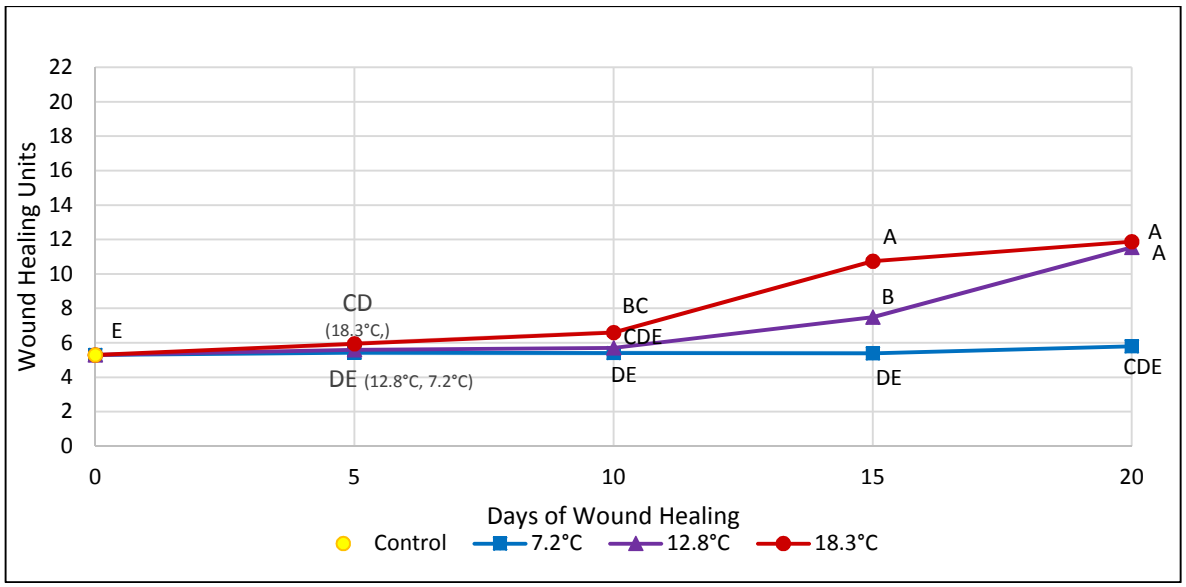

Figure A.12. Wound healing units of Clearwater Russet potato cores cured at 7.2°C, 12.8°C or 18.3°C for 0, 5, 10, 15, or 20 days in 2014-15 experiment 2. Cores with a 'Core Visual Appearance Rating of 2 and 3 (Table 2) were omitted. A control consisted of freshly cored tissue. At each curing interval, cores were force desiccated (65°C, 120 minutes) and percent weight loss recorded. Wound healing units were calculated as inverse of slope of the weight loss line Different letters indicate significant differences at P≤0.05.

Table A.2. ANOVA results of incremental weight loss effects and interactions of Russet Burbank, Ranger Russet and Clearwater Russet potatoes. Tubers were held at the Potato Storage Research Building at the Kimberly Research and Extension Center in Kimberly, Idaho in 2014-2015. Tubers were cured at 7.2°C, 12.8°C or 18.3°C for 14 days (95% relative humidity) then ramped +/- 0.3°C/day until the holding temperature of 8.9°C was reached. Tubers were held at 8.9°C until 205 days after harvest.

EFFECT	DF	PR > F
VARIETY	2	<0.0001
TEMPERATURE	2	<0.0001
REPLICATE	3	0.0035
DAH[1]	12	<0.0001
VARIETY*TEMPERATURE	4	0.0013
VARIETY*REPLICATE	6	0.0100
VARIETY*DAH	24	<0.0001
TEMPERATURE*REPLICATE	6	0.0005
TEMPERATURE*DAH	24	<0.0001
REPLICATE*DAH	36	0.6994
VARIETY*TEMPERATURE*DAH	48	0.0051

[1]DAH=Days after harvest

Table A.3. ANOVA results of accumulated weight loss effects and interactions of Russet Burbank, Ranger Russet and Clearwater Russet potatoes. Tubers were held at the Potato Storage Research Building at the Kimberly Research and Extension Center in Kimberly, Idaho in 2014-2015. Tubers were cured at 7.2°C, 12.8°C or 18.3°C for 14 days (95% relative humidity) then ramped +/- 0.3°C/day until the holding temperature of 8.9°C was reached. Tubers were held at 8.9°C until 205 days after harvest.

EFFECT	DF	PR > F
VARIETY	2	<0.0001
TEMPERATURE	2	<0.0001
REPLICATE	3	<0.0001
DAH[1]	12	<0.0001
VARIETY*TEMPERATURE	4	<0.0001
VARIETY*REPLICATE	6	<0.0001
VARIETY*DAH	24	<0.0001
TEMPERATURE*REPLICATE	6	<0.0001
TEMPERATURE*DAH	24	<0.0001
REPLICATE*DAH	36	0.9950
VARIETY*TEMPERATURE*DAH	48	0.9999

[1]DAH=Days after harvest

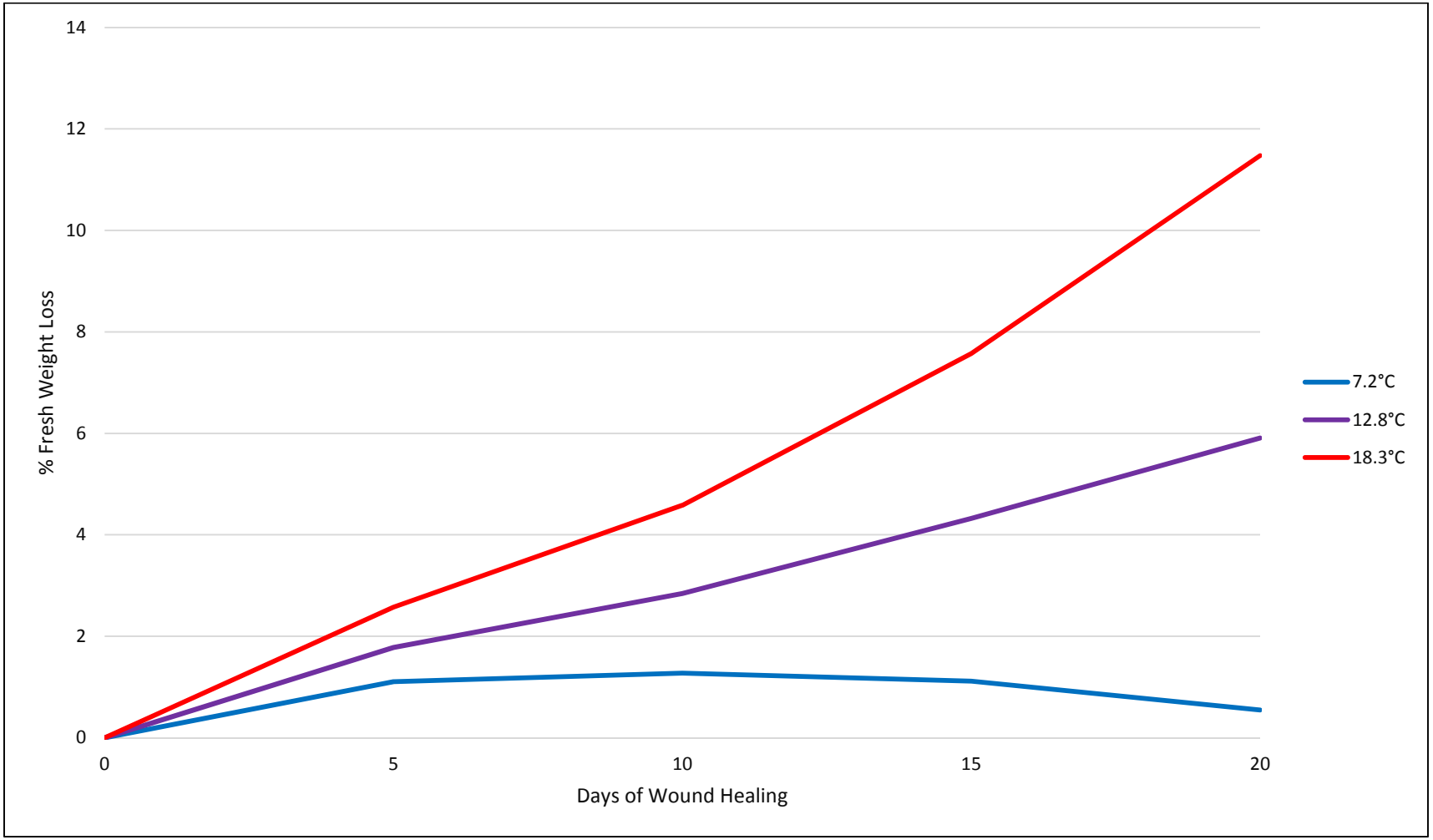

Figure A.13. Percent weight loss of Russet Burbank potato cores cured in incubators for 0, 5, 10, 15 or 20 days. Percent weight loss was calculated from the fresh weight of the core at the time the sample was taken from the tuber and the wound healed core weight.

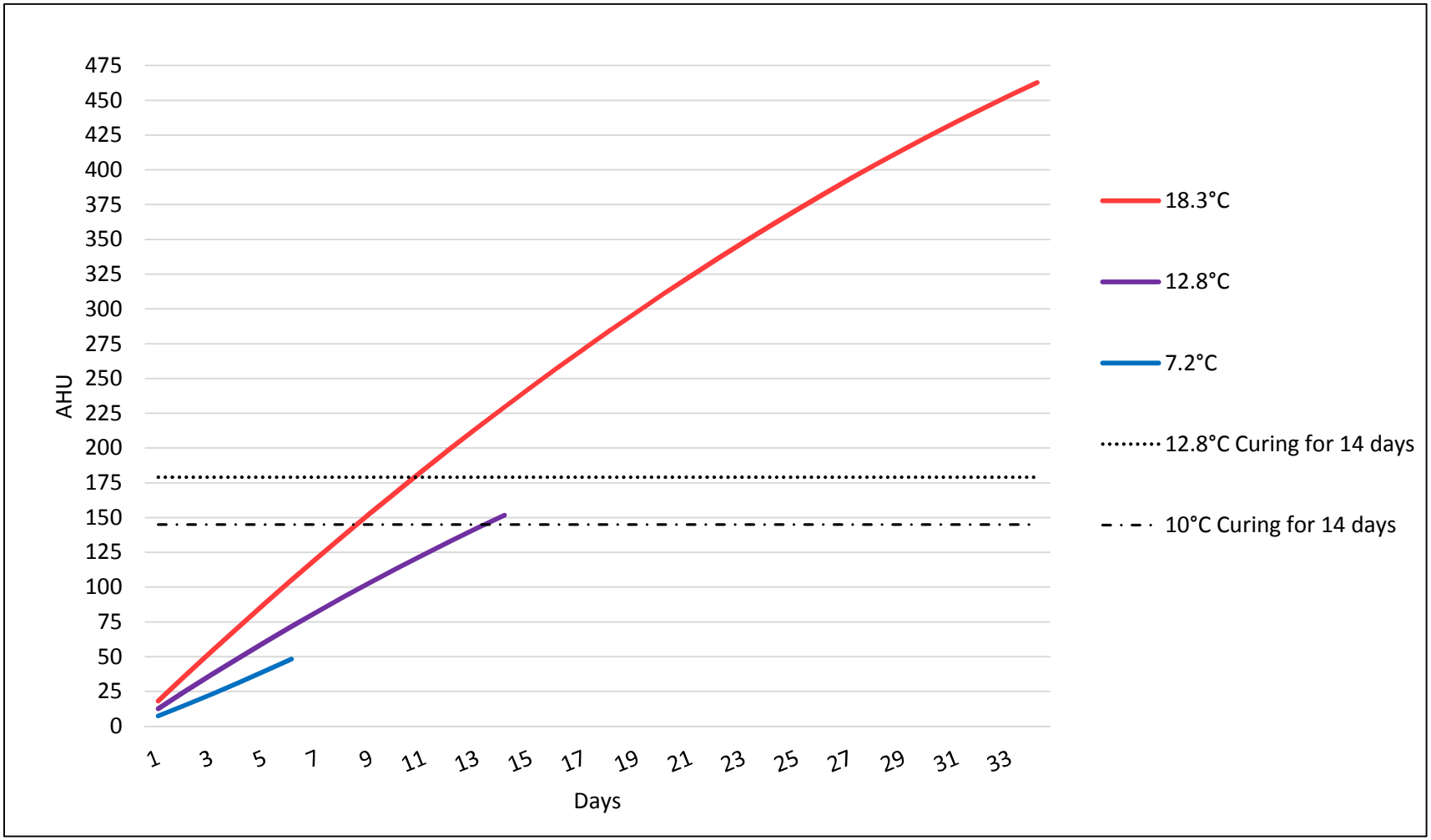

Figure A.14. Accumulated heat units (AHU) of three theoretical pulp temperatures ramped (0.3°C/day) to the holding temperature of 8.9°C without being held at a curing temperature.

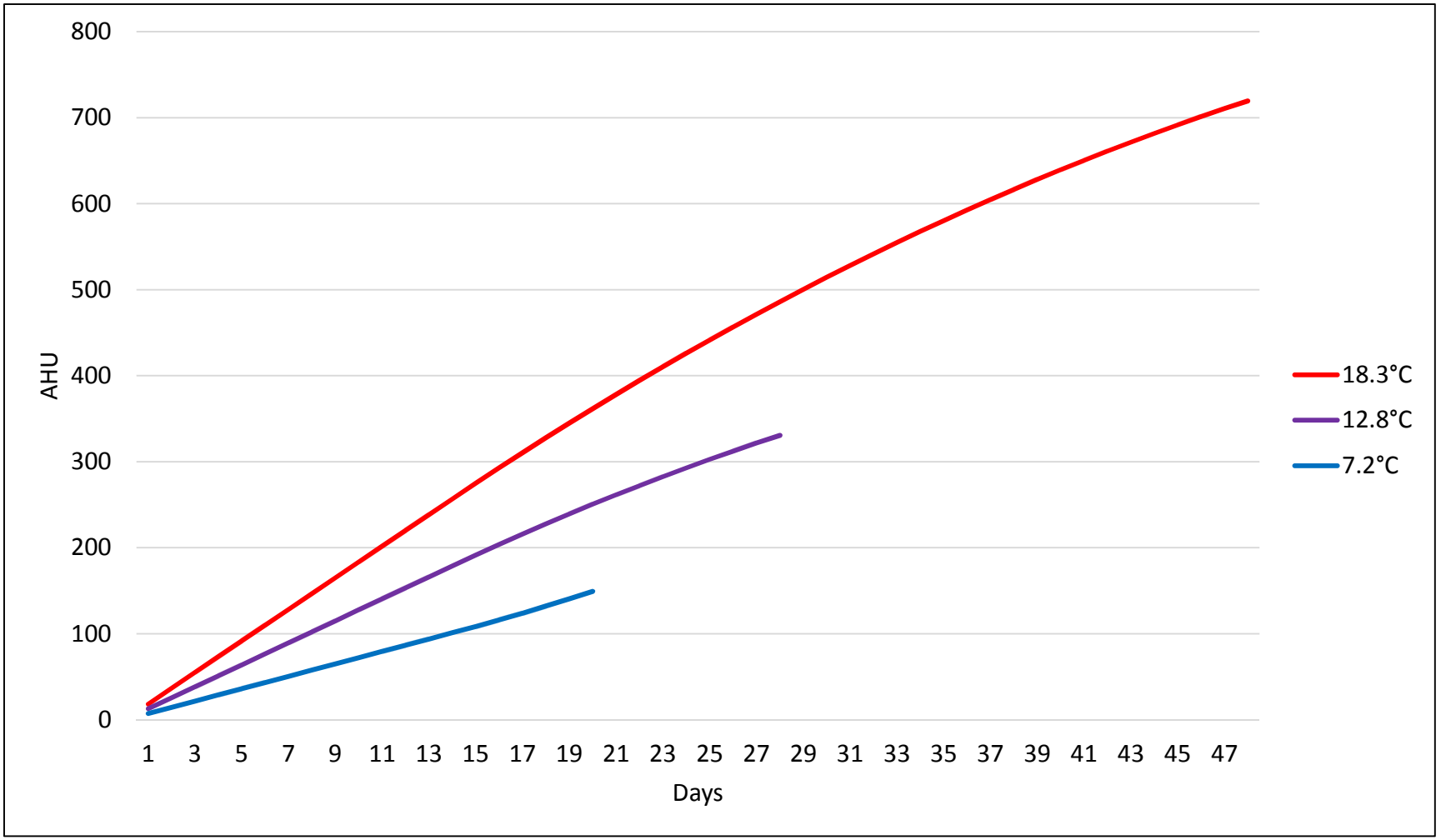

Figure A.15. Accumulated heat units (AHU) of three curing temperatures, 7.2, 12.8 and 18.3°C and the ramping regimen of 0.3°C/day.