Assessing the Impact of Heat Stress on Tuber Quality

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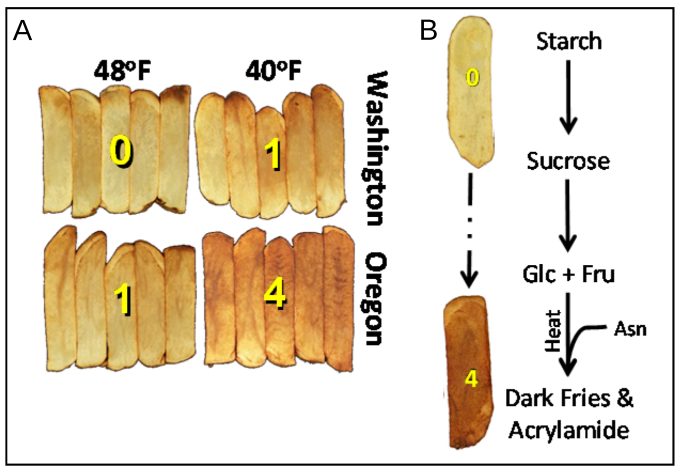
Introduction & Background

Environmental and cultural conditions during growth interact to affect postharvest quality and storability of potatoes. Isolating the effects of various in-season abiotic stresses (e.g., heat) on subsequent retention of postharvest quality is challenging, given the myriad variables that interact to affect crop growth and development in a production setting.

Processing quality in potatoes is largely determined by specific gravity (dry matter, starch content) and reducing sugar content (glucose and fructose). Tubers with optimal storability have high gravity and low reducing sugars at harvest and will maintain this relationship when stored at 48°F. Storage at lower temperature (e.g., 40°F) can reduce disease pressure, prolong dormancy, and extend marketability of potatoes; however, processing quality (French fries and chips) will be compromised by the cold-induced breakdown of starch to reducing sugars in a process known as low temperature sweetening (LTS) (Fig. 1). A major goal of potato breeding programs is to develop varieties with LTS resistance.

Fig. 1: (A) French fries prepared from clone A00324-1 (PNW Variety Development Program) grown in Othello, WA and Hermiston, OR and stored for 3 months. Numbers in yellow are the USDA fry color ratings (0-4, light to dark). (B) LTS - Starch is catabolized to reducing sugars which react with asparagine and other amino acids during frying to form acrylamide and dark fry color.



Stresses during production can affect sweetening during storage. Decades of research have shown that potatoes grown in the southern Columbia Basin at the Hermiston Agricultural Research & Extension Center (OR), as part of the Northwest Potato Variety Development Program, diminish in quality more rapidly than the same clones grown in WA and ID, regardless of storage temperature. This deterioration may be a consequence of higher growing temperatures and the effects of heat stress on the sweetening process. A focus of our studies is to determine the effects of soil temperature and thus tuber temperature on retention of postharvest quality.

Objectives

1. Develop methods to control soil temperatures at different stages of tuber development – bulking and maturation.
2. Assess the effects of soil temperature on yield and retention of processing quality in a LTS resistant (Premier Russet) and susceptible (Ranger Russet) cultivar.

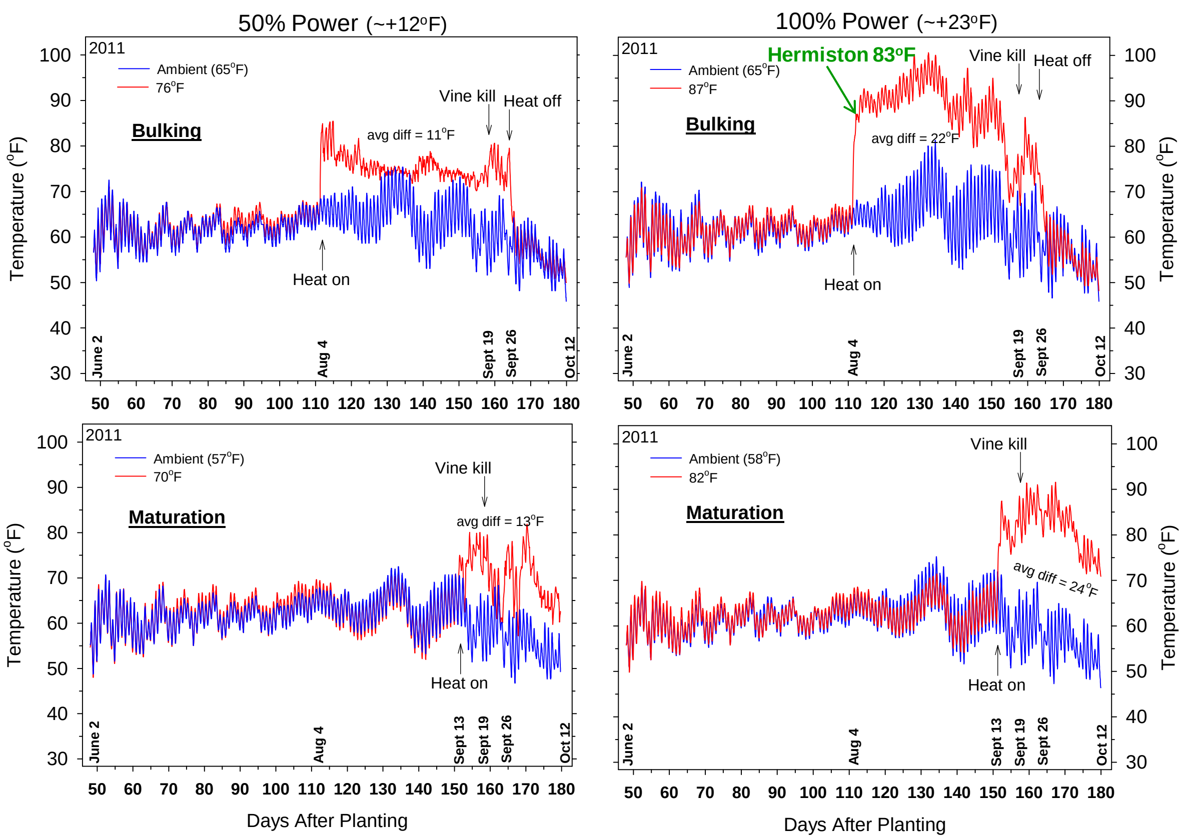
Results

Regulating Soil and Tuber Temperature

Soil heating cables (200 ft) were installed in-furrow in plots at Othello, WA to control temperature (Fig. 2). Two cables were placed at seed depth (8 inches), seed was hand planted (10-in spacing), and two upper cables were installed during hilling. Each 200 ft row was planted half with Premier Russet and half with Ranger Russet on April 15. These two cultivars were chosen because they represent extremes in ability to resist low temperature sweetening (LTS) during storage; Premier is highly resistant and Ranger is highly susceptible.

Soil temperature was modulated with rheostats set at 50% or 100% power and recorded hourly with Watchdog temperature recorders (probes at 5-in depth) (Fig. 2). Heat was applied separately to rows during the bulking (111-164 DAP, Aug 4 to Sept 26) and maturation (151-180 DAP, Sept 13 to Oct 12) phases of development. Differences in temperature between heated and control (ambient) plots averaged +12 and +23°F for rows receiving 50 and 100% power, respectively (Fig. 2). During the bulking and maturation periods, soil temperature in the control (ambient) plots averaged 61°F compared with 73°F and 84°F in plots receiving 50 and 100% power, respectively.

Fig. 2. Four soil warming cables were installed in-furrow (far left) to ensure a uniform temperature increase across the hill. Soil temperature was increased by an average of 12 and 23°F during tuber bulking (111-164 DAP, top graphs) and maturation (151-180 DAP, bottom graphs). The soil temperature in Hermiston, OR at 111 DAP is indicated (green).



Soil temperature Affects Yield, Specific Gravity, & Sweetening in Storage

Effects of temperature on yield, gravity, process quality at harvest, tuber respiration during wound-healing, retention of process quality when challenged with storage at low temperature (39^{o}F), weight loss during storage (48^{o}F), and length of dormancy at 48^{o}F were evaluated for each cultivar.

Total yield of Premier Russet increased 17% (33.6 vs. 28.7 T/A, P<0.05) in response to +12^{o}F increase in soil temperature (from 61 to 73^{o}F) during bulking, but not during maturation (Table 1). U.S. #1 (>4 oz) yields were not affected by the +12^{o}F increase in temperature during bulking or maturation. A soil temperature of ~84^{o}F (+23^{o}F above ambient) during bulking virtually eliminated tuber yield. Vine growth during bulking in these high heat plots appeared normal through at least 118 DAP; however, vine senescence was ~80% by 139 DAP. High heat (+23^{o}F to ~84^{o}F) during maturation reduced total and U.S. #1 yields by about 15 T/A each. This decrease was partly due to enhanced tuber decay from vine kill (157 DAP) to harvest (180 DAP). The effects of higher temperatures during bulking and maturation on yield and specific gravity of Ranger (Table 2) were similar to those described for Premier.

Table 1. Effects of soil heat on yield and specific gravity of **Premier Russet** tubers in 2011 (Othello, WA). Heat was applied in-furrow during bulking (111-164 DAP) and maturation (151-180 DAP) as described in Fig. 2. Soil temperatures are expressed as the average increase above ambient (control).

Growth Period	Soil ΔT (^{o}F) (avg temp)	Yield (T/A)		Specific Gravity
		Total	U.S. #1*	
-	ambient (61^{o}F)	28.7**b**	28.7**a**	1.103**a**
Bulking	+12 (73^{o}F)	33.6**a**	29.8**a**	1.084**b**
(111-164 DAP)	+23 (84^{o}F)	3.4**d**	1.5**c**	1.050**c**
Maturation	+12 (73^{o}F)	30.2**b**	27.1**a**	1.101**a**
(151-180 DAP)	+23 (84^{o}F)	15.3**c**	11.5**b**	1.096**a**
	$LSD_{0.05}$	**2.9**	**2.9**	**0.009**

***4-ounce and greater.**

Table 2. Effects of soil heat on yield and specific gravity of **Ranger Russet** tubers in 2011 (Othello, WA). Heat was applied in-furrow during bulking (111-164 DAP) and maturation (151-180 DAP) as described in Fig. 2. Soil temperatures are expressed as the average increase above ambient (control).

Growth Period	Soil ΔT (^{o}F) (avg temp)	Yield (T/A)		Specific Gravity
		Total	U.S. #1*	
-	ambient (61^{o}F)	35.6**b**	33.9**a**	1.089**a**
Bulking	+12 (73^{o}F)	42.0**a**	36.1**a**	1.077**b**
(111-164 DAP)	+23 (84^{o}F)	1.7**d**	0.4**c**	1.058**c**
Maturation	+12 (73^{o}F)	33.1**b**	29.3**a**	1.093**a**
(151-180 DAP)	+23 (84^{o}F)	25.3**c**	21.0**b**	1.090**a**
	$LSD_{0.05}$	**5.5**	**6.5**	**0.009**

***4-ounce and greater.**

Higher soil temperature during maturation (151-180 DAP) had no effect on specific gravity of Premier (Table 1) or Ranger (Table 2). In contrast, tubers grown at 73 and 84^{o}F (61^{o}F = ambient) during bulking had lower gravities of 1.084 and 1.050, respectively, for Premier and 1.077 and 1.058 for Ranger. Higher temperatures during bulking also resulted in substantially higher rates of tuber respiration during wound-healing (20% for Ranger and 60% for Premier), shorter dormancy during storage at 48^{o}F, and greater fresh weight loss (shrink) over the initial 100 days of storage at 48^{o}F than tubers grown under ambient conditions (data not shown).

Postharvest changes in process quality (bud- and stem-end fry color) of Premier Russet tubers grown at higher temperatures during bulking and maturation were significant. Tubers were harvested 180 DAP (Oct. 12), wound-healed for 9 days at 48^{o}F, and then stored at 39^{o}F (4^{o}C) to induce sweetening (LTS) for 24 days. Control tubers resisted LTS (an inherent characteristic of Premier Russet) and produced uniformly light, USDA 0 fries throughout storage at 39^{o}F (Fig. 3). Bud-end fry color of tubers grown at 73^{o}F (+12^{o}F above ambient) during bulking was equal (USDA 0) to control tubers through 22 days of storage; it then darkened appreciably through 34 days. These tubers had severe sugar ends (stem end) at harvest, which continued to darken during storage (Fig. 3). Bud and stem end fry color of tubers grown at 73^{o}F during maturation produced uniform USDA 0 fries through 16 days of storage followed by rapid deterioration of color of both ends, resulting in non-uniform USDA 3 fries by 34 days. Maturation of tubers at 84^{o}F (+23^{o}F above ambient) resulted in sugar ends at harvest and further rapid deterioration of fry color from 16 to 34 days of storage (Fig. 3). Increased temperatures during bulking and maturation resulted in loss of the LTS-resistant phenotype of Premier Russet. These results are interesting and highly relevant to developing breeding strategies for LTS and resistance to heat.

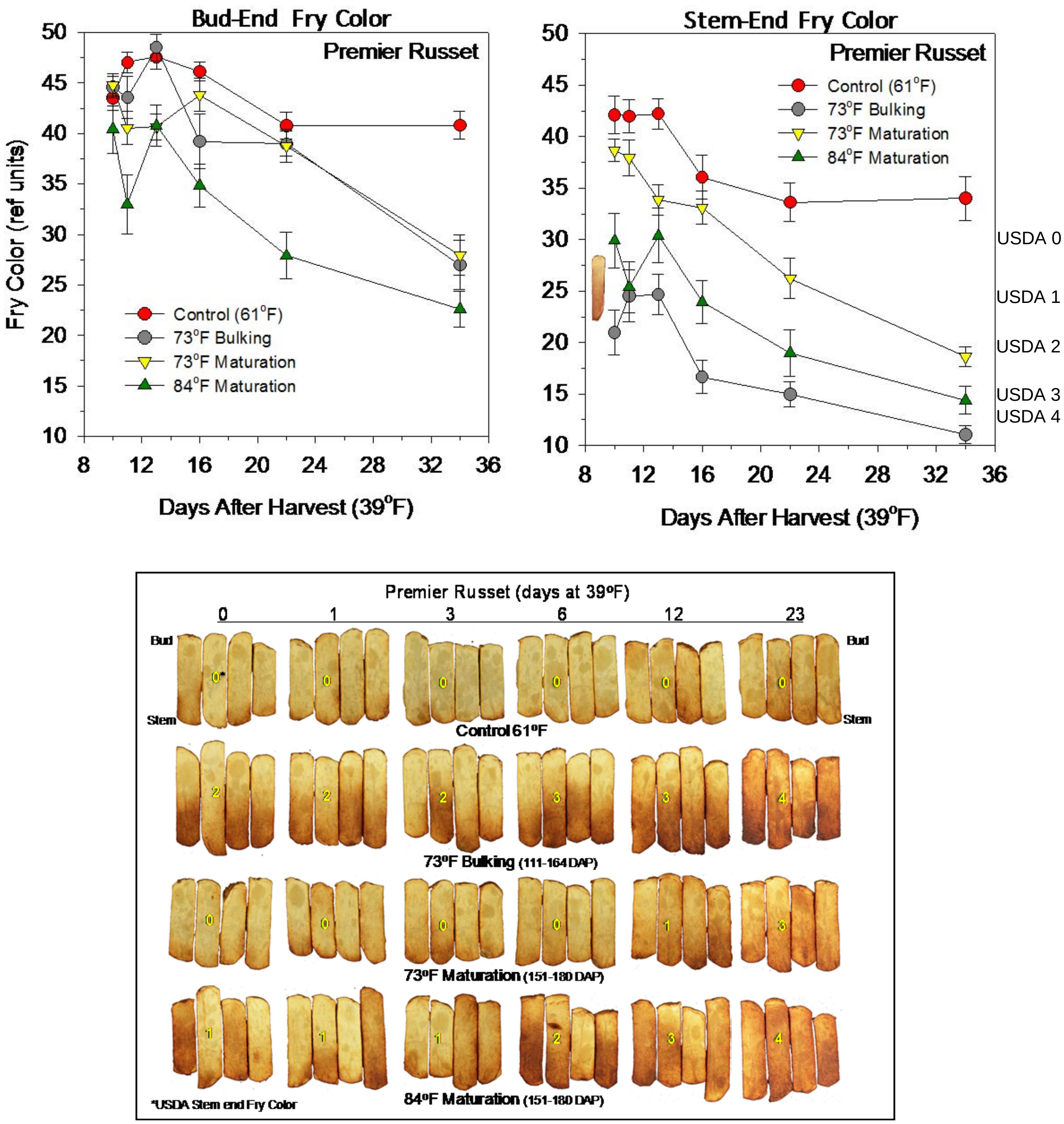
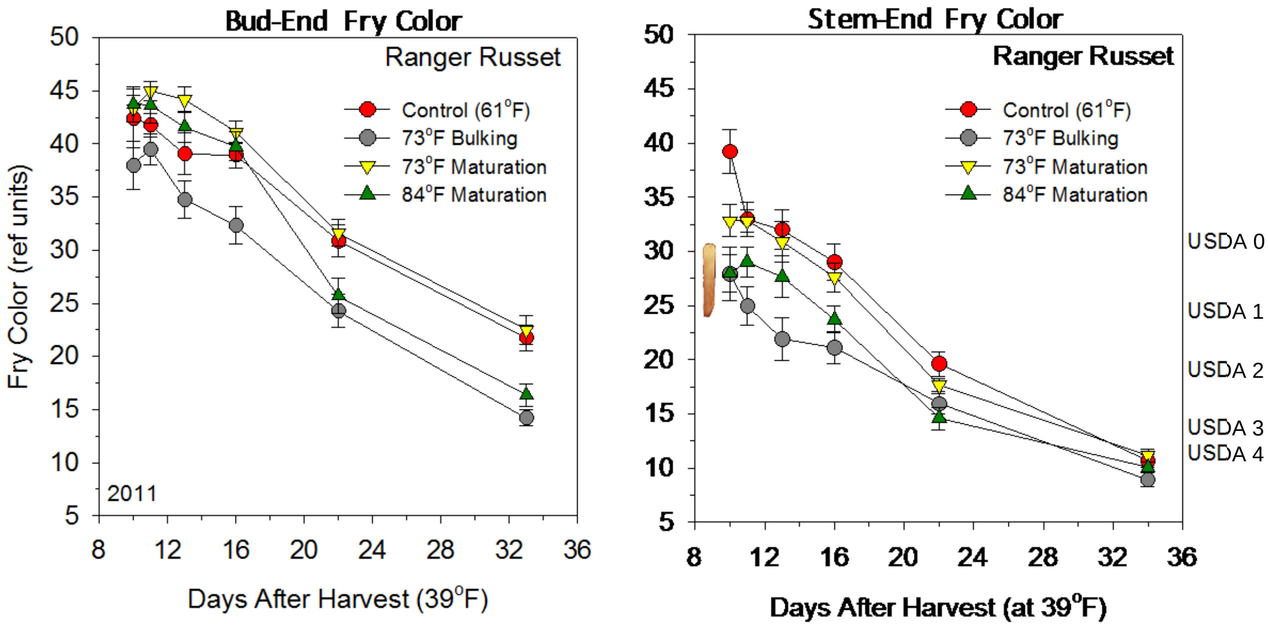


Fig. 3. Loss of processing quality (bud- and stem-end fry color) in **Premier Russet** tubers as affected by soil temperature during tuber development. Heat was applied in-furrow during the bulking and maturation phases of tuber development (see Fig. 2). Control tubers (grown at 61°F) resisted LTS (a characteristic of Premier Russet) and thus maintained light fry color. Moderate heat during bulking (73°F) induced sugar ends (dark stem ends) that increased in severity during storage at 39°F. Moderate heat during maturation (+73°F) hastened sweetening and darkening of fries during subsequent storage at 39°F, but not to the same extent as for tubers exposed to high heat during maturation. Tubers exposed to high temperature (84°F) during maturation completely lost their LTS-resistant phenotype and fry color darkened rapidly during storage at 39°F. Each fry plank is from a different tuber selected to represent the average fry color in a 16-tuber sample.

Postharvest changes in process quality (bud- and stem-end fry color) of Ranger Russet were also affected by higher temperatures during bulking and maturation. Process quality of control tubers deteriorated rapidly at 39°F (fry color darkened), reflecting the lack of resistance to LTS in this cultivar

(Fig. 4). A moderate temperature increase of +12°F during maturation (to 73°F) had no effect on deterioration of process quality. However, maturation of tubers at 84°F (+23°F above ambient) resulted in sugar ends at harvest and more rapid deterioration of bud-end fry quality from 16 to 34 days of storage (39°F) compared with controls. Plus 12°F during bulking produced tubers with sugar ends and significantly darker fries on average than all other treatments.



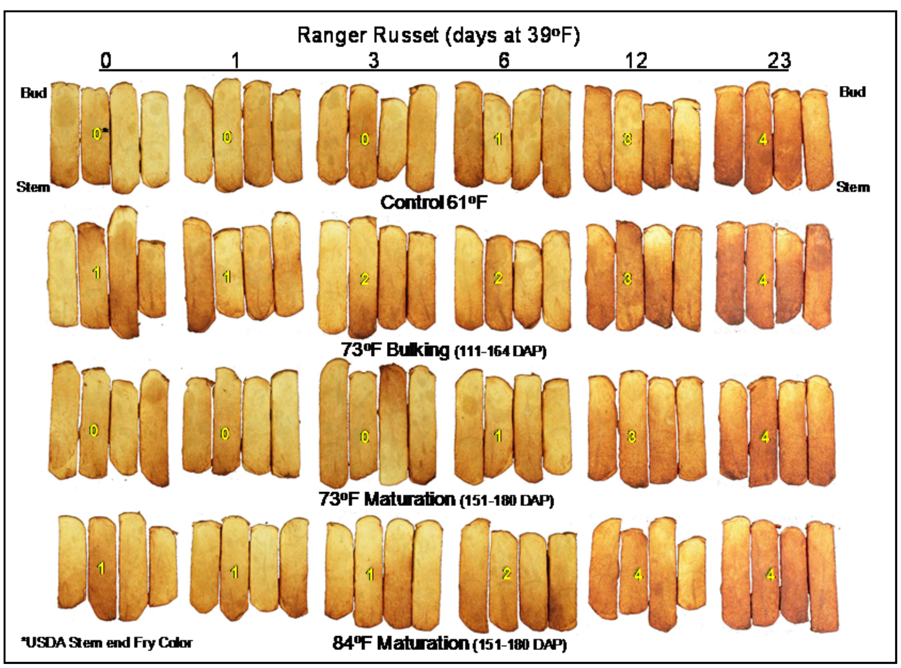


Fig. 4. Loss of processing quality (bud- and stem-end fry color) in **Ranger Russet** tubers as affected by soil temperature during tuber development. Heat was applied in-furrow during the bulking and maturation phases of tuber development (see Fig. 2). Process quality of control tubers deteriorated rapidly at 39°F (fry color darkened), reflecting the lack of resistance to LTS in this cultivar. Maturation of tubers at 73°F had no effect on deterioration of process quality. However, maturation at 84°F resulted in sugar ends and more rapid deterioration of bud-end fry quality from 16 to 34 days in storage at 39°F. Bulking at 73°F produced sugar ends and significantly darker fries than all other treatments. Each fry plank is from a different tuber selected to represent the average fry color in a 16-tuber sample.

Summary & Conclusions

- Using in-furrow soil warming cables, soil temperature was increased by an average of 12 and 23^{o}F during tuber bulking (111-164 DAP) and maturation (151-180 DAP) to study effects on tuber physiology and postharvest retention of processing quality.
- The effects of soil temperature on yield were similar for both cultivars. The nearly complete elimination of yield during bulking at 84^{o}F may reflect an inhibitory effect of the higher night temperature on tuber growth (Slater, 1968) or a general inhibition of stolon development by the higher average diurnal temperature (Struik et al., 1989).
- Increased soil temperature during bulking (vines are alive) decreased tuber specific gravity and increased reducing sugars (glc + fru), which are indicators of stress in potato tubers. This effect could reflect decreased sink strength during bulking of tubers at high temperatures (Lafta & Lorenzen, 1995).
- High temperature during maturation (vines are dead) accelerates physiological aging of tubers. Maturation of tubers at 84^{o}F enhanced tuber respiration, senescent (irreversible) sweetening, early dormancy break, and fresh weight loss during storage (data not shown).
- Soil (and thus tuber) temperature during bulking and maturation can greatly affect process quality at harvest and the ability to retain process quality during storage.
- A prolonged maturation period under dead vines in warm soils at season end can compromise retention of process quality in storage. Therefore, tubers should be harvested at physiological maturity (145-155 days after planting for most late season russet cultivars in the Columbia Basin) to avoid end of season heat stress and maximize retention of processing quality during storage.
- The inherent low temperature sweetening (LTS) resistance response of Premier Russet tubers was lost when tubers were grown at high temperature.
- Breeding strategies for more robust retention of postharvest quality and LTS resistance should consider tolerance to in-season heat stress.

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