Sweetening Responses to Storage Temperature Regimes in Relation to Tuber Maturity at Harvest

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Storage management decisions should be tailored to cultivar and the condition of the crop. The challenge for storage managers is to accurately estimate the physiological state of the incoming crop so that environmental conditions can be modified to preserve processing quality for the desired storage duration. Depending on crop condition, it may be necessary to cool and hold processing potatoes well below the cultivar-specific limits typically recommended for frozen processing. Varying the temperature regimes after wound healing could be an effective management practice to extend the processing window by controlling respiration, sprouting, shrink, and disease. An excellent review of techniques for storing 'problem' potatoes can be found on the Oregon State University Potato Information Exchange web pages at http://oregonstate.edu/potatoes/storproc.htm. Information on how frozen-processing cultivars respond to unorthodox storage temperature regimes is lacking. Such knowledge could greatly facilitate our ability to manage immature, over mature, or otherwise stressed potatoes.

With funding from the Washington State Potato Commission, we determined the responses of Ranger (RR), Umatilla Russet (UR), and Russet Burbank (RB) potatoes to a range of storage temperature regimes, in relation to tuber maturity at the time of harvest. The project had two major objectives:

1. Characterize the sweetening responses of UR, RR, and RB to different storage temperature regimes (different sequences of low and high storage temperatures) during a prolonged (250-day) storage season.
2. Evaluate the effects of tuber maturity on storability of UR, RR, and RB with a view to defining optimum temperature regimes for short-, medium-, and long-term storage of tubers of different maturities.

In general, processing quality is dictated by the extent of reducing sugar (glucose + fructose) buildup in tubers (Iritani and Weller, 1980), which in turn is affected by tuber maturity interacting with storage temperature and duration (Nelson and Sowokinos, 1983). The biochemical basis of tuber maturity has yet to be defined but is thought to relate to the relative levels of carbohydrates in tubers at harvest (Pritchard and Adam, 1992). Tubers of many cultivars can complete physical growth before attaining processing maturity. For processing purposes, tuber physiological maturity coincides with, and has thus been defined as, the window at the end of the growing season where tubers have reached maximum dry matter content (specific gravity), with minimum concentrations of sucrose and reducing sugars (Iritani and Weller 1980; Pritchard and Adam 1992). Coleman et al. (1996) used the term chemical maturity to refer to the point in tuber development when sucrose and glucose concentrations are minimal and processing quality is optimal.

Sucrose and reducing sugar levels fall during tuber bulking, gradually decreasing to their minimum as tubers mature. However, reducing sugar concentrations can also increase in tubers at the end of the season (Iritani and Weller, 1980), signaling over maturation and a propensity to sweeten prematurely during storage.

Processing quality will be retained the longest in tubers harvested at physiological maturity. Harvesting earlier or later can shorten the potential storage life, depending on the cultivar (Nelson and Shaw 1976; Nelson and Sowokinos 1983). The relative changes in sucrose, reducing sugars, and specific gravity during tuber development have yet to be characterized in RR and UR under long-season management conditions. This information is essential to defining the attainment of physiological maturity for these cultivars. The extent to which tuber maturity interacts with storage temperature to affect the processing quality of RR and UR is also unknown. Understanding how tuber maturity affects storability and processing quality may create opportunities to fine-tune postharvest handling and storage practices to improve the storability of these cultivars. Accordingly, developmentally linked changes in tuber carbohydrates and specific gravity were defined for these cultivars in the long-season growing environment of the Columbia Basin. This information was then used to estimate the windows of physiological maturity for harvest, thus maximizing the out-of-storage processing potential for early- and late-harvested crops.

The experimental approach was to:

- Characterize the attainment of physiological maturity for UR, RR, and RB by profiling the deposition of carbohydrates and tuber growth.
- Produce potatoes of different maturities for postharvest studies.
- Evaluate the suitability of different storage temperature regimes for maintaining processing quality in tubers of different maturity.

Attainment of Physiological Maturity in UR and RR

Changes in sucrose, reducing sugars, specific gravity, and tuber weight were profiled during the 2003 and 2004 growing seasons for RR and UR. The growth (bulking) rate of RR tubers averaged 1.3 oz/tuber/week in 2003 and 0.73 oz/tuber/week in 2004 from 77 to 125 days after planting (DAP) (Fig. 1). Over the same period, UR tubers bulked at 0.97 oz/tuber/week in 2003 and 0.65 oz/tuber/week in 2004 (Fig. 2). Tuber specific gravity also increased faster in 2003, reaching a maximum earlier than in 2004 for both cultivars (Figs 1 & 2, Table 1). Sucrose concentrations fell rapidly through 116 DAP with minimum concentrations in RR tubers at 157 and 122 DAP in 2003 and 2004, respectively. Minimum sucrose levels in UR tubers occurred at 157- and 167-DAP in 2003 and 2004, respectively. Trends in tuber reducing sugars were similar to those for sucrose; however, in both years the bud ends of tubers had much higher concentrations than the stem ends during early tuber growth. Reducing sugars were 0.15% (dry wt basis) or less by 110 DAP in both years and then increased in the stem ends of RR and UR tubers starting 157 DAP in 2003 and 142 DAP in 2004 (Table 1, Figs. 1 & 2).

While the end-of-season increases in reducing sugars were insufficient to affect at-harvest fry color, they indicate over-maturation and potentially an increased tendency for tubers to develop sugars prematurely in storage. Moreover, reducing sugars will likely continue to increase as harvest date is delayed, eventually affecting at-harvest processing quality. Based on these changes in tuber carbohydrates and growth, physiological maturity was attained approximately 158 DAP for both cultivars (Table 1), which coincided with maximum yields (Figs. 1 & 2).

Effect of Tuber Maturity on Storability

Umatilla, Ranger, and Russet Burbank potatoes were planted early (April 15) and late (May 15) to produce tubers of different maturities for storage studies. The rationale was twofold, first to characterize how tuber maturity affects storability and second to identify storage regimes best suited for maintaining processing quality in tubers of different maturity. Tubers were harvested September 25 – 163 and 133 DAP for the early and late plantings, respectively. Vines from the early-planted plots of all cultivars were senesced by harvest, while those from the late-plantings were mostly green. As expected, the late-planted crop produced lower yields than the early-planted crop. Effects of planting date on yield were of little concern however, as the main objective was to produce tubers of different maturity for subsequent storage studies. Eight- to ten-ounce tubers from the early- and late-planted crops were selected for storage. Physiological and chemical indicators of maturity were assessed for these tubers immediately after harvest (Table 2). Sucrose concentrations were higher in tubers from the late-planted plots. The effect of planting date on sucrose concentration was greatest for Ranger Russet tubers, where tubers from the late-planted crop had a 38% higher concentration than those from the early-planted crop. Ranger Russet tubers from the late planting also had higher specific gravity than from the early planting. Color (reflectance) of the stem ends of French fries from tubers conditioned at 44oF for 1 month was not affected by planting date in Russet Burbank and Umatilla Russet. However, the stem-end fry color of Ranger Russet tubers from the late-planted crop was significantly lighter (USDA 1) than that from the early-planted tubers (USDA 2) after 1 month storage at 44oF (Table 2). In contrast to RB and RR, the reducing sugar concentration in UR tubers from the late planting was 115% higher than in tubers from the early planting. On average, tuber respiration during wound-healing was higher and the length of dormancy longer for tubers from the late-planted crops. Collectively, these results demonstrate an effect of planting date on tuber physiology, even though tubers from the early- and late-planted crops were otherwise indistinguishable. RR tubers from the early-planted crop showed characteristics (lower gravity, darker stem end fries) of over-maturity, while the late-planted crop of UR appeared to be immature (higher respiration and reducing sugars). **The key questions are… Do these apparent differences in tuber maturity affect storability and are there storage temperature regimes that are better suited for maintaining processing quality in the tubers of different maturity?** A 'temperature grid' protocol was used to assess responses of tubers from the early- and late-planted crops to different temperature regimes (Fig. 3). After wound healing for 17 days at 54oF, reducing sugars were measured and the tubers were subsequently stored at 40, 44, and 48oF for 33 days (conditioning period). Reducing sugars and fry color were analyzed and conditioned tubers were then transferred to 40, 44, and 48 oF holding temperatures (Fig. 3) for a total of nine storage temperature regimes (3 conditioning x 3 holding temperatures). Tubers were treated with sprout inhibitor as needed during the storage season and sampled for sugar and fry quality at 111, 169, and 230 days from harvest. The tubers were reconditioned at 60 oF for 3 weeks at the end of the study (from 230 to 251 days in storage).

As expected, changes in processing quality (French fry color) of stored tubers mirrored the changes in reducing sugars and therefore only fry colors are presented. Changes in stem-end fry color of early- and late-planted RR tubers in response to storage temperature regimes are shown in Fig. 4. French fry color darkened as the initial conditioning temperature fell from 48 to 40oF for both the early- and late-planted crops. Averaged over planting date, the extent of fry darkening (loss of processing quality) was severe at 40oF, but was significantly reduced during the 182-d holding period (from 48 to 230 DAH) in tubers that were initially conditioned at 44 and 48oF (Fig. 4). This response was most evident for RB in 2003, where the extent of sweetening at lower holding temperatures (e.g. 40oF) was less in tubers conditioned initially at higher (e.g. 48oF) temperatures (Fig. 5). The opportunity to use lower storage temperatures in properly conditioned tubers increases the options for managing disease, shrink and sprouting. Ranger Russet tubers from the early-planted crop sweetened (data not shown) and lost processing quality to a greater extent than those from the late-planted crop, as evidenced by darker French fries from 48- to 230-d in storage at any temperature (Fig. 4). Tuber maturity (planting date) affected the way in which processing quality changed in response to conditioning and holding temperatures. These effects are clearly seen in the 230-d processing data (Fig. 4). On average, tubers from the late-planted crop produced lighter-colored fries than those from the early-planted crop following 230 d of storage at any conditioning and holding temperature. However, the planting date-induced differences in fry color diminished with increasing conditioning temperature in tubers subsequently stored at 48oF (Fig. 4). At lower holding temperatures (40 and 44oF), the superior (lighter) fry colors produced by tubers of the late-planted crop were maintained over those produced by the early-planted crop, regardless of conditioning temperature.

The decreased storability of Ranger tubers from the early-planted (over-mature) crop is readily apparent by the limited choice of storage temperature regimes resulting in acceptable quality of processed French fries. Tubers from the late-planted crop produced lighter colored fries under a broader range of temperature regimes (5 in total) than the chronologically older tubers from the early-planted crops (3 in total) (Table 3). Ranger Russet tubers had a tendency to over-mature if produced over a relatively long season (>160 days), particularly if the tubers were left under dead vines for more than 10 days prior to harvest. Vines from the late-planted crop of RR were greener than those from the early-planted crop at vine kill. Tubers thus matured under dead vines longer for the early-planted crop and this decreased the ability to maintain processing quality. The result was fewer conditioning/holding temperature options for storing tubers with acceptable quality (Table 3).

While tuber maturity was manipulated indirectly by varying the planting dates in this study, the results agree with previous studies in WA and ID where tubers harvested without vine kill (i.e. from partially green vines) maintained lower sugar levels and better processing quality than those left to mature for 2 to 4 weeks under dead vines (Knowles et al., 2001; Woodell et al., 2004). **Therefore, for Ranger Russet produced in the Columbia Basin of WA and destined for storage, planting dates, vine kill dates, and harvest dates should be adjusted and crops managed to limit the propensity of this cultivar to over-mature. One way to accomplish this is by planting no earlier than 15 April, vine killing approximately 145- to 155-days after planting, and harvesting within a week of vine kill to minimize tuber maturation under dead vines.** Growers can even harvest from partially green vines with diligence to minimize bruising and skinning during harvest, and desiccation during wound healing in storage through control of humidity and temperature.

Similar to Ranger, the storability of Umatilla tubers was affected by maturity. Umatilla Russet also maintained better processing quality under a wider range of temperature regimes if a chronologically younger (i.e. late- vs. early-planted) crop was placed in storage (Table 3). In contrast to RR however, the ultimate storage life of UR in terms of processing quality appeared to be limited by a faster rate of aging of tubers following vine kill. Several observations led to this conclusion. First, although processing quality is not a concern in seed potatoes, we have demonstrated that UR seed-tubers are more sensitive to accelerated aging at a particular storage temperature for increase in stem numbers and shift in tuber size distribution than either RR or RB. Secondly, the processing quality of UR tubers from the early-planted crop stored at constant temperatures of 44 and 48oF deteriorated progressively (more so than tubers from the late-planted crop) over the 230-d storage period (Driskill, 2005) and this was in contrast to RR (Fig. 4).

Lastly, unlike the other cultivars, UR gradually lost the ability to improve fry color through reconditioning over the 230-day storage period in some years (e.g. 2004 see Fig. 6). This response is consistent with a higher rate of aging, which would eventually result in senescent sweetening. Unlike cold-induced sweetening, senescent sweetening is irreversible and thus reconditioning would not improve processing quality. The propensity of UR to age faster than the other cultivars underscores the importance of processing this cultivar within 200 days of harvest if possible. This is the first report of a progressive decline in the reconditioning ability of UR tubers with time in storage and explains the high year-to-year variability in reconditioning potential observed for this cultivar (Driskill, 2005).

Summary and Commercial Implications

- The temperature grid study protocol is ideal for evaluating the storage potential of advanced selections and newly released cultivars.
- Ranger Russet processing quality was maintained for 230+ days (mid May) with higher conditioning/holding temperature regimes.
- Cold-sweetened RR and RB tubers reconditioned well after 230+ days of storage; however, the reconditioning ability of UR tubers was variable from year to year, decreasing to near zero by 230 days of storage in some years.
- Manipulating conditioning temperature relative to holding temperature broadens our storage management options for dealing with 'problem' potatoes.
- In the Columbia Basin, planting dates, vine kill dates, and harvest dates should be adjusted and crops managed to limit the propensity of Ranger Russet to over mature if tubers are destined for storage. One way to accomplish this is by planting no earlier than 15 April, vine killing approximately 145- to 155-days after planting, and harvesting within a week of vine kill to minimize tuber maturation under dead vines. Storage temperature options for maintaining processing quality are more numerous if tubers have not over matured.
- For optimum storability, the production window for Umatilla Russet should be limited to about 155 to 160 days, including vine kill and maturation.
- Due to the tendency of UR tubers to age and lose reconditioning ability and sometimes processing quality faster than other cultivars in storage, the storage duration should be limited to within 200 days if possible.

References

Coleman, W.K., LeBlanc, J. and T. Morishita. 1996. A rapid test for chemical maturity monitoring of tubers. Am. Potato J 73:501-507.

Driskill, E.P. Jr. 2005. Physiological maturity and its effects on sweetening and processing quality of stored potatoes. MS Thesis, Washington State University, Pullman.

Iritani, W.M. and L.D Weller. 1980. Sugar development in potatoes. Cooperative Ext, College of Agric, Washington State University.

Knowles, L.O., N.R. Knowles and M. Martin. 2001. Postharvest behavior of vine-desiccated versus green-harvested Ranger Russet tubers. Potato Progress 1(7):1-4.

Nelson, D.C. and R.Shaw. 1976. Effect of planting and harvest dates, location in hill and tuber size on sugar content of Kennebec potatoes. Am Potato J 53:15-21.

Nelson, D.C. and Sowokinos, J.R. 1983. Yield and relationships among tuber size, sucrose and chip color in six potato cultivars on various harvest dates. Am Potato J 60: 949-958.

Pritchard, M.K. and Adam, L.R. 1992. Preconditioning and storage of chemically immature Russet Burbank and Shepody potatoes. Am Potato J 69: 805-815.

Woodell, L., Olsen, N., Brant, T.L., and G.E. Kleinkopf. 2004. Vine kill and long-term storage of Ranger Russet potatoes. University of Idaho Extension Bulletin, CIS 1119.

Table 1. Estimations of the attainment of tuber physiological maturity for Ranger Russet, Russet Burbank and Umatilla Russet crops produced in the Columbia Basin of WA during the 2003 and 2004 growing seasons. The crops were grown using production practices recommended for late-season management under the long-season conditions characteristic of this region. Days to attainment of the various quality factors contributing to maturity were estimated from the growth curves presented in Figs. 1 & 2 (see footnotes). The crops were vine-killed at 150 and 153 days after planting (DAP) in 2003 and 2004, respectively. The final harvests were at 169 DAP in 2003 and 181 DAP in 2004.

	Ranger Russet		**Russet Burbank**		**Umatilla Russet**	
Tuber Quality Factor[a]	**2003**	**2004**	**2003**	**2004**	**2003**	**2004**
			Days After Planting			
Specific $gravity_{max}$	161	178	151	157	153	163
Tuber fresh wt_{max}	160	186	145	162	163	164
$Sucrose_{min}$	157	122	148	153	157	167
Red. Sugar increase	157	142	148	153	157	142
Estimated maturity[b]	159	157	148	156	158	159

[a]Timing of the attainment of maximum (max) specific gravity and tuber fresh weights were calculated from polynomial equations describing the curves in Figs 1 & 2. DAP to minimum (min) sucrose concentrations were derived from Figs. 1 & 2 (RB not shown). Reducing (Red.) sugar increase is defined as the harvest date beyond which there was an increase in reducing sugar concentrations within the stem ends of tubers late in the season.
[b]Estimated maturity was calculated as the average of the four quality factors.

Table 2. Effects of planting date on chemical and physiological indices of tuber maturity. Tubers were harvested 25 September from early- (15 April) and late-planted (15 May) plots of Russet Burbank, Umatilla Russet and Ranger Russet at Othello, WA. Unless otherwise specified in the footnotes, data are averaged over the 2002-2004 growing seasons. All data pertains to 10- to 12-oz tubers.

Maturity Indicators	Russet Burbank		Umatilla Russet		Ranger Russet	
	Early	Late	Early	Late	Early	Late
Sucrose (mg·g dry wt^{-1})	5.48	7.02*	7.33	9.10*	6.96	9.61**
Glu + Fru (mg·g dry wt^{-1})	3.98	5.02	2.49	5.35***	4.81	4.35
Specific Gravity[a]	1.077	1.076	1.088	1.089	1.079	1.086***
Stem end Reflectance (30 d @ 44^{o}F)	18.9	19.6	29.6	30.5	24.0	28.1**
Tuber Respiration (mg CO_2 kg^{-1}·h^{-1})[b]	4.06	5.09**	4.66	5.67**	4.64	4.90
Dormancy (days to 1.7 mm sprouts)	138	146	104	119*	79	92*

[a]2002 season only. [b]RR and RB 2002 and 2004 only. *, **, ***P≤0.05, 0.01 and 0.001 levels, respectively. Suc, Glu, Fru assessed 17 days after harvest. Respiration rates are averaged over 14 days of healing at 54^{o}F directly following harvest. Length of dormancy was assessed in tubers stored at 48^{o}F following wound healing.

Table 3. Combinations of storage conditioning (CT) and holding (HT) temperatures that resulted in acceptable processing quality of French fries from Ranger and Umatilla Russet tubers of different maturity stored for 111- 169-, 230- and 251-d. The 251-d storage period included 21 days of reconditioning (R) at 60°F (from 230- to 251-d). Tuber maturity was manipulated by planting date. The early- and late-planted crops were harvested on 25 Sept, 163- and 133-d after planting, respectively. Tubers were then wound-healed at 54°F for 17 d following harvest, conditioned at 40, 44 and 48°F for a month, and then stored at 40, 44 and 48°F (holding) for an additional 182 d (until 13 May), resulting in nine CT/HT combinations. After 230 days in storage, the tubers were reconditioned for 21 d at 60°F (from 13 May to 3 June). Fries were processed after the indicated storage days and fry color and uniformity were evaluated for acceptability. For a storage CT/HT regime to be acceptable, less than 20% of the tubers produced French fries exceeding a USDA 2 rating and the difference in color (lightness) from stem to bud end was less than 9 photovolt reflectance units. These data represent the storability of tubers over three storage seasons (2002-04).

Cultivar	**Storage days**	**Planting Date** Early (15 Apr)	**Planting Date** Late (15 May)
		conditioning/holding temperature (°F) producing acceptable French fries	
Ranger Russet	111	44/48, 48/44, 48/48	40/48, 44/44, 44/48, 48/44, 48/48
	169	Same as above	Same as above
	230	48/48	Same as above
	251-R*	44/40, 44/44, 48/44 48/48	40/40, 40/44, 40/48, 44/40, 44/44, 44/48, 48/40, 48/44, 48/48
Umatilla Russet	111	44/44, 44/48, 48/44, 48/48	40/48, 44/40, 44/44, 44/48, 48/44, 48/48
	169	48/44, 48/48	40/48, 44/44, 44/48, 48/40, 48/44, 48/48
	230	44/48, 48/48	40/48, 44/44, 44/48, 48/44, 48/48
	251-R*	40/48, 44/48, 48/48	40/40, 40/48, 44/40, 44/44, 44/48, 48/40, 48/44, 48/48

*230 days of storage plus 21 days of reconditioning at 60°F.

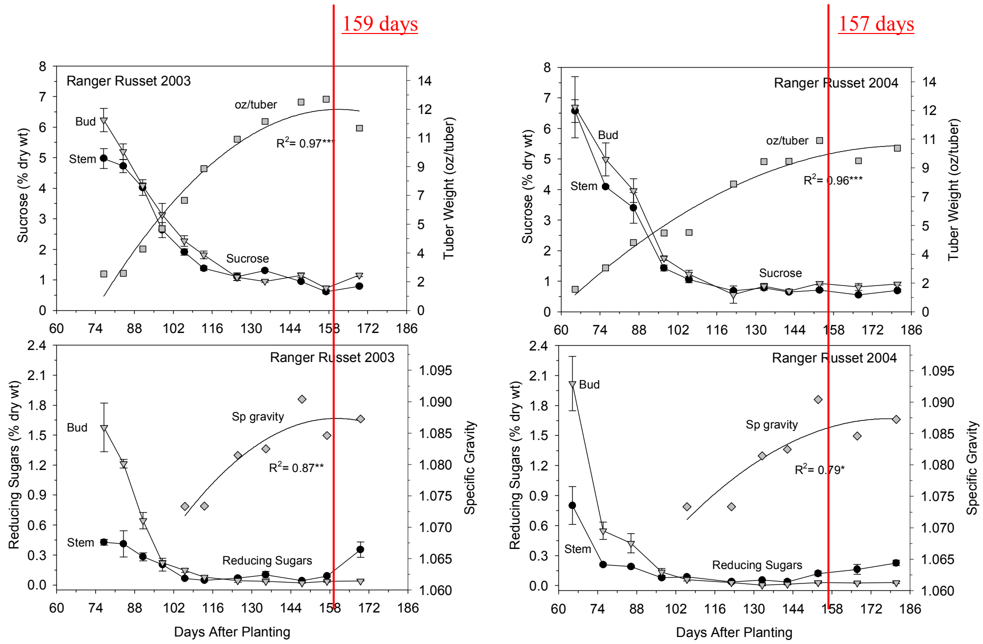

Fig. 1. Changes in sucrose, reducing sugars (glucose and fructose), specific gravity, and average tuber fresh weight with time during growth of Ranger Russet during the 2003 and 2004 growing seasons (Othello, WA). Tuber physiological maturity was estimated to be at 159 DAP in 2003 and 157 DAP in 2004 (vertical lines). Plots were planted April 13 and 15 in 2004 and 2003, respectively. Vine kill was at 150 DAP in 2003 and 153 DAP in 2004. Final yields were 35.8 T/A in 2003 and 37.4 T/A in 2004. *,**,***P<0.05, 0.01, and 0.001, respectively.

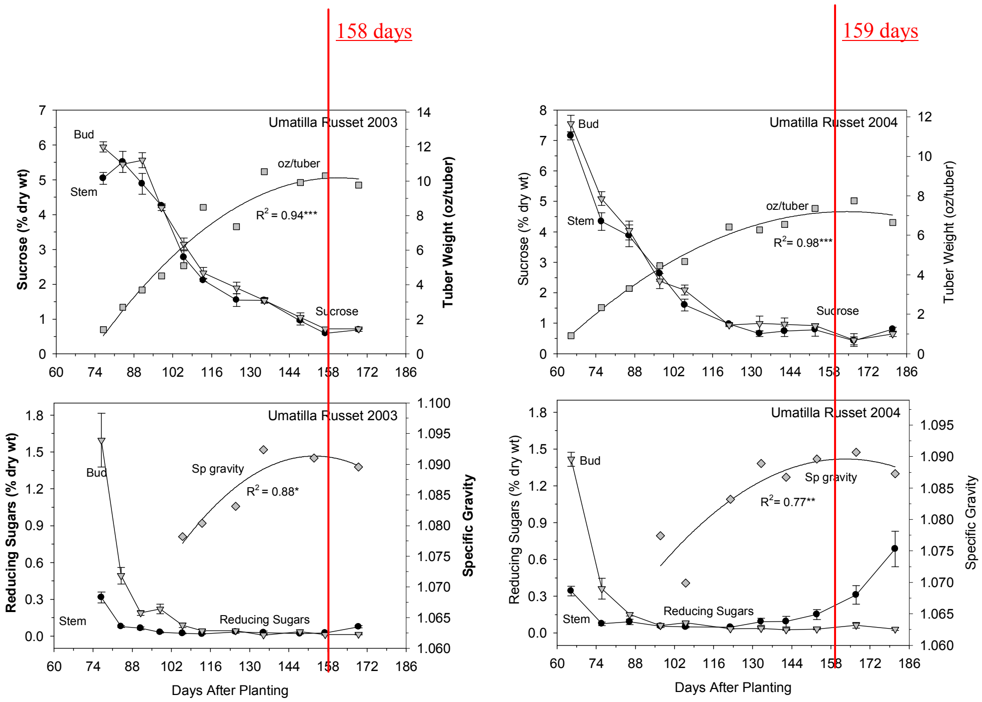

Fig. 2. Changes in sucrose, reducing sugars (glucose and fructose), specific gravity, and average tuber fresh weight with time during growth of Umatilla Russet during the 2003 and 2004 growing seasons (Othello, WA). Tuber physiological maturity was estimated to be at 158 DAP in 2003 and 159 DAP in 2004 (vertical lines). Plots were planted April 13 and 15 in 2004 and 2003, respectively. Vine kill was at 150 DAP in 2003 and 153 DAP in 2004. Final yields were 30.9 T/A in 2003 and 35.3 T/A in 2004. *,**,***P<0.05, 0.01, and 0.001, respectively.

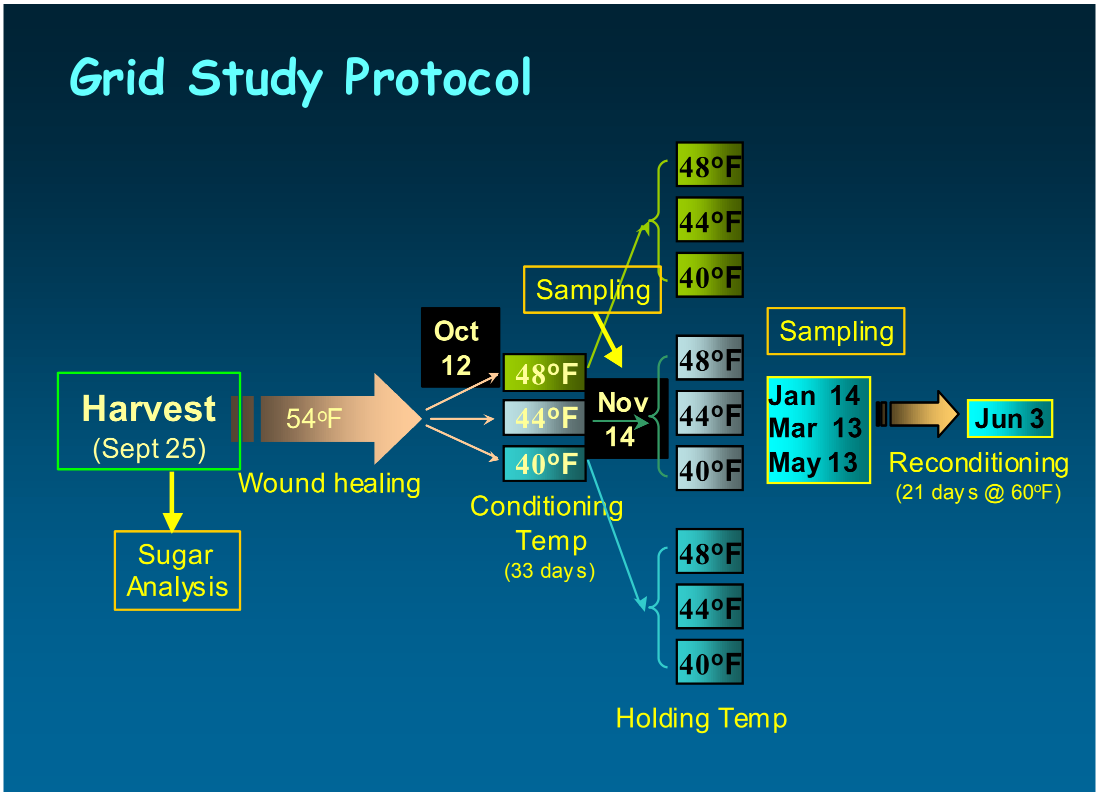

Fig. 3. Temperature regimes and sampling times used in the 2002-2004 grid studies to assess the storability of early- and late-planted Ranger Russet, Russet Burbank and Umatilla Russet tubers.

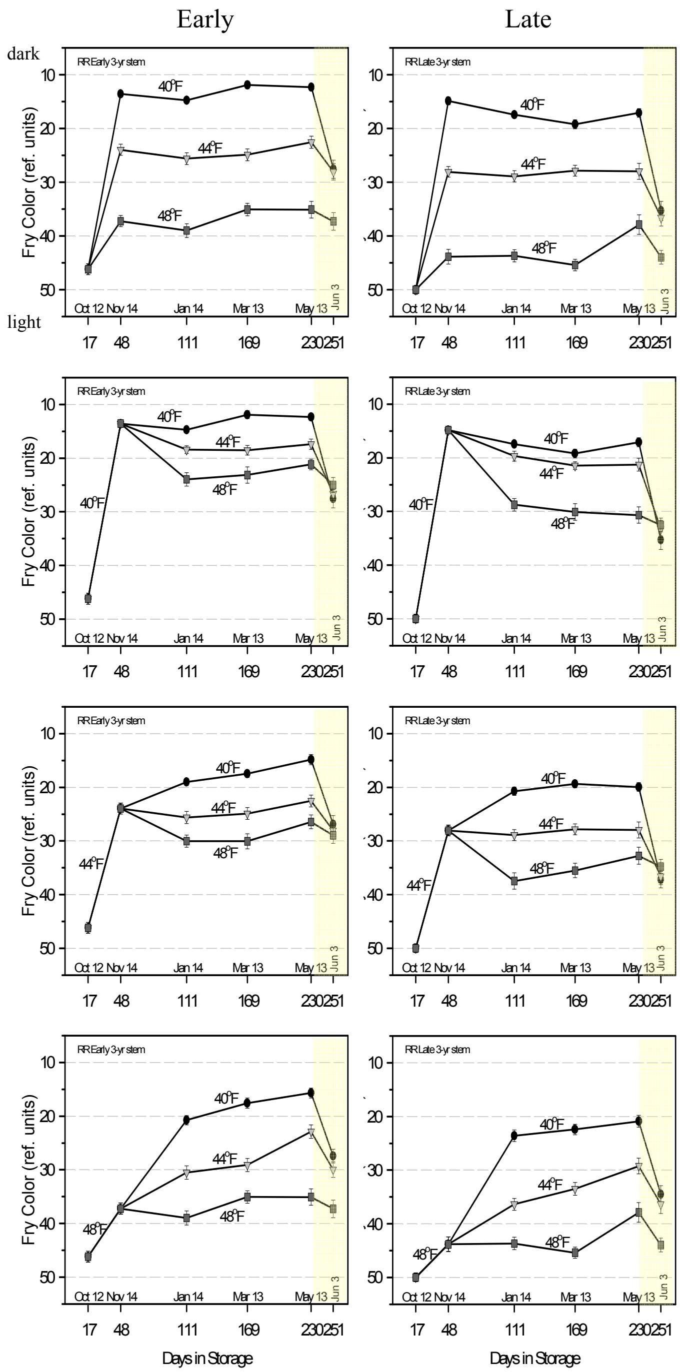

Fig. 4. Changes in the processing quality of French fries (photovolt reflectance units of the stem ends of fries) prepared from Ranger Russet tubers from early- (left column) and late-planted crops (right column) in response to different combinations of conditioning (initial), holding, and reconditioning temperatures over a 251-d storage interval. The early- and late-planted crops were harvested on 25 Sept, 163- and 133-d after planting, respectively. Tubers were wound-healed at 54°F for 17 d following harvest, conditioned at 40, 44 and 48°F for a month (12 Oct.-14 Nov.), and then stored at 40, 44 and 48°F (holding) for an additional 182 d (until 13 May), resulting in nine conditioning/holding temperature combinations. The tubers were then reconditioned for 21 d at 60°F (13 May-3 June). Note the inverted scale on the French fry color axis. Low photovolt reflectance values indicate darker fries. A photovolt reflectance ≤19 is unacceptable by industry standards (≥USDA 3). The temperature regimes giving acceptable fry color (based on USDA values and color uniformity) are summarized in Table 3 for RR and UR. Data are averaged over the 2002-04 storage seasons. Each point is the average of 36 tubers ±SE (bars).

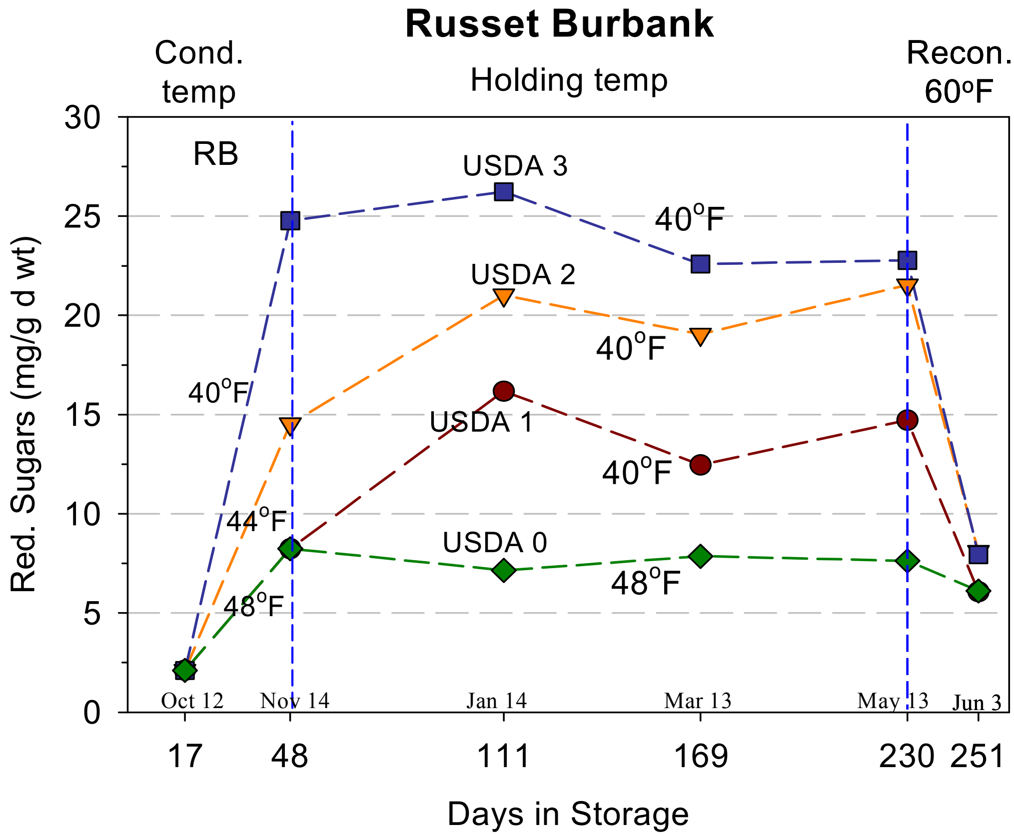

Fig. 5. Effects of initial (conditioning) storage temperatures (17 to 48 days after harvest) on the accumulation of reducing sugars in Russet Burbank tubers stored subsequently at 40°F. Storage at a constant 48°F is included as a control. The USDA color ratings of French fries from tubers held under each temperature regime are indicated. Tubers were reconditioned at 60°F for 21 days from 230 to 251 days after harvest. Note that the sweetening responses during the main storage period at 40°F are lessened with higher conditioning temperatures.

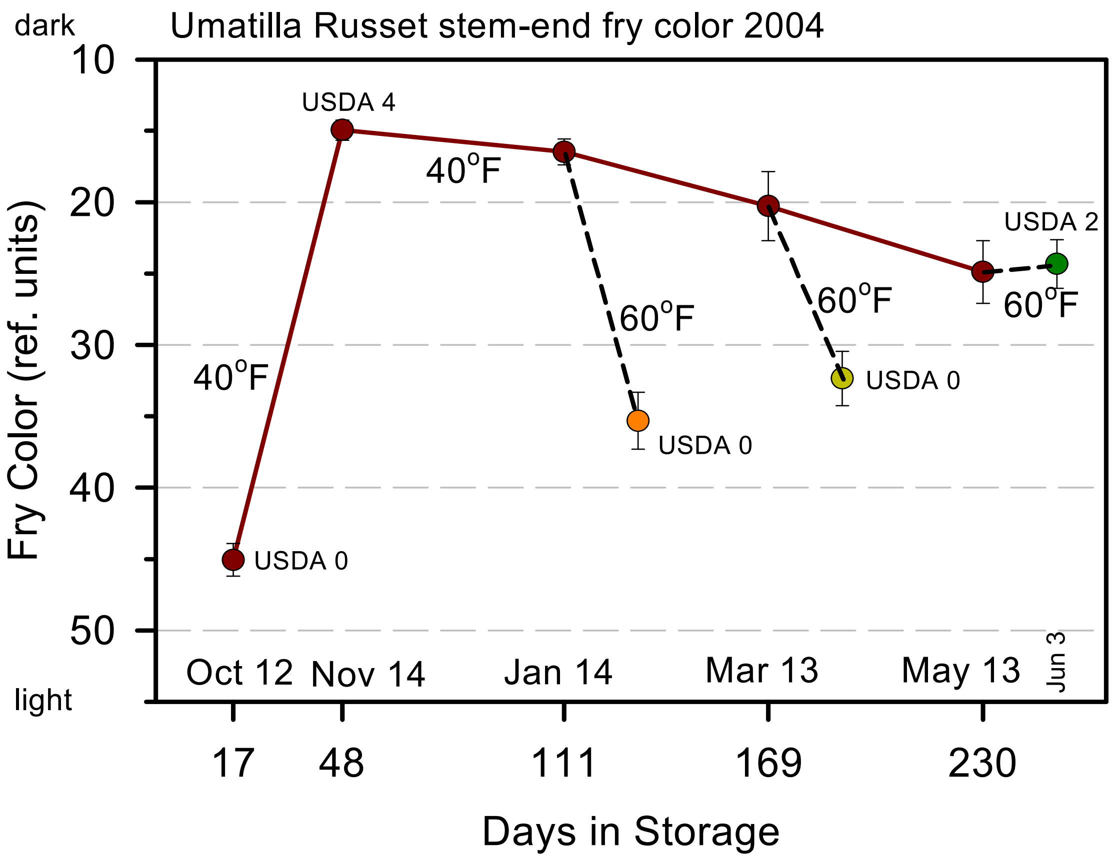

Fig. 6. Changes in processing quality (stem-end French fry color) and reconditioning ability of Umatilla Russet tubers during 230 d of storage at 40°F. Tubers were wound-healed at 54°F for 17 d prior to storage. Tuber samples were reconditioned for 21 d at 60°F after 111-, 169- and 230-d of storage at 40°F. Note the inverted scale on the French fry color (photovolt reflectance) axis. Low photovolt reflectance values indicate darker fries. A photovolt reflectance $\leq$19 is equal to a USDA 3 or greater French fry, which is unacceptable by industry standards. Data are averaged over tuber samples from the early- and late-planted crops from the 2004-05 storage season. Each point is the average of 24 tubers ±SE (bars). The improvement in photovolt reflectance due to reconditioning decreased significantly with increasing days in storage (time x reconditioning, $P \leq 0.001$).