Growth, Development & Postharvest Behavior of Newly Released Cultivars in the Columbia Basin

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Tuber maturity affects the postharvest behavior and quality of processing potatoes. Environmental conditions and agronomic practices during production dictate the physiological maturity of tubers at harvest. Understanding how production influences the retention of processing quality in stored potatoes is key to developing best management practices for newly released cultivars. We have a major interest in defining how growing environment and harvesting, handling, and storage conditions interact to affect tuber maturity and the storability and quality of potatoes for the processing market. Our research is currently focusing on new cultivars for which best management practices for production and storage remain to be defined in the Columbia Basin.

Background

GemStar Russet, Defender, Premier Russet (A93157-6LS), and Alturas are among the newest frozen-processing cultivars released from the Pacific Northwest Variety Development Program since Ranger (1991) and Umatilla Russet (1997). Ranger and Umatilla Russet have had a significant impact on the processing industry, accounting for 22.8% and 11.9% of WA processing potatoes in 2006, respectively. It is anticipated that GemStar, Defender, Premier, and Alturas will also find niches in the WA potato industry, with the potential to capture a significant portion of the frozen French fry market in particular. However, as was the case with Ranger and Umatilla, developing best management practices to optimize yield and quality for these cultivars under Columbia Basin growing conditions will involve a 'learning curve'.

A major goal of our research is to provide comparative data on growth & development and storage of these cultivars to the WA potato industry, to enhance the ability of growers to optimize production. Specific questions include:

- In relation to our growing season, how do foliar & tuber growth compare among the cultivars over the 5 stages of development (emergence and plant establishment, vegetative growth, tuber initiation, tuber bulking, maturation)?
- How do seasonal patterns of carbohydrate accumulation in tubers relate to specific gravity, the attainment of physiological maturity, and the development of sugar-end disorders?
- How resistant or sensitive are these cultivars to variation in end-of-season tuber maturity for subsequent storability and processing quality (e.g. the onset of sweetening in storage, development of sugar ends, etc.)?

These questions are best answered by detailed analyses and comparisons of growth patterns over several seasons to identify critical growth stages and the optimum 'windows' of physiological maturity in relation to storability. Physiological maturity is 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 & 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.

Analyses of foliar and tuber growth curves is necessary to define the onsets and durations of the five growth stages for each cultivar through the growing season. This information can ultimately be used as an aid to schedule irrigation, fertilizer, and pesticide applications more effectively, according to the stage of crop development. Susceptibility to sugar-end development, in relation to tuber maturity and environmental stresses (e.g. heat) inherent in the Columbia Basin, are being noted for each cultivar.

Characterizing how storage temperature regimes affect processing quality over time will reveal the best storage management practices for WA-grown tubers of each cultivar. **In short, crop development is being modeled to identify the 'windows' corresponding to the fives stages of growth and to determine the attainment of tuber physiological maturity, which coincides with maximum storage life.** The research is ongoing and thus only a brief synopsis of the results to date is presented herein. The specific objectives and experimental approaches are:

Objectives

1. Develop comprehensive crop growth stage & storability profiles for newly released russet cultivars for the Columbia Basin – Premier Russet (A93157-6LS), GemStar Russet (A9014-2), Defender, Alturas.
2. For each cultivar, estimate the attainment of tuber physiological maturity and determine how storability and processing quality are affected by conventional and non-conventional storage temperature regimes over an 8-month storage period.

Experimental Approach

- Model foliar & tuber development for each cultivar through the season – define the growth curves, compare bulking rates and harvest indices.
- Identify the 'windows' corresponding to the five growth stages and characterize the attainment of tuber physiological maturity by modeling sugar content with time through the season for each cultivar.
- Evaluate the extent to which differences in crop maturity affect tuber size distribution, crop value, and bruise susceptibility; compare basal respiration rates and changes in tuber processing quality among the cultivars during storage.

Results - 2005-2006 Progress

- Seven cultivars (Defender, Premier, GemStar, Alturas, Ranger, Russet Burbank, Umatilla) were planted in replicated plots at the Othello Research Station in April. Plants and tubers were harvested at approximately 10-day intervals from 62- to 176-days-after-planting (DAP) and foliar and tuber growth were modeled through the season for each cultivar (Figs. 1 and 2). Harvest indices were compared at maximum foliar fresh weight for each cultivar (Fig. 3). Harvest index is a measure of the efficiency with which plants partition fresh weight to tubers, expressed as a percentage of the whole plant. At maximum foliar fresh weight, Ranger Russet, Premier Russet, and Alturas tubers accounted for 53, 45, and 38% of plant fresh weight, respectively (Fig.3).
- The 'windows' of tuberization were calculated for each cultivar, based on polynomial models describing the percentage of stolons tuberized versus time. GemStar, Premier Russet, and Alturas tuberized slightly later than the other cultivars in both years (Table 1). Initial tuber bulking (growth) rates were compared over the period ranging from first harvest to maximum foliar fresh weight (Table 2). Averaged over years, Ranger and GemStar Russet had the highest initial bulking rates (~1217 lbs/A/d); Defender, Umatilla and Premier were intermediate (~1026 lbs/A/d); and Alturas had the lowest (~845 lbs/A/d). However, Alturas and Premier produced more foliar growth that persisted longer than the other cultivars, resulting in continued bulking late in the season (Figs. 1 and 2), which explains their high total yields (Table 3).

- The tubers were then analyzed for dry matter (specific gravity) and sugar (sucrose, glucose and fructose) content during development to define the attainment of physiological maturity for each cultivar (Figs. 1 and 2). Physiological maturity was calculated as an average of the DAP to reach maximum yield, maximum specific gravity, minimum sucrose, and beginning of end-of-season increase in reducing sugars in the stem end of tubers (Figs. 1 and 2). In 2006, physiological maturities ranged from 150 DAP for Premier to 163 DAP for Ranger (Table 4).
- Additionally, changes in tuber size profiles were compared among the cultivars over the last three harvest dates (128-, 149-, and 176-DAP). Economic analysis of the marketable yields shows how crop value changes for each cultivar, based on the tuber size clauses in processing contracts (Table 4). Note the relatively little added yield and value in Ranger from 149- to 176-DAP. Harvesting beyond physiological maturity in hopes of maximizing yield can negatively affect the overall value because over mature crops of Ranger tend to lose processing quality faster during storage (Driskill et al., 2007). On the other hand, the increases in value of GemStar and Premier from 149- to 176-DAP were greater than Ranger but limited by a high percentage of oversize (>14 oz) tubers late in the season. Since these cultivars achieve very low levels of reducing sugars at the end of the season and resist sweetening in storage (see below), delayed harvest for higher yield can add substantial value, particularly if tuber size distribution is controlled. We are currently working on methods to optimize tuber size distribution for these two cultivars.
- GemStar, Defender, and Premier Russet tubers (8- to 12-oz) from the final harvest (176 days) were cured at 54°F for 2 weeks and placed in storage under a range of conventional and non-conventional temperature regimes (nine total). Tubers from the 2006 trials are being sampled from storage at 44- to 60-day intervals through approximately 250 days for analysis of sugars and processing quality. The postharvest phase of the 2006 study is still in progress.
- Changes in sugars and processing quality from the 2005/06 postharvest study revealed important differences in the storability of Defender, Premier, and GemStar. Relative to GemStar and Premier, processing quality of Defender deteriorates rapidly in storage (Fig. 4), particularly at 44 and 40°F. Defender also had the highest rate of respiration initially in storage. Defender should be stored at no less than 48°F and storage duration should not exceed 150-170 days for frozen processing. While Premier tubers had considerable resistance to low temperature sweetening, the extent of fry mottling increased during storage of the 2005 crop. Mottling appeared less when stored at 40°F than at higher temperatures, suggesting a tendency of Premier tubers to age faster and undergo irreversible senescent sweetening sooner than the other cultivars. Premier had a higher respiration rate than all cultivars (Ranger, Burbank, Umatilla, GemStar, Alturas) except Defender initially in storage, which is consistent with a faster rate of aging. Premier also absorbed more oil than the other cultivars during frying. GemStar sweetened uniformly from bud to stem end as storage temperature declined; however, tubers stored for 227 days at 44 and 40°F still produced acceptable USDA 1 and 2 colored fries, respectively (Fig. 4).

Summary & Recommendations

- The study is confirming our previous work (Driskill *et al.*, 2007) that Ranger be harvested close to physiological maturity to minimize the maturation period under dead vines for maximum longevity and retention of processing quality in storage.
- Defender has higher reducing sugars than GemStar & Premier Russet at physiological maturity and, similar to Ranger Russet, reducing sugars tend to increase in the stem end of Defender during maturation. Therefore, Defender should be harvested at physiological maturity (~156 DAP) for maximum storage life.
- Defender sweetens rapidly and loses processing quality progressively in storage at all temperatures. Tubers should be stored at 48°F for no longer than 150-170 days for processing.
- The reducing sugar content of Premier and GemStar Russet tubers decreases to very low levels during maturation. These cultivars are therefore more "forgiving" than Ranger & Defender for deleterious effects of delayed harvest (beyond physiological maturity) on storability.

- Premier and GemStar can produce very high yields (>40 T/A) when grown for more than 150 days; however, these cultivars tend to produce a high percentage of oversize (>14 oz) tubers late in the season, which limits crop value (Table 4). This tendency can likely be mitigated by closer in-row spacing (<10 inches) and/or planting seed that will produce more stems (physiologically older). We are currently modeling stem number and tuber size distribution relationships for these cultivars. This work will lead to recommendations for storage of seed to optimize tuber size distribution for Columbia Basin growers.
- Premier and GemStar Russet are resistant to cold-induced sweetening. GemStar had the lightest fry color at harvest and maintained the lowest sugars and lightest colored fries when stored at 48°F for 227 days (Fig. 4). Fry colors were also acceptable when stored at 44 and 40°F.
- Premier absorbs more oil and can develop irreversible mottling, particularly when stored at higher temperatures (e.g. 48°F). In contrast, GemStar produces very uniform fry color with little oil absorption.

References Cited

Coleman WK, J LeBlanc and T Morishita. 1996. A rapid test for chemical maturity monitoring of tubers. Am Pot J 73:201-507.

Driskill EP Jr., LO Knowles and NR Knowles. 2007. Temperature-induced changes in potato processing quality during storage are modulated by tuber maturity. Am J Pot Res (in press).

Iritani WM and LD Weller. 1980. Sugar development in potatoes. Coop Ext Bull #0717, Washington State University, Pullman.

Pritchard MK and LR Adam. 1992. Preconditioning and storage of chemically immature Russet Burbank and Shepody potatoes. Am Pot J 69:805-815.

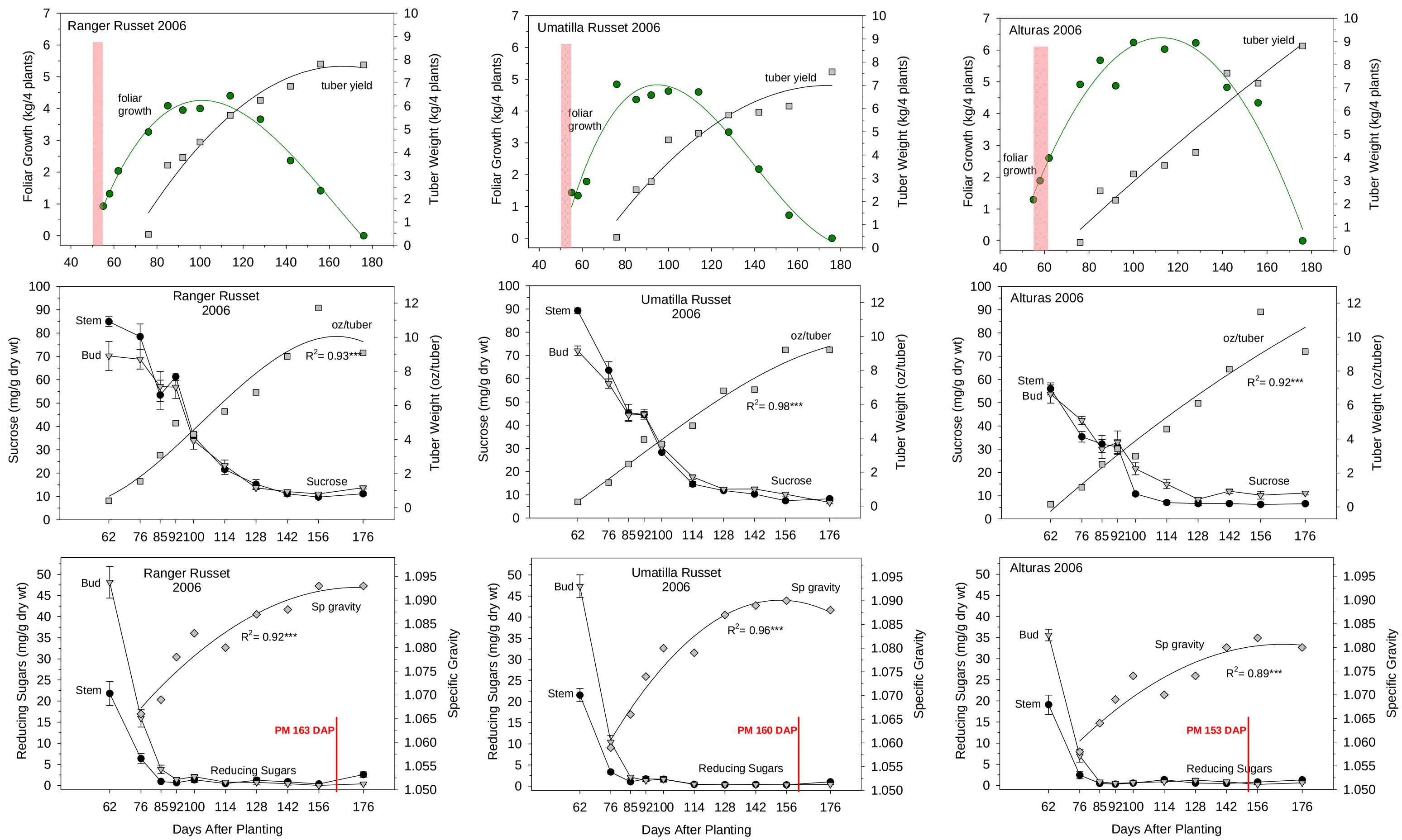

Fig. 1. Foliar growth and tuber development (top row) of Ranger Russet, Umatilla Russet, and Alturas potatoes under late-season management at Othello, WA from April 11 to Oct. 4, 2006 (176 DAP). Plants were harvested at approximately 10-day intervals over the 176-d growing season. Changes in sucrose concentration and average tuber weight (middle row), and reducing sugars (glucose and fructose) and specific gravity (bottom row) are also shown. Y-axis scales are equal across cultivars. Alturas produced more foliar growth that persisted longer than the other cultivars, resulting in higher yield and larger tubers than Ranger and Umatilla. Tuberization (shading) of Alturas was 54-61 DAP compared with 49-54 DAP for Ranger and Umatilla. The 6-fold increase in reducing sugar concentration in the stem end of Ranger Russet tubers from 156 to 176 days after planting may indicate increased tendency to develop sugar ends during storage. Physiological maturity (PM) was estimated at 163-, 160-, and 153-DAP for Ranger, Umatilla, and Alturas, respectively.

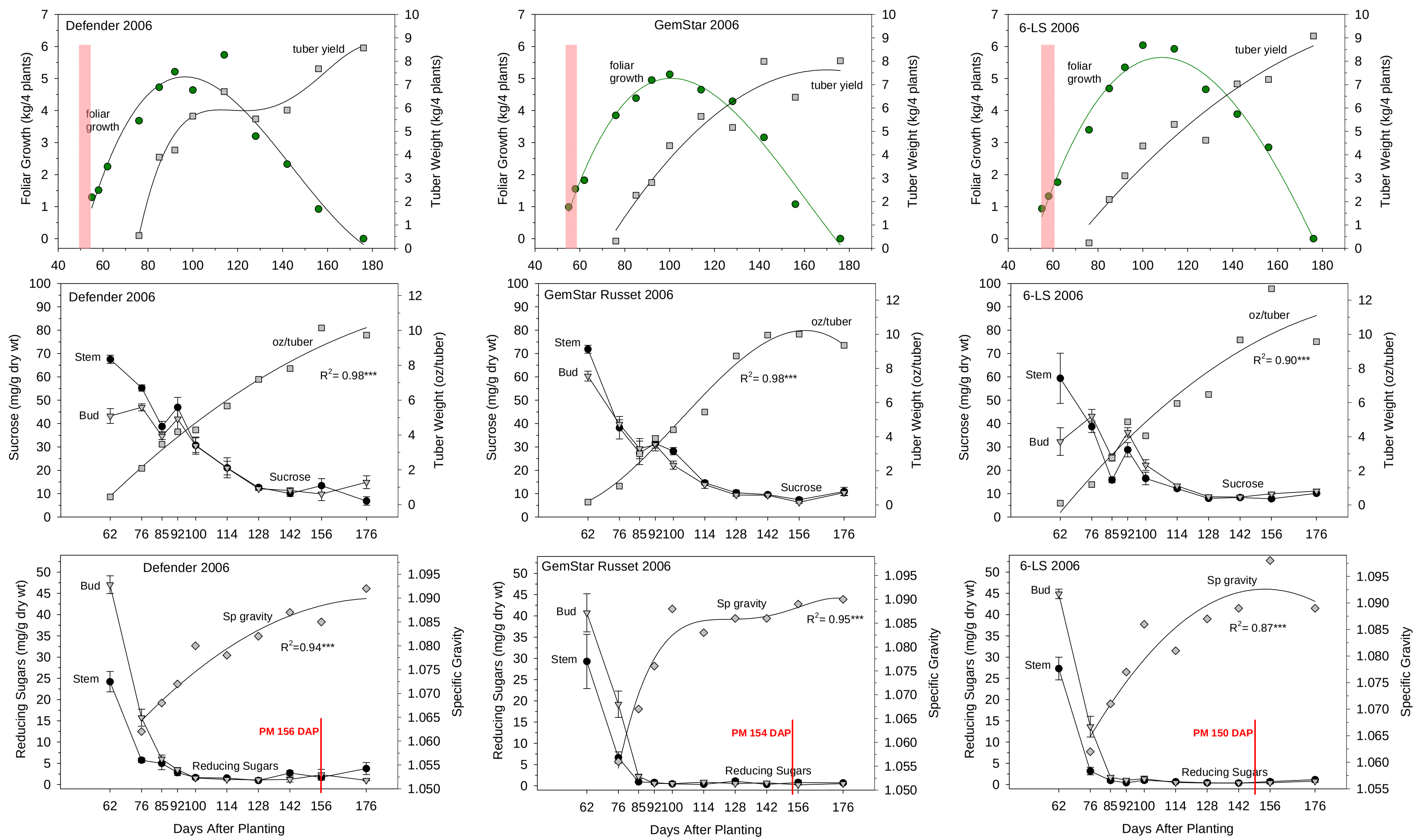

Fig. 2. Foliar growth and tuber development (top row) of Defender, GemStar Russet, and 6-LS (Premier Russet) potatoes under late-season management at Othello, WA from April 11 to Oct. 4, 2006 (176 DAP). Plants were harvested at approximately 10-day intervals over the 176-d growing season. Changes in sucrose concentration and average tuber weight (middle row), and reducing sugars (glucose and fructose) and specific gravity (bottom row) are also shown. Y-axis scales are equal across cultivars. Premier Russet (6-LS) produced more foliar growth that persisted longer than the other cultivars, resulting in higher yield and larger tubers than GemStar (41 T/A) and Defender (43 T/A). Tuberization (shading) of 6-LS and GemStar occurred 53-60 DAP compared with 49-53 DAP for Defender. Defender tubers had a 3-fold higher concentration of reducing sugars at 176 DAP compared with GemStar and 6-LS, indicating increased tendency to lose processing quality faster during storage. Physiological maturity (PM) was estimated at 156-, 154-, and 150-DAP for Defender, GemStar, and 6-LS, respectively.

Fig. 3. Harvest index (HI) of seven cultivars grown under late-season management at Othello, WA in 2006. HI is the ratio of tuber fresh wt to tuber plus foliar fresh wt (expressed as a percentage) and is a measure of the efficiency with which a cultivar partitions total fresh wt into tubers. HI was measured at maximum foliar fresh weight (see Figs. 1 and 2), as indicated on the bars (DAP, days after planting).

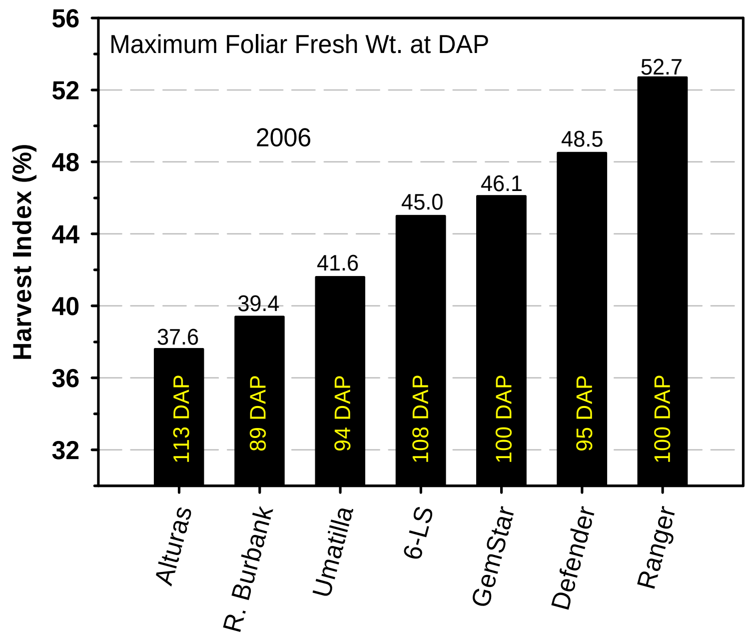

Table 1. Timing of tuberization for cultivars grown at the Irrigated Agriculture Extension and Research Center (IAERC), Othello, WA. Planting dates were April 13 and 11 in 2005 and 2006, respectively. The days after planting (DAP) to 35% tuberization and 20-50% tuberization 'windows' were calculated from polynomial regressions of percentage stolons tuberized versus DAP. Note that GemStar, 6-LS (Premier), and Alturas tuberize later than the other cultivars. The tuberization windows for 2006 are shaded in Figs. 1 and 2 (top rows).

	2005 Tuberization (% stolons)		2006 Tuberization (% stolons)	
Cultivar	**35%**	**20–50%**	**35%**	**20–50%**
		Days After Planting		
R. Burbank	42	40–45	50	47–52
Defender	43	41–47	51	49–53
Umatilla	47	44–51	52	50–54
Ranger	42	40–45	52	50–54
GemStar	50	47–52	56	53–58
Premier	50	47–53	57	54–58
Alturas	53	49–57	57	54–61

Table 2. Initial tuber bulking (growth) rates of seven cultivars under late season management at Othello, WA in 2005 and 2006. Bulking rates were calculated from the initial harvest (64- and 76-DAP in 2005 and 2006, respectively) to the time of attainment of maximum foliar fresh weight (FM) for each cultivar (see Figs. 1 and 2).

	Initial Tuber Bulking Rates		
Cultivar	**2005**	**2006**	**Average**
	lbs/acre/day		
R. Burbank	NA	1048	-
Defender	1037	1062	1050
Umatilla	929	1092	1011
Ranger	1114	1234	1174
GemStar	1223	1295	1259
Premier	1027	1023	1025
Alturas	822	867	845

Table 3. Final tuber yields of seven cultivars under late-season management at Othello WA. Plots were planted April 13 in 2005 and April 11 in 2006. Tubers were harvested Sept. 30 and Oct. 4 in 2005 and 2006, respectively (170- and 176-days-after-planting). Foliar and tuber growth analyses of the 2006 crops are shown in Figs. 1 and 2.

Cultivar Maturity Trial 2005/06

	Total Yield (T/A)	
Cultivar	2005	2006
Alturas	42.0	45.0
GemStar	40.6	40.8
Defender	40.9	43.6
-6LS	35.5	46.2
Ranger	34.7	39.5
Umatilla	34.5	38.5
R. Burbank	NA	38.3

Table 4. Changes in crop values and marketable yields from 128- to 176 DAP at Othello, WA during 2006. Values are based solely on tuber size clauses in processing contracts and thus reflect changes in yield and tuber size distribution only. No premiums or penalties were applied for bruise, internal defects, gravity, sugar content, or fry color. Physiological maturity (PM) was reached at the indicated days after planting (DAP).

		Days After Planting		
Cultivar	**PM***	**128**	**149**	**176**
	DAP	*$/Acre (T/A)*		
R. Burbank	158	1,854 (24.7)	2,517 (31.1)	3,397 (40.4)
Defender	156	2,218 (27.7)	2,781 (34.5)	3,424 (41.9)
Umatilla	160	2,151 (29.1)	2,348 (30.6)	3,034 (37.6)
Ranger	163	2,664 (31.8)	3,085 (36.9)	3,189 (38.4)
GemStar	154	2,230 (26.3)	2,931 (36.7)	3,148 (40.1)
Premier	150	1,929 (23.5)	3,008 (36.2)	3,657 (45.2)
Alturas	153	1,682 (21.5)	3,182 (31.1)	3,622 (40.4)

*PM, physiological maturity. Vine kill = 156 DAP

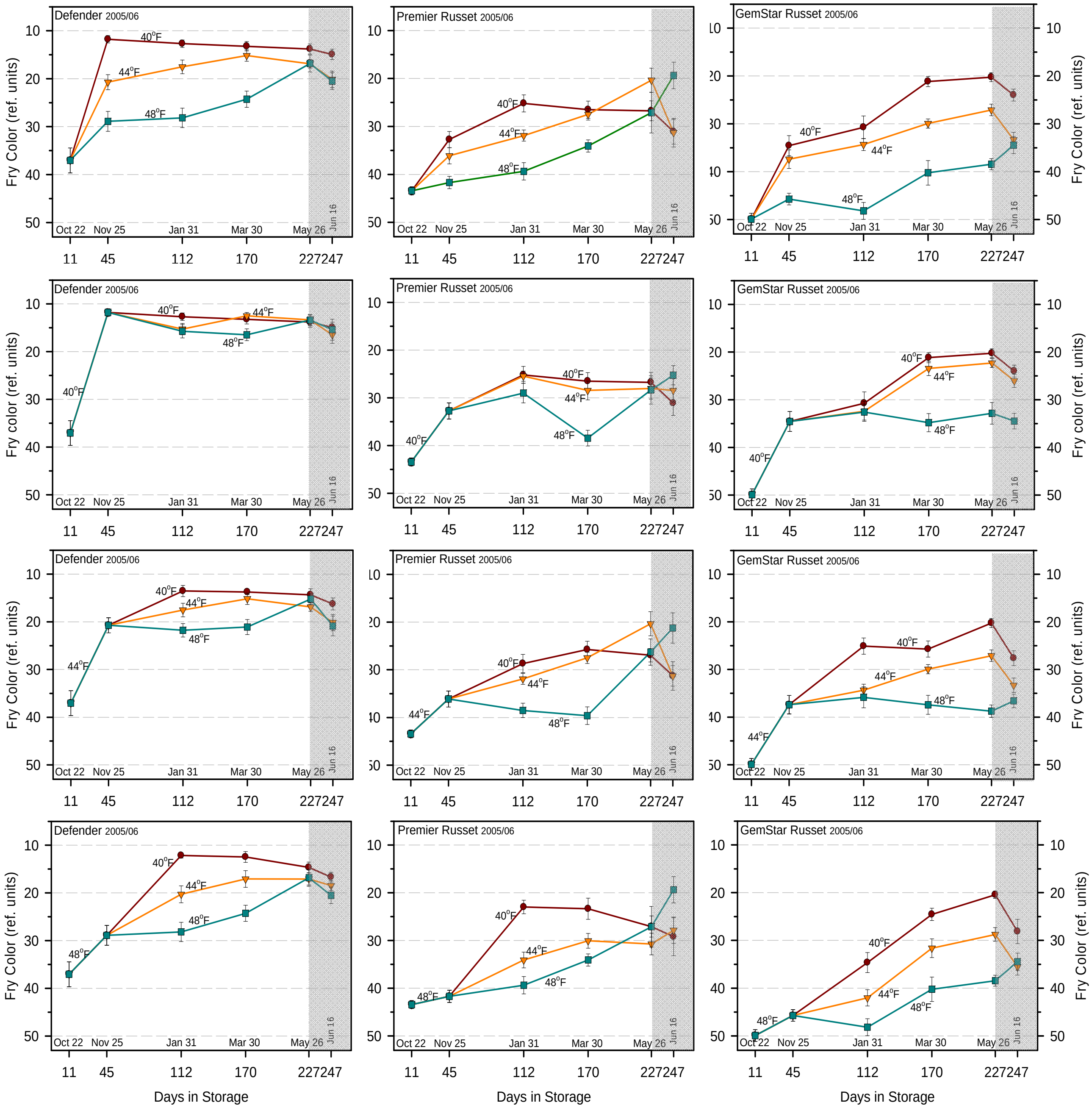

Fig. 4. Changes in the processing quality of French fries (photovolt reflectance units of the stem ends) from Defender (left column), Premier Russet (middle column), and GemStar Russet (right column) in response to different combinations of conditioning, holding, and reconditioning temperatures over a 247-day storage interval. The cultivars were grown at Othello, WA from April 13 to Oct. 11, 2005 (181 days). The 8- to 12-oz tubers were selected for subsequent storage. The tubers were wound-healed at 54°F for 11 days following harvest, conditioned at 40, 44, and 48°F for 34 days (Oct. 22-Nov. 25), and then stored at 40, 44, and 48°F (holding) for an additional 216 days (until May 26), resulting in nine conditioning/holding temperature combinations. The tubers were then reconditioned for 21 days at 60°F (May 26-Jun 16, shaded). Note the inverted scale on the French fry color axis. Low photovolt reflectance values indicate darker fries. A photovolt reflectance ≤19 is equal to a USDA 3 or greater French fry, which is unacceptable by industry standards. Each point is the average of 12 tubers ±SE.