Manipulating Stand Establishment and Yield Potential of Seed-Potatoes in Storage

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Physiological age of seed potatoes can have a substantial influence on stand establishment and overall productivity. Seed-tuber age significantly affects tuber set, total yield and grade (Iritani et al., 1983; Knowles and Botar, 1991; 1992) and is likely an important contributor to the variation in productivity observed among seedlots imported from different areas. While seed-tuber age is determined by a complex set of interactions among agronomic and environmental variables of the production and postharvest environments, we still do not understand the biochemical/physiological basis of 'old' and 'young' (and thus the different productive potentials represented by each). Moreover, the ideal age for maximum productivity depends on, among other factors, variety, length of the growing season and the particular market to which the tubers are targeted. In general, maximum yields of larger-size tubers are obtained from young seed-tubers planted in the Columbia Basin, where the growing season is quite long. In a shorter growing season area however, older seed-tubers may be desirable for production, as crop development from these tubers is accelerated, resulting in earlier tuber set and a longer bulking period over a greater portion of the available season (Knowles and Botar, 1991; 1992).

The most practical method for manipulating age and thus productive potential of seed potatoes is through management of storage temperature. Addition of heat-units during storage can accelerate the lifecycle of the crop, causing plants to set tubers earlier. This in turn provides a longer bulking period to achieve size in shorter growing season areas, or to harvest a main season crop earlier in longer growing season areas. Thus, a very effective way to alter emergence and stand establishment from, and yield potential of seed potatoes is through 'aging' the tubers in storage prior to planting. We are using this technique to modify growth and development and yield of potatoes in two independent, yet overlapping studies. The first study focuses on the extent to which seed aging can be used to modify and optimize growth and yield of Umatilla for production in the Columbia Basin. Identification of physiological markers or indices of seed-tuber age and determination of their efficacy for predicting productivity in short- and long-season growing regions is the focus of the second study.

Effects of Seed Age on Growth and Yield of Umatilla

Industry has expressed concerns regarding a number of growth characteristics of Umatilla that may negatively impact production in the Columbia Basin. These characteristics include:

- Delayed emergence
- Non-uniform emergence and stand establishment
- Low mainstem numbers leading to low tuber number per hill and a high proportion of oversize tubers in some years
- Late tuber set
- Rapid, concentrated bulking toward the end of the growing season
- Delayed foliar senescence

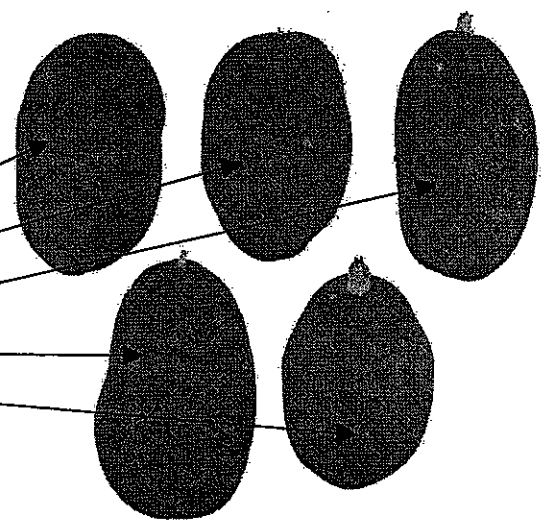
Relative to other cultivars, Umatilla tends to stay green and vigorous at the end of the season, requiring the use of desiccants to facilitate harvesting. If harvested from vigorously growing plants, tubers tend to lack maturity and are more susceptible to shatter bruise and thus Fusarium and other diseases while in storage. Shifting the annual lifecycle of Umatilla earlier in the growing season would likely improve crop quality and reduce production costs. We thus tested the efficacy of aging treatments for modifying the growth and yield responses of Umatilla in the Columbia Basin.

Five physiological ages of Umatilla seed-tubers were created in storage from Jan. 18 to March 1 (Table 1). All tubers were initially wound-healed at 54°F for 16 days at the beginning of the storage season (=126 degree-days), which approximates the age that normally would be used for commercial production in the Columbia Basin. Further aging was accomplished by storing the tubers either at a constant temperature of 90°F or by cycling the temperature between 39°F and 90°F every 3 days to create 475- and 950-degree-day seed (degree days calculated in °C above the base temperature of 4°C). The relatively high aging temperature of 90°F was selected so that accumulation of the desired degree-days could be completed in minimal time (12 and 30 days at 90°F for 475- and 950-degree day (DD) seed-tubers, respectively) to avoid the potential confounding effects of premature sprouting on growth and development. Lower aging temperatures late into the storage season would have induced appreciable sprouting and likely desiccation of the tubers during the subsequent holding period at 39°F. Moreover, by giving the degree-day treatments two different ways (constant and cycling temp. regimes), we were able to assess whether storage degree-days accurately portrayed the productive potential and thus age of Umatilla seed potatoes. Following the aging treatments, tubers were held at 39°F until planting.

Table 1. Aging treatments imposed on Umatilla seed-tubers in storage.

Seed-Tuber Portion	StorageDegree Days*	Aging Temp (°F)
Bud end	126	54
	475	90
	475	39↔90
	950	90
	950	39↔90
Stem end	126	54
	475	90
	475	39↔90
	950	90
	950	39↔90

*Storage degree days (>39°F) given from Jan 18 to March 14 (calculated in °C).



The degree to which the various aging treatments affected sprout development from Umatilla seed at the end of the storage season (prior to planting) is shown (photo with Table 1). Minimal sprouting was observed in response to the aging treatments. Furthermore, the degree of sprout development was dependent on the temperature regime used for aging. For both the 475- and 950-degree-day seed, aging at a constant 90°F resulted in less sprouting than the cycling treatment, indicating that physiological age (and thus sprouting potential) was not adequately reflected by storage degree days (unless the temperature of aging was specified). Differences in the productivity of seedpieces from bud- and stem-end tuber portions of the aged tubers were also studied, as a possible factor contributing to variability in stand establishment and yield of this cultivar.

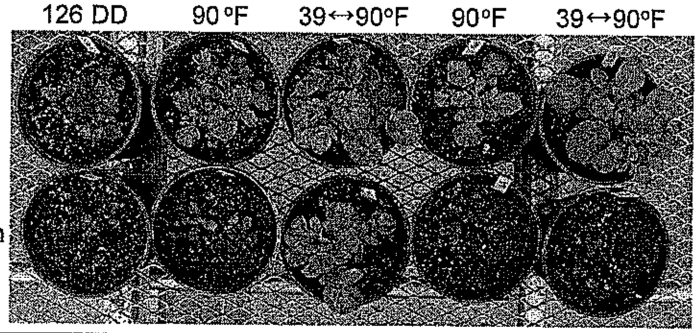
Fig. 1. Effects of seedpiece origin and tuber age on emergence and plant establishment (14-day-old plants) from Umatilla seed-tubers.

475 DD | 950 DD

126 DD | 90 °F | 39↔90°F | 90°F | 39↔90°F

Bud

Stem



Tuber portion and age greatly affected the rate of plant emergence from Umatilla seed in field and greenhouse studies. Plants emerged faster from the bud-end seedpieces and thus developed more leaf area by 14 days after planting than those from the stem-end seedpieces (Fig. 1). Emergence and stand establishment results from the greenhouse were the same as that observed in field trials. Hence, seedpiece origin (bud- or stem-end) is likely responsible for much of the variation in emergence and stand establishment observed for this cultivar in the field. Moreover, seedpiece origin and seed age interacted to affect emergence and plant establishment. Relative to control (126-DD seed), all of the age treatments hastened plant establishment from bud-end seedpieces. The cycling temperature treatments had the greatest stimulatory effects on plant establishment from bud-end seedpieces. Seed aging had much less of an effect on plant establishment from stem-end seedpieces, except for the 475-DD cycling temperature treatment. This particular age greatly stimulated plant establishment relative to control seed (126-DD stem-end seedpieces) and virtually eliminated the delayed emergence response attributable to seedpiece portion from young (126-DD) seed.

Table 2. Effect of seedpiece origin on yield, grade and size distribution of Umatilla tubers produced in the Columbia Basin. Data are for 126-DD seed.

	Seedpiece Origin		
Yield Component	Bud End	Stem End	% Change
Stem No./plant	3.6	3.3	-8
U.S. #1 Tubers/plant	7.2	6.4	-11
U.S. #1 Tubers/stem	2.0	1.9	-5
	(Tuber Yield T/A)		
Total U.S. #1	23.2	25.1	8
< 4 oz	3.3	2.3	-30
4 – 6 oz	5.9	3.8*	-36
6 – 10 oz	9.8	8.4	-14
10 – 12 oz	2.9	4.4**	52
12 – 14 oz	1.8	2.7*	50
> 14 oz	2.9	6.0**	107
Culls + U.S.#2	1.3	3.1*	138
Total	27.7	30.5	10

*,**Significant at $P < 0.05$ & 0.01, respectively

Seedpiece portion significantly affected the size distribution of tubers produced by plants grown from young (126-DD) seed. On average, plants from stem-end seedpieces produced a 33% lower yield of smaller size (<6oz.) tubers and a 72% higher yield of larger size (>10 oz.) tubers (Table 2). These effects on tuber size distribution were likely related to an 11% reduction in the number of tubers per plant from stem-end seedpieces (Table 2). Total and U.S. No. 1 yields were not significantly affected by seedpiece portion for the 126-DD seed. Hence, despite the delay in emergence and stand establishment from stem-end seedpieces, fewer tubers per plant effected greater size development. Larger size tubers (e.g. >12 oz) can be problematic for the processing industry with respect to the French fry cutting operation and obtaining fries of uniform length.

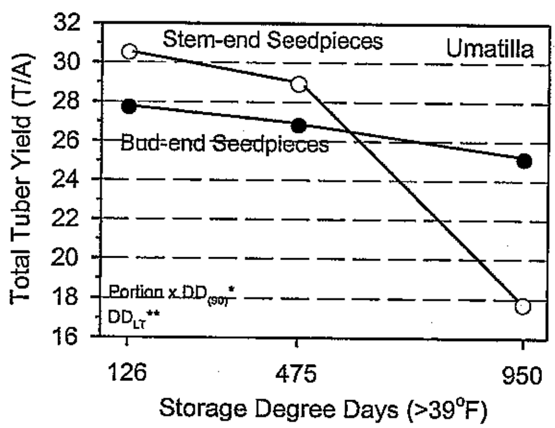


Fig. 2. Total tuber yield response from Umatilla as affected by seed-tuber age (90°F trtmt.) and portion.

The effects of the aging treatments on total yield of Umatilla depended on seedpiece portion. Aging at a constant 90°F had much less of an impact on yield of plants from bud-end seedpieces relative to that from stem-end seedpieces (Fig. 2). As seed age increased from 126- to 950-DD, total yield fell 9% and 42% for bud- and stem-end seedpiece treatments, respectively. The variation in yield attributable to seedpiece portion can thus be greatly magnified if whole seed-tubers are exposed to high temperatures for various periods following harvest. Clearly, the bud end of a seed-tuber perceives storage environment differently than the stem end, reflecting basic physiological differences between the two portions that ultimately impact yield.

Can aging treatments be used to moderate the seedpiece portion-induced variation in tuber yield and size distribution in Umatilla? The data in Table 3 indicates that aging significantly reduced the yield of larger size tubers from stem-end seedpieces (126-DD seed-tubers). The yield profile from 475-DD (cycling temperature) stem-end seedpieces more closely resembled

Table 3. Modification of seedpiece origin effects on yield of Umatilla by aging seed-tubers in storage prior to planting. Control seed-tubers = 126 DD; 475 DD = 39-90°F treatment.

Yield Components	Bud End Control	Bud End 475 DD	Stem End Control	Stem End 475 DD
Stem No./plant	3.6	4.6**	3.3	3.0
U.S. #1 Tubers/plant	7.2	8.1	6.4	7.9
U.S. #1 Tubers/stem	2.0	1.8	1.9	3.4*
	(Tuber Yield T/A)			
U.S. #1	26.4	25.2	27.4	25.6
< 6 oz	9.2	12.0*	6.0	11.4**
6 – 10 oz	9.8	9.8	8.3	8.8
> 10 oz	7.4	3.5**	13.1	5.3**
Culls + U.S.#2	1.3	1.0	3.1	0.6**
Total	27.7	26.1	30.5	26.1*

*,** Within a tuber portion, aged treatment was significantly different from control at P< 0.05 and 0.01, respectively

that from 126-DD bud-end seedpieces than that from 126-DD stem-end seedpieces. Aging thus resulted in greater yield of smaller size tubers for both bud- and stem-end seedpieces and eliminated much of the seed-portion-induced difference in yield within the various size classes. This latter effect was consistent with the more uniform plant emergence and establishment from bud- and stem-end seedpieces from aged seed-tubers (see 14-day-old plants from 475-DD, 39 to 90°F seed in Fig. 1).

In Summary:

- Seedpiece portion contributes significantly to the variation in emergence and stand establishment reported for Umatilla.
- Seedpiece portion did not affect total and No. 1 yields but did affect tuber size distribution.
- Plants grown from stem-end seedpieces produced a lower yield of <6-oz. tubers and a higher yield of >10-oz. tubers.
- Seed-tuber aging resulted in earlier, more uniform plant emergence, lower yield of >10-oz. tubers, and less variation in yield between bud- and stem-end seedpieces.

Although the aging temperatures used in this study were extreme, the results indicated that aging has potential as a management technique to modify yield and tuber size distribution without greatly impacting total and U.S. No. 1 yields of Umatilla. More moderate aging treatments are being tested to identify aging regimes that effect maximum uniformity in crop growth and yield of this relatively new cultivar.

Indices of the Productive Potential of Seed Potatoes

Biochemical markers of physiological age could be used for estimating the productive potential of seed potatoes. From a commercial production standpoint, the key questions are: How do we quantify seed-tuber physiological age at harvest? Or how can we assess the productive potential of seed-tubers before planting? Then if we can do this, how do we manipulate either physiological age (prior to planting) or agronomic management (after planting) so that we can control tuber set, size distribution and overall yield to desired specifications? Knowing the productive potential of a particular seedlot would allow for an adjustment of primary production practices to optimize yield and grade from that seed, within the constraints of a particular growing season. Our research is focusing on identifying specific biochemical/physiological markers of tuber age that may be useful for predicting yield potential.

Producing seed-tubers that possess a broad range in growth and yield potential is a prerequisite to identifying physiological markers of productivity. To accomplish this, Russet Burbank and Ranger Russet seed-tubers were acquired at harvest and stored under seven temperature/time regimes over a 200-day storage interval (Table 4). All seed-tubers received the initial 80-degree days (DD) at 54°F to facilitate wound-healing at the start of storage. Aging treatments were then given to the tubers while they were dormant at the beginning of the storage season. After the appropriate aging interval, tubers were placed at 39°F for the remainder of the storage season. Seed-tubers thus accumulated 80-, 450- and 900-degree-days (above 39°F). The 450- and 900-degree-day ages were

Table 4. Storage temperature treatments given to Russet Burbank and Ranger seed-tubers to create 7 physiological ages.

Tuber Age* (Degree days)	Aging Temperature (°F)	Aging Time (days)
80	54	10
450	54	48
450	72	20
450	90	13
900	54	102
900	72	45
900	90	29

*Storage degree days (>39°F) given from harvest through Jan (calculated in °C).

created at three different temperatures to test whether degree-days accurately reflect seed-tuber age and thus growth potential and productivity over a wide temperature range.

The only treatment that stimulated sprouting during the aging phase of the study was 900-DD at 54°F (required 102 days of storage) (Table 4). As expected, Ranger seed-tubers produced more sprouts than Russet Burbank seed-tubers in response to this treatment (data not shown). On average, Russet Burbank produced higher mainstem numbers per plant than Ranger (Fig. 3). Plant mainstem numbers increased with seed-tuber degree-days, although the response depended on cultivar and aging temperature. In general, the aging treatments were effective in creating seed-tubers with different productive potentials. U.S. No. 1 yield of Russet Burbank tubers fell linearly with tuber age (degree-days). The decline ranged from 14% (3.7 T/A) in 900-DD seed aged at 72°F to 42% (11 T/A) for that aged at 90°F (Fig. 4).

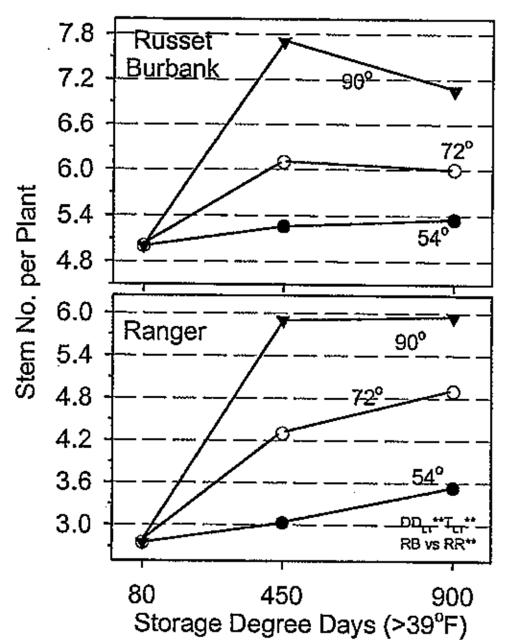


Fig. 3. Effect of seed storage temperature and degree days on mainstem numbers from Russet Burbank and Ranger seed-tubers in the field.

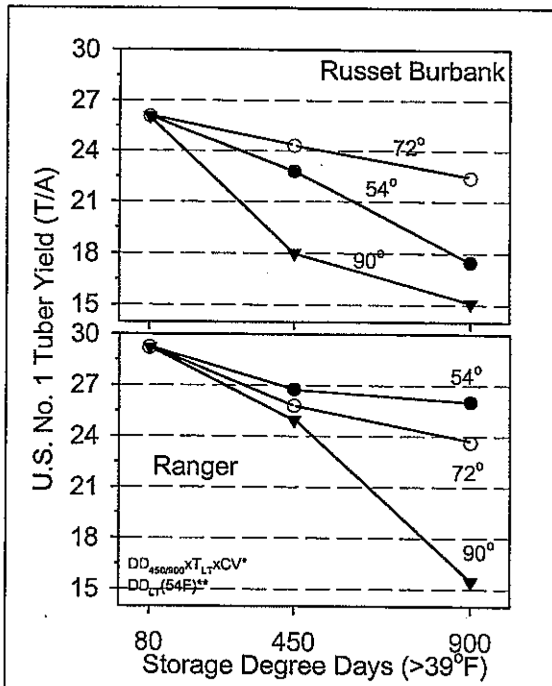


Fig. 4. Effect of seed storage temperature and degree days on the U.S. No. 1 yield response from Russet Burbank and Ranger seed-tubers

Degree-days and aging temperature interacted to affect tuber size distribution (data not shown). Yield responses to the aging treatments were also somewhat dependent on cultivar (Ranger vs. Russet Burbank) (Fig. 4) and seed source (data not shown). For a particular cultivar, seed-source effects reflected an impact of seed growing environment on tuber physiological status, which in turn altered tuber response to the aging treatments in storage (data not shown).

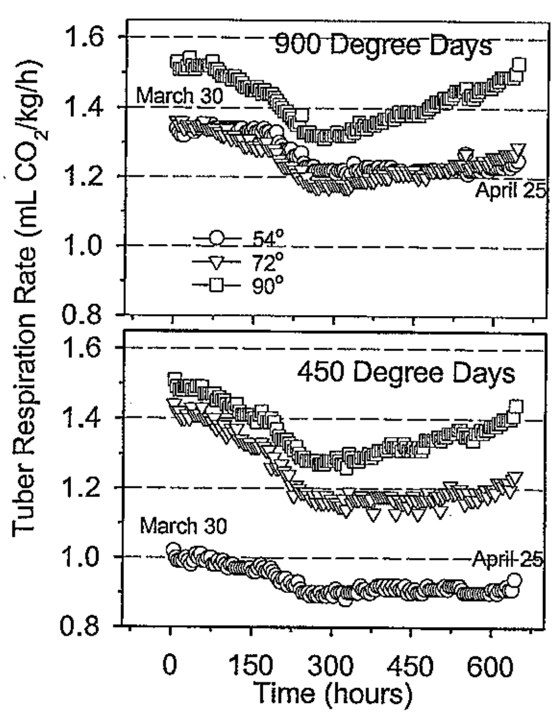


Fig. 5. Effect of aging temperatures and storage degree days on respiration of Russet Burbank seed-tubers after 6.5 months of storage. Tubers were held at the aging temperatures for various periods (see Table 4) directly following harvest. Respiration rates were measured at 39°F prior to planting.

The goal of the aging treatments was to produce seed that had a range in vigor and yielding ability so that physiological and biochemical markers that correlate with the different yield potentials could be identified. Although our research is far from complete, the aging treatments have been very successful in this regard. Physiological indicators of age were measured in tubers at the end of storage concomitant with planting. The tuber age markers were classified into: (1) general indicators of overall metabolic status (2) indices of protein mobilization and (3) measures of the degree of oxidative stress. Examples of the effects of tuber age on selected indices of tuber metabolic status and protein mobilization appear below.

Whole-tuber respiration reflects overall metabolic activity, and thus can indicate whether heat-unit accumulation during aging in storage affected the basal metabolic rates of tubers. Tubers aged at higher temperatures at the beginning of the storage season (e.g. 90°F) had higher respiration rates while still at 39°F at the end of the storage season (Fig. 5). Hence, 450-DD at 90°F induced a higher metabolic rate than 450-DD at 54°F, and this in turn led to different physiological ages and thus growth and yield responses in the 450-DD seed. Similar trends in respiration rate with aging temperature

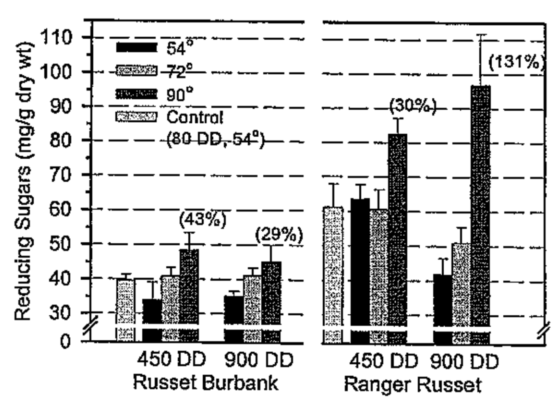


Fig. 6. Effects of aging temperature and storage degree days on reducing sugar content of Russet Burbank and Ranger seed-tubers at the end of a 200-day storage season. Tubers were aged as indicated in Table 4.

were apparent during sprouting at room temperature at the end of the 6.5-month storage period (data not shown).

Reducing sugar content of seed-tubers was also assessed at the end of the 6-month storage period, just prior to planting. Relative to control (80-DD seed), reducing sugar concentration decreased as age increased to 450-DD at 54°F in Russet Burbank seed-tubers (Fig. 6). Sugars increased linearly in aged (450- and 900-DD) Russet Burbank tubers with increasing temperature of aging. Ranger was particularly sensitive to high temperature (90°F) exposure at the beginning of the storage season, which resulted in substantially higher sugar levels by the end of the storage season in the 450- and 900-DD tubers, respectively. Interestingly, aging of Ranger for 900-DD at 54 and 72°F at the beginning of storage resulted in significantly lower sugar buildup at the end of the storage season relative to control (80-DD) tubers. This should be explored further as a potential method by which tuber-processing quality could be maintained longer in tubers stored at lower temperatures.

Tuber protein is broken down during sprouting to supply the developing sprouts with nitrogen for their growth. Proteinases are enzymes that break down tuber proteins and are thus responsible for liberating the nitrogen to support plant growth during establishment. On the other hand, proteinase inhibitors are enzymes that inhibit protein breakdown. Since aging affected the speed and degree of stand establishment, along with the number of sprouts per tuber, it was reasonable to expect that the degree of protein mobilization may differ with seed-tuber age. Changes in the relative activities of proteinases and proteinase inhibitors may thus constitute sensitive markers of tuber age.

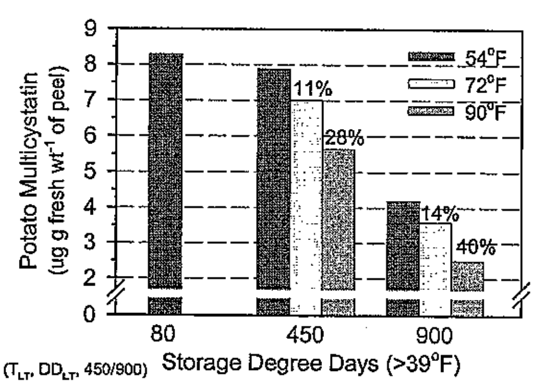


Fig. 7. Effects of aging temperature and storage degree days on PMC content of Russet Burbank seed-tubers at the end of a 200-day storage season. Tubers were aged as indicated in Table 4.

Temperature of aging and degree days had no resolvable effects on total soluble protein content of tubers; however, the concentration of potato multicystatin (PMC) decreased with increasing degree-days and aging temperatures (Fig. 7). PMC is a potent inhibitor of proteinases and thus protein breakdown in potato. Other proteinase inhibitors showed similar trends with degree-days and aging temperatures. As expected, tubers aged at 72° and 90°F had significantly higher levels of proteinase activity than those aged at 54°F (data not shown). The activities of proteinase inhibitors appear to correlate well with degree-days and temperature of aging and, pending further research, may provide an index of the age and productive potential of seed potatoes.

Concluding Remarks

This report displays a small fraction of the biochemical, physiological, growth and yield data that we have gathered to date on this project. An overall summary of two years of marker analysis for tuber age appears in Table 5. While this table does indicate markers that show promise in resolving differences in metabolic status of various ages of seed-tubers, it greatly oversimplifies the results. For example, changes in many of the markers were defined by interactions among storage temperature, degree-days, cultivar and seed source, as was the case for the growth and yield results. Correlation's among age-marker levels; plant growth and yield-potential differences will be developed based on 3 years of data, following the 2001-growing season.

Table 5. Potential physiological and biochemical markers of seed-tuber age assessed to-date. Asterisks indicate whether the marker changed significantly with seed source (production region), cultivar and/or age of seed-tubers. (?) remains to be determined. (-) no change in marker.

Potential Markers of Age	Seed-Tuber Source	Seed-Tuber Cultivar	Seed-Tuber Age
I. Overall Metabolic Status			
• Tuber Respiration	*	*	**
• Soluble Sugars	**	**	**
II. Protein Mobilization			
• Protein Content	-	**	**
• Proteinase Inhibitors	?	**	**
• Proteinases	?	?	**
• Protein Profiles	-	**	-
III. Oxidative Stress			
A. Biochemical Indices			
• Malondialdehyde	-	**	**
• Tuber Volatiles	**	?	**
B. Enzymes			
• Lipolytic acyl hydrolase	*	**	-
• Superoxide dismutase	**	**	*
• Glu-6-P dehase	-	-	**
• 6-Phospho gluc dehase	-	-	-
• Glutathione Reductase	?	?	?
• Catalase	?	?	?
• Peroxidase	?	?	?

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