Shifting Potato Tuber Size Distribution with Plant Growth Regulators

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Introduction & Background

Potato tuber size distribution can substantially affect crop value. The optimum size distribution for maximum value depends on end use. Different markets (fresh pack, processing, seed) pay premiums for various size classes of potatoes; hence, there is great interest in developing techniques to predict and control tuber set and size distribution. For fresh market potatoes, tubers are often graded according to diameter (e.g., round, colored skin/flesh specialty cultivars) and/or weight (e.g., long russet bakers) and packed into 50 lb cartons with returns dependent on carton count (Fig. 1 C). Tubers less than 1 5/8 inch (41 mm) diameter often bring a premium price as baby potatoes ('creamers') for their high nutritive values and for use in the gourmet restaurant trade. Seed growers strive to produce smaller tubers that result in less waste and 'blind' seed when cut into seedpieces, and some commercial growers pay a premium for 'single-drop' whole seed.

Tuber set and size development are correlated with the degree of apical dominance (i.e. number of stems) produced by seed tubers (Knowles & Knowles, 2006). Factors that affect stem number and/or tuber size distribution include cultivar, crop maturity (harvest date), seed age, seed spacing, and plant growth regulators. Two plant growth regulators in particular have potential for modifying tuber size distribution – auxin and gibberellins. Studies were conducted to:

- Model the relationships between stem number tuber set, tuber size distribution, and crop value for selected cultivars.
- Determine the extent to which treatment of seed with auxin and gibberellin can modulate apical dominance to effectively shift tuber size distribution for added crop value.

Results

Stem Number, Tuber Set, Size Distribution & Crop Value Relationships

Temperatures greater than 39^{o}F (i.e. heat-unit accumulation) increase seed-tuber respiration and accelerate physiological aging. Apical dominance, tuber set, tuber size distribution, and economic return can be greatly affected by differences in the physiological age of seed (Knowles and Knowles, 2006). The degree of apical dominance is a good indicator of physiological age. As seed age advances, apical dominance decreases, resulting in more stems per plant. While cultivars vary in the extent of their response to seed age, in general, tuber set per plant increases with stems, resulting in a decrease in average tuber size.

Tuber set and size distribution can be optimized for a particular market by increasing or decreasing the average number of stems per seedpiece, without affecting overall yield (Knowles and Knowles, 2006). The values of seed, fresh-market, and processing potatoes are dictated in part by the specific array of tuber size classes; therefore, manipulating tuber size profiles by varying the physiological age of seed lots can significantly affect crop value. The extent of aging induced by a given period of high temperature exposure and the target stem number for a particular size distribution are cultivar-dependent.

The relationships among stem numbers, tuber set, tuber size distributions, and crop value have been determined for many mainstream long-russet cultivars (e.g. Ranger Russet, Umatilla Russet, Russet Burbank, Russet Norkotah) (see Knowles and Knowles, 2006; Knowles et al., 2008). An example of these relationships is shown for Russet Norkotah CO strain 3 in Fig. 1.

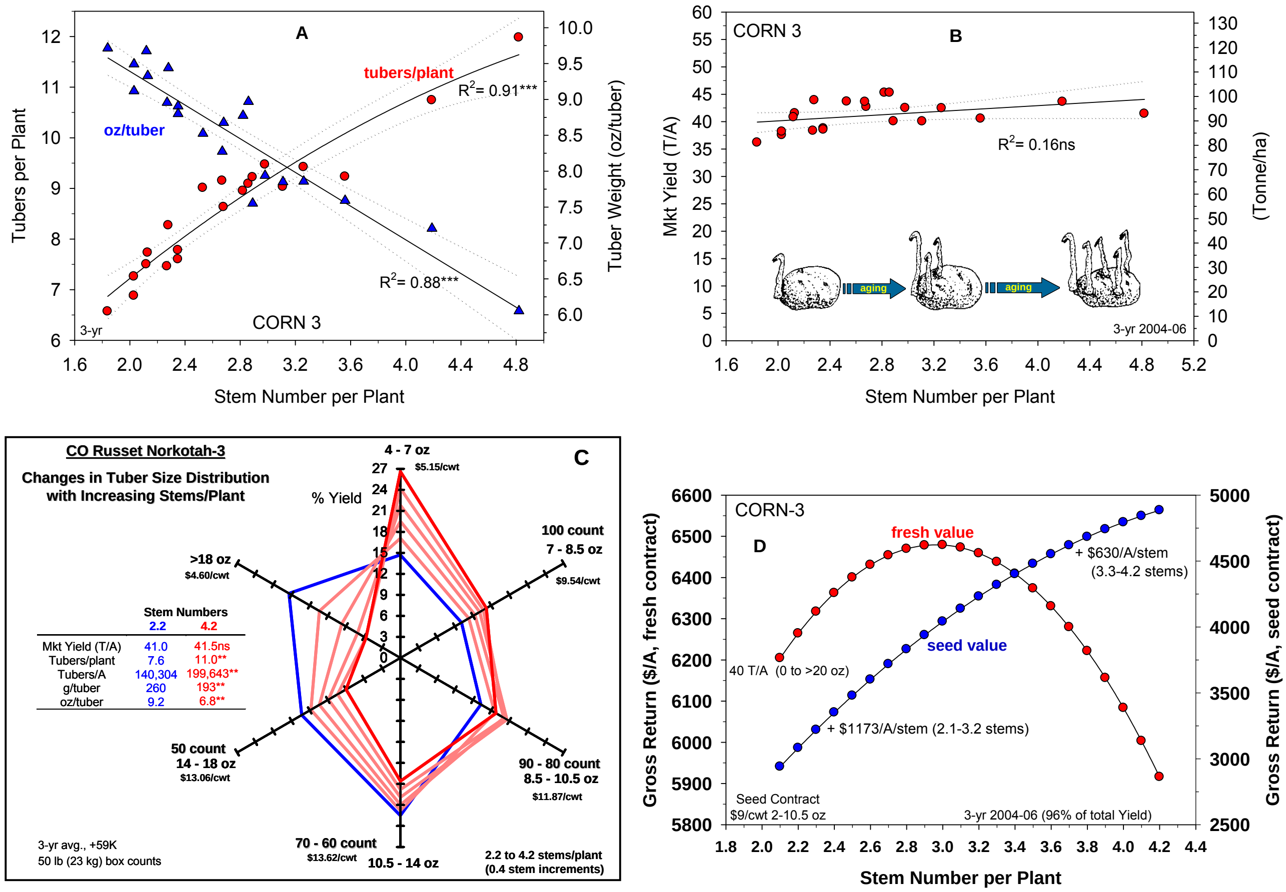


Fig. 1. Stem number, tuber set (A), marketable yield (B), tuber size distribution (C), and crop value (D) relationships for Colorado Russet Norkotah selection 3 (CORN 3) potatoes in the Columbia Basin. Data are averaged over three growing seasons. The overlapping polygons (C) illustrate the progressive shift in tuber size distribution as stem number increases in increments of 0.4 from 2.2 stems (blue polygon) to 4.2 stems (red polygon). The broad range in stem numbers (i.e. degree of apical dominance) was created by storing seed tubers at different temperatures over a 200-day storage period. Higher storage temperatures accelerate tuber aging, resulting in more stems (inset B). The ideal number of stems for maximum value of fresh market and seed potatoes was 3.0 and 4.2 stems per seedpiece, respectively, for CORN 3 (D).

<u>Auxin Restores Apical Dominance & Decreases Tuber Set</u>

Apical dominance (the inhibition of growth of lateral buds by the terminal bud of a stem) is hormonally regulated and strongly affected by cultivar and the physiological age of seed (Table 1 and schematic). Auxin is a growth promoting plant hormone involved in regulating apical dominance (Fig. 2). Auxin (IAA), produced by the apical meristem of an actively growing sprout, is transported to lateral buds in the eyes of a tuber. The auxin concentration builds to a level sufficient to inhibit growth of lateral sprouts. As tuber physiological age advances, the ability to translocate auxin decreases, contributing to reduced apical dominance and multiple sprouts from older seed-tubers.

Table 1. Effect of degree-day accumulation as an aging treatment on apical dominance (stem numbers) of Ranger Russet and Russet Burbank seed-tubers. Seed-tubers were aged as described in Fig. 3. Older seed produces more stems and this has a direct impact on tuber set and size distribution. The degree of apical dominance and response to accelerated aging treatments is cultivar dependent.

Seed Age[1]	Stems per Seedpiece	
	Ranger	Burbank
Young	2.6	3.3
Old	4.7**	5.9**

[1]80 and 600 degree days at 32°C (90°F). **P<0.01.

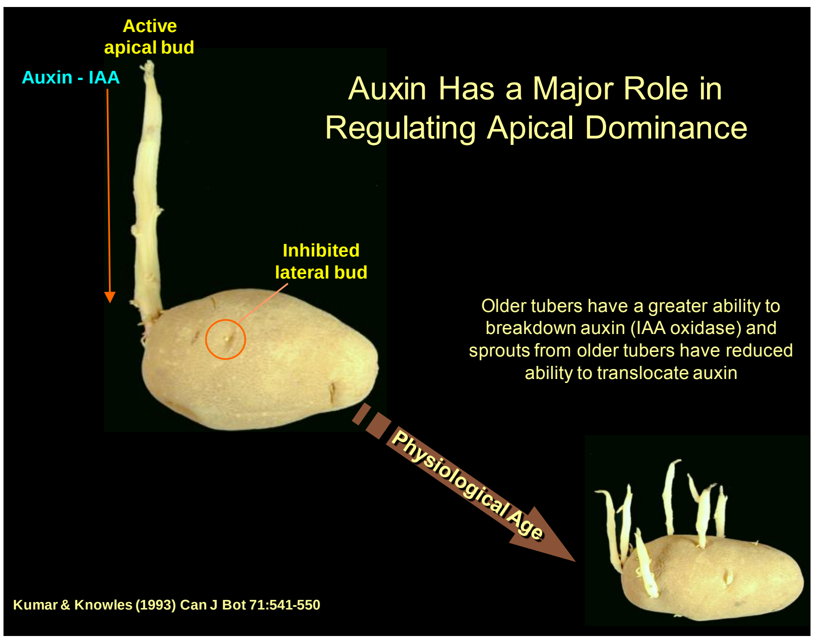
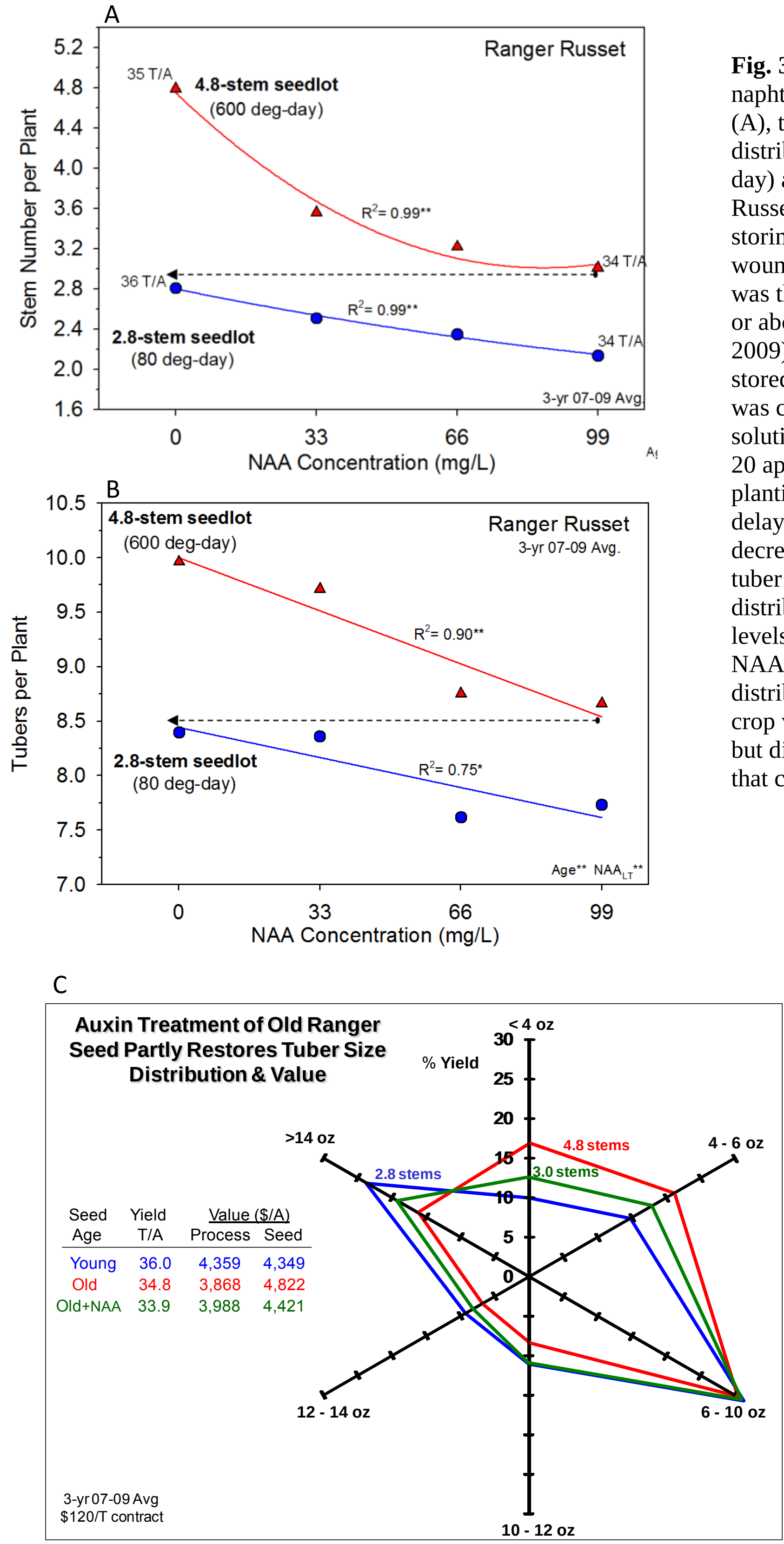


Fig. 2. Schematic diagram illustrating a regulatory role for auxin in the loss of apical dominance with advancing age of seed-tubers.

Studies were conducted to determine if treatment of physiologically older seed with auxin can restore apical dominance and shift tuber size distribution toward larger tubers. Auxin (NAA) effectively decreased stem number, tuber set, and increased average tuber size when applied to older seed (Fig. 3). NAA is also effective for increasing apical dominance and shifting tuber size distribution in cultivars that have an inherent tendency to produce too many stems (data not shown).



Seed Age	Yield T/A	Value ($/A) Process	Value ($/A) Seed
Young	36.0	4,359	4,349
Old	34.8	3,868	4,822
Old+NAA	33.9	3,988	4,421

Fig. 3. Effects of auxin (NAA, naphthalene acetic acid) on stem numbers (A), tuber set (B), and tuber size distribution (C) from young (80 degree-day) and old (600 degree-day) Ranger Russet seed. Seed-tubers were aged by storing at 90°F for 19 days after a 10-day wound-healing period at 54°F. The seed was then placed at 39°F until planting on or about April 15 in all 3 years (2007-2009). Young (80 degree-day) seed was stored at 39°F after wound-healing. Seed was cut and treated by immersing in solutions of NAA containing 0.1% Tween 20 approximately four days prior to planting. NAA treatment of old seed delayed plant emergence (not shown), decreased stem numbers (A), restored tuber set (B), and shifted tuber size distribution (C) to more closely match levels characteristic of young seed. The NAA-induced shift in tuber size distribution of old seed (inset C) increased crop value (process contract) by $120/A, but did not totally restore crop value to that characteristic of younger seed.

Gibberellins Hasten Emergence, Decrease Apical Dominance & Increase Tuber Set

Gibberellins (GA) are plant hormones that have a number of growth promoting effects, including hastening release from dormancy and stimulating stem elongation. We investigated the extent to which GA treatment of seed could be used to increase stems and thus tuber set to produce smaller tubers to add value to selected specialty cultivars destined for the fresh market.

Certified seed-tubers of five cultivars (Satina, Cal White, Red LaSoda, Yukon Gold, Chieftain) were acquired directly from a commercial grower in October 2010. The seed was stored at 39°F from October 10, 2010 to April 6, 2011. In preparation for planting, seed-tubers were cut (50-64 g seedpieces), stored for 2 days at 48°F (98% RH), treated on April 8 by immersing for 5 min in 0, 2, 4, or 8 ppm GA (0.1% Tween 20), and held at 48°F until planting on April 11, 2011 (3 days after treatment).

The seed was planted 8 inches deep into replicated 20-foot plots at the WSU Othello Research Unit. Seed was spaced 10 inches apart within a row and rows were 34 inches apart on center. Five replicates of each treatment (four GA concentrations) were planted in a randomized block design for each cultivar. The effects of GA on plant emergence, stem number, tuber set, yield and tuber size distribution were evaluated separately for each cultivar. Emergence data was collected from May 10 through June 16. Stems were counted on June 16 (Cal White) and June 20 (other cultivars). In preparation for harvest, vines were removed with a flail type mower. Vines of Yukon Gold, Satina, and Cal White were mechanically mowed on July 25 (105 days after planting) and Chieftain and Red LaSoda on July 29 (109 days after planting). Plots were harvested Aug. 4 (Yukon Gold, Satina, Cal White) and Aug. 8 (Red LaSoda, Chieftain). Tubers were counted, graded (U.S. #1's, 2's, culls), and weighed. Treatment effects on tuber size distributions were assessed on a 50-lb carton count basis as well as for "A", "B" and "C" grades. The effects of GA on total, U.S. No. 1 (>4 oz), and marketable yields (U.S. #1 + < 4 oz) were determined.

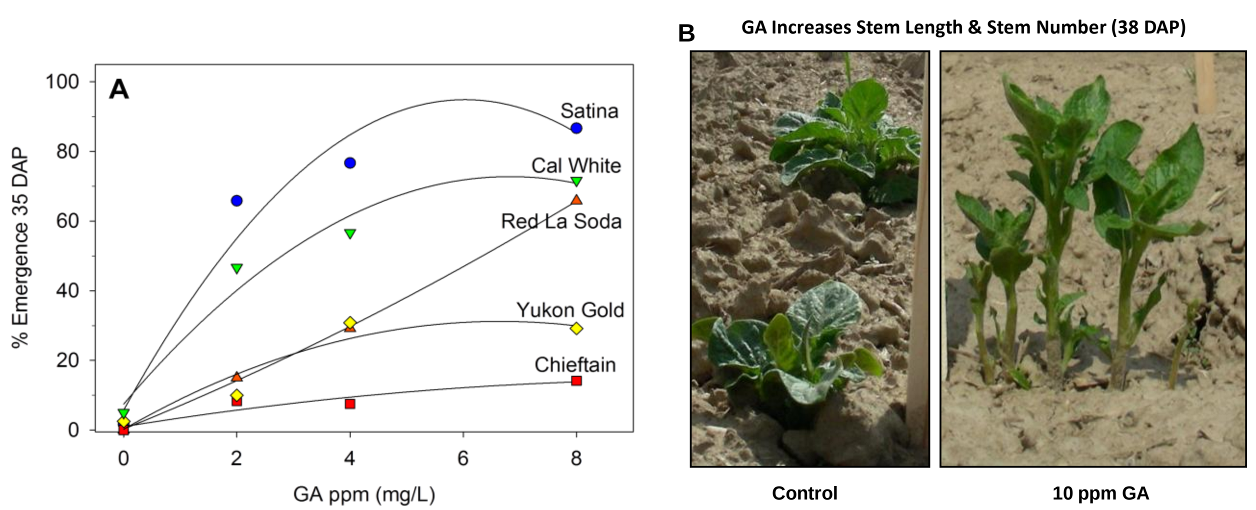


Fig. 3. Gibberellin (GA) treatment of seed of five fresh market potato cultivars hastened plant emergence **(A)** and stimulated elongation of plant internodes, which resulted in an upright growth habit of plants during establishment. The distinctive upright morphology of plants from GA-treated seed is depicted for cv. Summit Russet **(B)** at 38 days after planting (DAP). This effect of GA was no longer apparent by 60 DAP.

Plant emergence occurred from approximately 25 to 57 days after planting (DAP) for all cultivars. At 35 DAP, plant emergence from non-treated seedlots was 0% for Red LaSoda, 1.7% for Satina, 5% for Cal White, 2.5% for Yukon Gold, and 0% for Chieftain (Fig. 3). Relative to non-treated seed, GA significantly hastened plant emergence (Fig. 3) and the effects were concentration-dependent.

Satina was the most sensitive cultivar to GA-induced stimulation of plant emergence, attaining 87% by 35 DAP when treated with 8 ppm GA. Plant emergence from the 8 ppm GA-treated seed of Cal White, Red LaSoda, Yukon Gold, and Chieftain was 72, 66, 29, and 14%, respectively, at 35 DAP. All cultivars achieved 100% plant emergence by 57 DAP.

On average, non-treated seed of Satina produced the most stems (3.3) followed by Red LaSoda and Cal White (2.9), and Yukon Gold and Chieftain (2.4) (Fig. 4, table insets). GA significantly reduced apical dominance (increased stems) in all cultivars and the effect was concentration-dependent. The maximum GA-induced increase in stems was greatest for Cal White (83% increase) followed by Yukon Gold (79%), Chieftain (67%), Satina (55%), and Red LaSoda (31%). Except for Red LaSoda, the greatest change in stem number was apparent with only 2 ppm GA (increases over non-treated seed ranged from 54-76% depending on cultivar) (data not shown). The greatest change in stem number for Red LaSoda was observed between 0 and 4 ppm GA. Increasing GA levels higher than 2 or 4 ppm did not result in further increases in stem number (Fig. 4, inset tables).

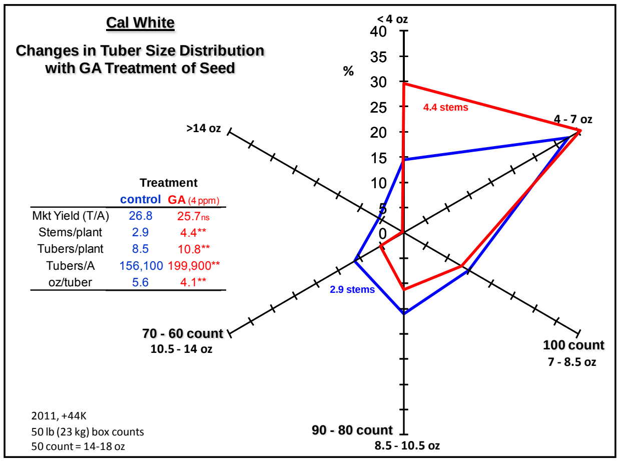
Total and U.S. #1 yields were greatest for Red LaSoda followed by Cal White, Chieftain, Satina and Yukon Gold (data not shown). Treatment of seed with GA significantly affected yields, tuber set, average tuber size, and tuber size distributions compared with non-treated seed (Fig. 4). At 8 ppm, GA decreased total, U.S. #1 (>4 oz), and marketable (U.S. #1 + <4 oz) yields for all cultivars except Satina (data not shown). However, lower concentrations of GA (2 and 4 ppm) either had no effect on total and marketable yields (4 cultivars) or significantly increased these yields (Satina) (Fig. 4).

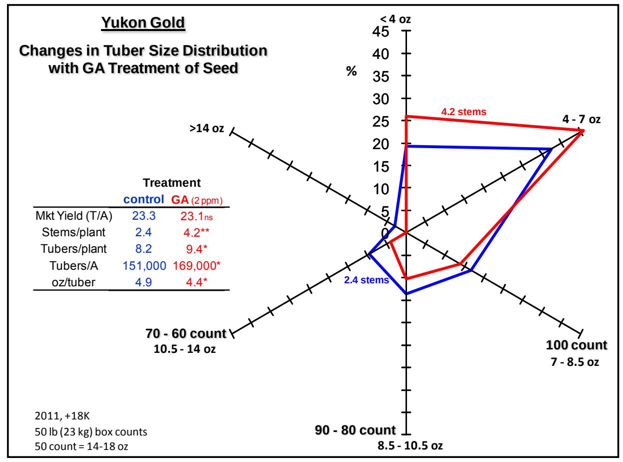
Relative to non-treated seed, GA increased tuber set per plant and decreased average tuber fresh weight in all cultivars (Fig. 4 and inset tables). Maximum tuber set per plant was achieved with 2-4 ppm GA. For all cultivars, GA reduced the yields of larger tubers and increased the yields of smaller tubers. This effect was apparent regardless of whether the tubers were sorted into weight categories corresponding to 50-lb carton counts (Fig. 4) or sorted based on “A”, “B” and “C” diameters (converted to weight equivalents) (data not shown).

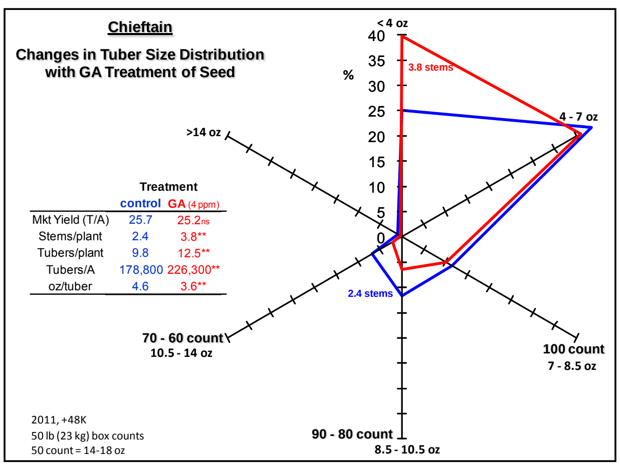
Tuber size profiles were dominated by a high percentage of 4- to 7-oz tubers and relatively low percentage of tubers greater than 10.5 oz (Fig. 4). Satina produced the smallest tubers compared with the other cultivars, with negligible yield of tubers over 8.5 oz.

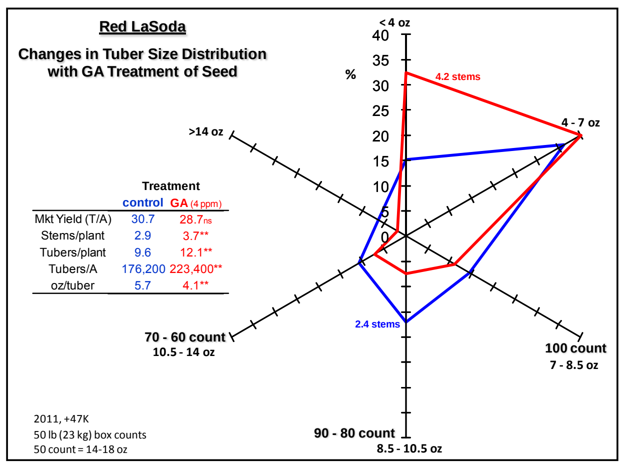
The GA-induced shift in tuber size distribution is clearly evident in the polygonal diagrams of Fig. 4. At the ideal concentrations of 2 or 4 ppm (depending on cultivar), GA increased stems, tubers per plant and per acre, and decreased average tuber size without reducing marketable yields (U.S. #1 + <4 oz tubers) (Fig. 4 table insets). For all cultivars, GA treatment decreased the percentage of 7 oz and greater tubers, and increased the percentage of tubers less than 7 oz. Red LaSoda showed the greatest GA-induced shift in size distribution followed by Cal White, Chieftain, Yukon Gold, and Satina. While concentrations of GA higher than those specified in Fig. 4 also shifted tuber size distributions, the decrease in marketable yield would likely offset any potential benefits (value) of smaller size tubers. Higher concentrations of GA (e.g. 8-10 ppm) stimulated elongation of tubers (increased length/width ratio) and the extent of this response was cultivar-dependent (data not shown). Yukon Gold and Cal White responded to increasing GA concentration with increased yields of #2 grade tubers, which partly reflected their increased sensitivity to elongation and pointed ends as a result of GA treatment. The greatest decreases in apical dominance, increases in tuber set and shifts in tuber size distribution occurred at the lowest concentrations of GA (Fig. 4). Hence, lower concentrations of GA can be used to effectively alter tuber size distribution while maintaining yield potential and tuber shape in these cultivars.

Effects of the GA-induced changes in tuber size distribution on crop values depended on cultivar. Tubers were graded into ‘A’, ‘B’ and ‘C’ USDA size classes and values were calculated based on the USDA Agricultural Marketing Service 4-year average price (post packhouse) for 50 lb cartons of each grade on approximately the day of harvest. The GA-induced shift to smaller size tubers increased the overall crop values of Satina and Chieftain by 22 and 5%, respectively (Table 2). The shift in tuber size distribution of Yukon Gold with 2 ppm GA was not sufficient to change overall crop value (fresh contract) and increasing the concentration to 4 ppm decreased the U.S. No. 1 yield, resulting in loss of value. Returns could be much different depending on market (e.g. seed) and/or specific contracts for custom packaging (e.g. 1 lb poly), which would substantially alter values associated with GA treatment of the different cultivars.









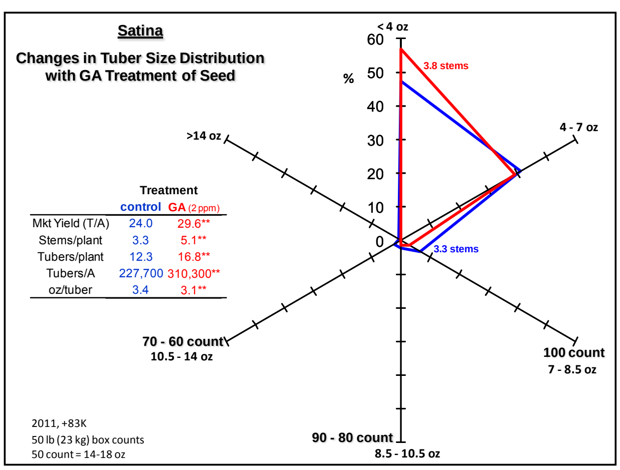


Fig. 4. Effects of GA on yield, stems per plant, tuber set, and tuber size distributions of five fresh market cultivars. Seed was cut and treated by immersing in GA (2 or 4 ppm) prior to planting. The yields (as % U.S. #1) of <4-oz, 4-7 oz, 7-8.5 oz, 8.5-10.5 oz, 10.5-14 oz, and >14-oz U.S. No. 1 tubers are plotted on the six axes for each cultivar. The 50 lb carton counts associated with selected grades are indicated. Shifts in position of the red polygons relative to the blue polygons illustrate the effect of GA on tuber size distribution for each cultivar. Yield, stem number, tuber set, and average tuber size are shown in the inset tables. Note that GA significantly increased stems, tubers per plant and per acre, and decreased average tuber size. At 2 or 4 ppm, GA either had no effect on U.S. # 1 yields (4 cultivars.) or increased yield (Satina).

Table 2. Changes in values of the U.S. No. 1 tuber yields of cultivars Yukon Gold, Satina, and Chieftain as affected by treatment of seed with GA (gibberellin). Tubers were graded into 'A', 'B' and 'C' USDA size categories and values were calculated based on the USDA Agricultural Marketing Service 4-year average price (post packhouse) for 50 lb cartons of each grade. (A's = 61-101 mm diameter, ~4-20 oz.; B's = 39-61 mm, ~2-4 oz.; C's (creamers) = 20-39 mm, ~0.5-2 oz). The GA-induced shifts in tuber size distribution are depicted in Figure 4.

Cultivar	GA ppm	Yield T/A	% Change in value from control			Total % Change
			A's	B's	C's	
Yukon Gold	0	23.0	0.0	0.0	0.0	0
	2	23.2	-7.5	38.1	-19.2	-0.4
	4	19.3	-29.3	40.3	21.5	-17.1
Satina	0	24.1	0.0	0.0	0.0	0
	2	29.6	0.9	48.2	45.5	21.9
	4	27.7	-14.2	46.7	73.7	13.6
Chieftain	0	25.8	0.0	0.0	0.0	0
	2	26.6	-13.7	51.7	96.1	5.0
	4	25.2	-21.4	53.1	142.2	0.3

Summary & Conclusions

- The ability to predict and modulate tuber set and size distribution is of great interest to the potato industry.
- Tuber set and size distribution are highly correlated with the degree of apical dominance (stem numbers) produced by seed-tubers.
- Early season stem counts are a good predictor of tuber set and size development but the specific relationships are cultivar dependent.
- Apical dominance is affected by seed-tuber physiological age, is hormonally regulated and cultivar dependent.
- Treatment of seed with auxin is an effective method for restoring apical dominance, reducing tuber set, and increasing average tuber size for seed lots of advanced age or for cultivars that naturally produce excessive stems, and where larger tubers are desired.
- Treatment of seed with GA is an effective method for reducing apical dominance, increasing tuber set, and decreasing average tuber size for physiologically young seed lots or for cultivars (e.g., Yukon Gold, Cal White, Chieftain, Satina, and Red LaSoda) that inherently produce too few stems with low tuber set, are resistant to aging, and where smaller tubers are desired.
- Applications of NAA and GA to modulate tuber size distribution can substantially alter crop value.

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