Enhancing Tuber Calcium by in-Season Calcium Application can Reduce Tuber Bruising during Mechanical Harvest

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Abstract

Previous field experiments suggest that supplemental calcium applications can increase tuber calcium and decrease the incidence of internal defects. The present study extends this research to determine if tuber calcium deficiencies may also contribute to heightened bruise potential. For three seasons, 1999-2001, two commercially relevant (*Solanum tuberosum* L.) cultivars ('Russet Burbank', 'Atlantic') were supplied in the field with 168 kg.ha^{-1} supplemental calcium in a complete randomized design (three split applications) while control plots were given none. The supplemental calcium treatment CUC consisted of calcium nitrate, calcium chloride and urea. All plots received equal nitrogen. Calcium levels increased dramatically following supplemental calcium application with increase up to 30% compared to control. This result is consistent with earlier research showing that tuber calcium concentration can be significantly increased by application of soluble calcium during the tuber bulking period. Our results also demonstrated that, analyzed over three seasons, cultivars 'Atlantic' and 'Russet Burbank' showed reduction in blackspot bruising with calcium treatment as compared to control. Though the exact mechanism has not been determined, research suggests that improvement of tuber calcium concentration may lead to improved cell membrane stability and wall structure. Our study provides evidence that we have the potential for reducing tuber bruising through in season application of calcium.

INTRODUCTION

Tuber bruising of commercially cultivated potatoes occurs during harvest, handling and storage and can render tubers unsuitable for fresh market, increase processing costs or affect seed piece performance. Bruising can also predispose stored tubers to loss by microorganisms and premature physiologic aging. Bruised tubers are known to have elevated levels of respiration (Pisarczyk, 1982), which in turn can render tubers more susceptible to bacterial soft rot (Bartz and Kelman, 1986). Several other cultural factors also contribute to susceptibility including cold handling temperatures and dehydration (Thornton and Timm, 1990), maturity at the time of harvest (Pavek et al., 1985), and harvesting equipment (Brook, 1996).

Several studies have examined an association between mineral nutrition and incidences of tuber bruising. According to Brook (1996), potassium and nitrogen are most often cited as influencing tuber susceptibility to bruise. Nitrogen in excess is capable of affecting tuber size, reducing dry matter and delaying maturity (Kunkel, 1968; Reeve et al., 1971 and 1973). Similar conclusions are drawn about phosphorus, which does not appear to directly affect susceptibility except as they affect tuber maturity (Brook, 1996). Potassium deficiency has also been reported to be associated with a higher blackspot bruise incidence (Aeppli and Keller, 1979).

Potato tubers are underground storage organs with low rates of transpiration. Since water and calcium move together, organs with low transpiration exhibit calcium deficiency (Palta, 1996). Recent studies have provided evidence that tuber calcium concentration can be significantly enhanced by in season application of water soluble

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calcium in the soil surrounding the tubers (Kratzke and Palta, 1985 and1986; Kleinhenz et al., 1999). Recent studies have also provided evidence that by increasing tuber calcium, one can expect a dramatic reduction in the internal defects such as internal brown spot and hollow heart (Kleinhenz et al., 1999; Ozgen et al., 2000; Karlsson et al., 2001). These studies provide evidence that tuber tissue health can be improved by in season application of calcium fertilization. Because both internal defects (brown center and internal brown spot) and bruise involve discoloration of tuber tissue it follows that localized calcium deficiencies may also contribute to heightened bruise potential.

The present study was undertaken to investigate the potential of reducing tuber bruising by in season supplemental calcium applications. Our objective was to compare the effectiveness of a supplemental calcium formulation in field grown and machine harvested potatoes to the control ammonium nitrate treatment. Over the period 1999-2001, two cultivars and over 2000 tubers were analyzed for blackspot bruise for each treatment.

MATERIALS AND METHODS

Certified, whole A-grade seed tubers of (cvs 'Atlantic' and 'Russet Burbank') potato were cut, suberized and planted on a Plainfield loamy sand (sandy, mixed, mesic, Typic Udipsamment) in 1999, 2000, and 2001 under linear irrigation at the University of Wisconsin Hancock Agriculture Research Station, Hancock. Individual plots consisted of two 6.1 m experimental rows bordered by two 6.1 m guard rows. In-row seed tuber and between row spacing was 30 and 91 cm, respectively. (Treatments are listed in Table 1). Starter fertilizer (6:24:24) pretreated with admire was applied at a rate of 560 kg.ha^{-1}. At emergence, 392 kg.ha^{-1} of ammonium sulfate (21-0-0) was given. Total nitrogen was 255 kg.ha^{-1} to all treatments. The balance of 138 kg.ha^{-1} of nitrogen was split equally into these applications starting at hilling, using ammonium nitrate for control treatments and a combination supplemental calcium treatment of liquid calcium nitrate, solid calcium chloride and urea designated 'CUC'. A completely randomized design was used in all years. Irrigation was applied when needed to replace soil water lost due to evapotranspiration. Weed, disease, and insect pest pressures were maintained by using cultivation and agrichemicals common to commercial practices in the Central Sands region of Wisconsin. For applications made at hilling, 3 weeks after hilling and 6 weeks after hilling half the fertilizer was diluted and dispensed from a calibrated container containing 6 L solution in one direction uniformly to the top of the hill with minimal foliar contact. The second half of the treatment was applied in the other direction to equalize discrepancies due to watering. Two weeks after chemical vine dessication, tubers were removed from the two inner rows of each four-row plot with a single-row Gallenburg harvester. During mechanical harvest, tubers were allowed to drop 0.63 m into crates before they were washed and graded within one day of harvest. At this time, tubers were rinsed free of soil, and graded with an electronic grader. Immediately after grading, 170-284 g tubers and tubers greater than 284 g were collected separately and transferred into 5°C, 85% relative humidity in Madison for evaluation of tuber bruise and Ca concentration. After 2 months in storage, tubers were rated by halving lengthwise and the presence or absence of blackspot bruise was noted. Blackspot bruise here is defined as discolored (brown, grey or black), hollow or starch filled anomaly generally external to the vascular ring which was 3 mm or greater in diameter. A tuber was counted as bruised whether it had one or several bruises. All procedures described in this section were performed on individual tubers from each experimental row for a total of approximately 100 A grade tubers and 10-30 large (greater than 10 ounce tubers) per replication per treatment. For calcium determinations medullary tissue samples were taken which contained the central pith and consisted primarily of parenchymous storage tissue. The procedure described by Kratzke and Palta (1986) was used for Ca analysis.

RESULTS AND DISCUSSION

Tuber Calcium Concentrations

The supplemental calcium treatment, CUC, of calcium nitrate, calcium chloride and urea imparted significant tuber calcium concentration increases to both the cultivars (Table 2). On average over three years, tuber calcium concentration following calcium treatment increased 21% for 'Atlantic' and 34% for 'Russet Burbank' as compared to control. These results suggest that application of soluble forms of Ca during the bulking period can enhance the Ca level of the non-periderm tissue. These results are consistent with earlier studies and support the concept that tuber calcium concentration can be significantly increased by application of soluble Ca during bulking period (Kratzke and Palta, 1985 and 1986; Kleinhenz et al., 1999; Ozgen et al., 2000; Gunter et al., 2000; Karlsson et al., 2001).

Analysis of Bruise Potential Following Supplemental Calcium Applications

Analyzed over three seasons, both cultivars demonstrated significant treatment effect (Table 3), as well as, annual reduction in blackspot bruising with calcium treatment as compared to control (Table 2). 'Atlantic' had much greater bruise potential than 'Russet Burbank'. Larger tubers showed a similar response but the incidence of bruise was significantly higher. Blackspot bruise using our assay conditions occurred primarily in the cortical tissue, to the exterior of the vascular cambium, though blackspot bruise is often reported within the medullary tissue interior to the vascular cambium.

This is the first study to report mitigated bruise potential by addition of in season supplemental calcium applications. Historically, 'Russet Burbank' is susceptible and 'Atlantic' has moderate resistance (Brook, 1996). 'Russet Burbank' was moderately susceptible to bruise, but Atlantic to be highly susceptible. The literature also suggests Atlantic to be susceptible to other internal defects including necrotic lesions and brown spot (Ehlenfeldt, 1992; Rex and Mazza, 1989; Sterrett et al., 1991; Wannamaker and Collins, 1992). A possible explanation for relatively high rates of bruising for a susceptible cultivar is: 1) the use of a 0.63 m drop at the end of the harvester mechanism and 2) that sandy soils separated easily from the tubers leaving them in direct contact with the rollers and harvester mechanism (Brook, 1996). Another explanation for a relatively high rate of tuber bruising is that tubers from sandy soil have previously proven more susceptible because of higher dry matter and lower potassium (Ophius et al., 1958).

The analysis of variance also demonstrated a significant effect of year for both cultivars. Similar variation was mentioned in previous studies. Field soil temperature and soil moisture varied from year to year and potentially contributed to variability in incidence of bruise for the cultivars. For example, Workman and Holm (1984) noted that bruise varied from year to year in the same clones. In conclusion, analysis over three seasons demonstrated significant reduction in blackspot bruising with combined calcium nitrate, calcium chloride and urea treatment as compared to control for cultivars 'Atlantic' and 'Russet Burbank'.

Calcium may affect the level of tyrosine or phenolase present in the tuber tissue as suggested by Mapson et al. (1963) where they reported that tyrosine and phenolase activity decreased with calcium fertilization. Tyrosine found free in the cell is correlated to bruise formation, but reach levels of saturation when free tyrosine levels reach 175 to 200 µg per g of fresh tuber (Dean et al., 1993). Another potential component for regulation by calcium are polyphenols, which lead biochemically to melanin formation (bruise). Tubers are known to be deficient in calcium. Since water and calcium move together, organs with low transpiration can exhibit calcium deficiency (Palta, 1996) and tuber being a low transpiring organ would be expected to have low tissue calcium. It has been suggested that improvement in tuber calcium concentration may lead to improved cell membrane stability and wall structure (Marschner, 1995; Palta, 1996). In support of this suggestion an improved tuber quality, with reduced internal defects and better storage, has been reported in tubers supplied with in season calcium fertilization

(Kleinhenz et al., 1999; Gunter et al., 2000; Ozgen et al., 2001; Palta, 1996). The present study provides evidence that in addition to improving tuber internal quality there is potential for reducing tuber bruising through in season application of calcium.

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Tables

Table 1. Source, timing and rate of N and Ca source application to individual plots of cultivated potatoes 'Atlantic' and 'Russet Burbank'. All plots received the same total amount of N (251 $kg.ha^{-1}$) and the same total Ca (168 $kg.ha^{-1}$), if Ca was applied. Nutrient sources and application methods are described in the materials and methods.

Application of Nutrients				
Treatment	Source	Amount (kg/ha/application)		Application Timing[1]
		Nitrogen	Calcium	
Split Ammon Nitrate	NH_4NO_3	41	0	H,H+3,H+6
CUC	$CaNO_3$	23	28	H,H+3,H+6
	Urea	23	0	H,H+3,H+6
	$CaCl_2$	0	28	H,H+3,H+6

[1] H,H+3,H+6 = At hilling, three weeks post and six weeks post hilling, respectively.

Table 2. The effect of supplemental calcium treatment CUC on the incidence of mechanical harvester bruise and tuber sample calcium concentration in 1999, 2000 and 2001 seasons for two cultivars ('Atlantic', 'Russet Burbank'). CUC treatment consists of three split applications of calcium nitrate, calcium chloride and urea with a total season application of 168 $kg.ha^{-1}$ calcium. Both CUC and ammonium nitrate treatments received equal nitrogen. Calcium concentration is based on bulk 10 tuber samples (170-284g only) replicated three times per replication for treatment and cultivar. Bruise is reported as percent of 170 – 284 g tubers evaluated for five replications in 1999 and 2000 and ten in 2001. Each replication is the percent bruised tubers out of all tubers from two combined 6.1 m rows (one plot = 12.2 m). All tubers were halved and rated for bruising. A tuber with one or more bruises (> 3 mm in diameter) was counted as bruised. Means from the two treatments were compared by LSD for tuber calcium concentration and incidence of bruise for two tuber sizes in each year. Each comparison of ammonium nitrate and CUC treatment within the same row having the same letter are not significantly different (based on SAS General Linear Model procedure, alpha = 0.05).

	Tuber Calcium (ppm)		Incidence of Bruise (%)			
			170-284 g		> 284 g	
Cultivar	Amm Nit	CUC	Amm Nit	CUC	Amm Nit	CUC
Atlantic						
1999	119.2a	142.9b	32.6a	17.8b	39.1a	21.6b
2000	131.6a	160.5b	45.2a	34.8a	65.1a	48.1b
2001	144.4a	178.4b	44.7a	22.5b	45.7a	36.6b
Russet Burbank						
1999	-	-	-	-	-	-
2000	173.8a	223.6b	30.3a	21.7a	55.2a	40.4a
2001	176.3a	246.5b	20.7a	12.1b	-	-

Table 3. The effect of supplemental calcium treatment (CUC) on incidence of tuber bruising for two grades of two commercial cultivars (Atlantic, Russet Burbank) following mechanical harvest in 1999, 2000 and 2001 seasons. The data collected over three seasons were analyzed using a generalized mixed model (MIXED) procedure of the SAS Statistical Software (SAS Institute, Inc., Cary, N.C.). Tubers > 284 g for 'Russet Burbank' were insufficient in number to complete analysis. Year was modeled as a random effect and treatments and cultivars as fixed effects. The effect of year in the ANOVA is the value obtained using years as a fixed effect to see if years were significantly different in incidence of bruise. Analyses of variance (ANOVA) were performed separately on each tuber grade to test treatment effects, year effects, and interactions between year and treatment.

		P value and Grade	
Cultivar	Source	170-284 g	> 284 g
Atlantic	Treatment	<0.0001**	<0.0001**
	Year	<0.0001**	<0.0001**
	Year*Treatment	0.0443*	0.2117^{NS}
Russet Burbank	Treatment	0.0045**	-
	Year	0.0014**	-
	Year*Treatment	0.9857^{NS}	-

^{NS},*,**: Non significant, significant at $P \leq 0.05$, significant at $P \leq 0.01$, respectively