Calcium Accumulation, Calcium Distribution, and Biomass Partitioning in Collards

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Abstract. 'Vates' collard (*Brassica oleracea* L. Acephala Group) was more susceptible to tipburn than 'Blue Max' or 'Heavi Crop' in field and nutrient solution culture experiments. The root system of Vates' was smaller than that of 'Blue Max' in all experiments. Because of its smaller root system, 'Vates' may be more susceptible to moisture stress than 'Blue Max' when grown under high-temperature conditions on sandy soils, thus increasing susceptibility to tipburn. Root system size, however, did not influence Ca accumulation or Ca concentration in the plants. Calcium accumulation rate was higher for 'Blue Max' and 'Heavi Crop' than for Vates' during the 3rd through the 5th weeks of culture, in a nutrient solution that contained 5 mM Ca. Calcium efficiency ratio (CaER, milligrams of dry matter produced per milligram of Ca in tissue) for young leaves was higher for 'Blue Max' and 'Heavi Crop' than for 'Vates' when plants were grown with 1 mM Ca, which may partly explain the greater susceptibility of 'Vates' to tipburn. 'Heavi Crop' had a higher total plant CaER than 'Blue Max' when grown with 5 mM Ca.

Tipburn of young leaves of collards was observed during Summer 1988 in growers' fields in central South Carolina. The inward cupping and marginal burn of the young collard leaves appeared to be similar to that associated with tipburn of cabbage, cauliflower, and lettuce. Studies on cabbage (Maynard et al., 1965), cauliflower (Maynard et al., 1981), and lettuce (Collier and Tibbitts, 1984; Thibodeau and Minotti, 1969; Yanagi et al., 1983) indicated that tipburn is caused by a localized Ca deficiency in the leaf tip. Transport of ⁴⁵Ca to young leaves was increased and tipburn decreased when transpiration rate was reduced and root pressure flow was increased (Palzkill et al., 1976). Restriction of root growth in Chinese cabbage has been reported to increase the incidence of tipburn (Aloni, 1986).

Variation in CaER (i.e., milligram of dry matter produced per milligram of Ca in the tissue) among cultivars has been reported for cauliflower (Hochmuth, 1984; Rosen, 1990) and tomato (English and Barker, 1982; English and Maynard, 1981; Giordano et al., 1982). Rosen (1990) reported that the best method to control tipburn of cauliflower was to use resistant cultivars. 'Blue Max', a hybrid collard cultivar, is less susceptible to tipburn than 'Vates', the standard open-pollinated collard cultivar (Johnson, 1991). Soil application of CaSO₄ or foliar application of Ca(NO₃)₂ or CaCl₂ did not decrease the incidence of tipburn in 'Vates'.

Objectives of these studies were to determine the influence of cultivar on Ca accumulation rate, Ca distribution in the plant, and the size of the root system and to determine the relationship between these factors and the incidence of tipburn of collards grown under high temperatures.

Field experiment. 'Vates' and 'Blue Max' collards were grown on a Lakeland sandy soil (Thermic type quartzipsamments) during Summer 1989 at Clemson Experiment Station, Columbia, S.C. Dolomitic lime was applied at 560 kg/ha⁻¹ at 8 weeks before initiating the study to adjust the pH to 6.0. Preplant broadcast fertilizer was 10N-4.4P-8.3K applied at 560 kg/ha⁻¹. Seeds were planted with a precision seeder on 27 June 1989 at

15 cm apart in the row. Plants in the three-leaf stage were thinned to 30 cm between plants in the row. Plot size was 1.8 x 12.2 m. Each plot included two rows of collards with 71 cm between individual rows on the bed. The design was a randomized block with four replications. The average air maximum and minimum over the duration of the study was 32 and 21°C.

Collards were harvested 58 days after planting the seeds by cutting the plant at the soil surface. Data collected at harvest included a visual tipburn rating, where 1 = no tipburn and 5 = severe tipburn. Dry weights of foliage and roots were recorded. Roots were removed from a 30-cm² area directly below the harvested plant to a depth of 60 cm. The roots were washed with water to remove soil. Whole-leaf (blade and midrib) tissue samples of young and old leaves were collected for elemental analyses. Young leaves were the terminal five leaves that were 2 to 6 cm long. All young leaves from the three cultivars were fully exposed to light. 'Vates' has a vertical leaf orientation, whereas 'Blue Max' and 'Heavi Crop' have a more horizontal leaf orientation. The difference in leaf orientation resulted in the young leaves of 'Vates' being somewhat further below the top of the older leaves than for 'Blue Max' and 'Heavi Crop'. Old leaf samples were the eighth leaf from the terminal of the plant. Leaf samples were washed for 1 min in deionized water before dehydration. The root and foliage samples were dried at 70°C and ground to pass through a 20-mesh screen. Leaf Ca concentrations were determined by atomic absorption spectroscopy.

Nutrient solution culture experiments. In two greenhouse experiments, 'Vates', 'Blue Max', and 'Heavi Crop' collard plants were grown in 8-liter, 30-cm-diameter plastic containers. These were filled with 7 liters of nutrient solution that was changed every 7 days. Water was added each day to maintain the solution level during the experiments. Air was bubbled into the nutrient solution through glass-bonded air diffusers. The nutrient solution was a modified Hoagland's solution No. 1 (Hoagland and Amen, 1950). All nutrient solutions contained (mg-liter⁻¹, 234 K, 31 P, 49 Mg, 0.5 B, 0.5 Mn, 0.05 Zn, 0.02 Cu, 0.01 Mo, and 1 Fe. Semrestrene 330 [iron chelate) was the source of Fe. Calcium treatments were 1 and 5 mM. The 1 mrvt Ca nutrient solution contained 40 mg Ca/liter and 184 mg Na/liter. The 5

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Abbreviation: CaER, calcium efficiency ratio.

mM Ca nutrient solution contained 200 mg Ca/liter. The nutrient solution containing 5 mM Ca is the Ca concentration used in the standard Hoagland nutrient solution (Hoagland and Amen, 1950).

Studies were conducted in a greenhouse with an average daily maximum of 32C and a minimum of 21C. Seeds were planted in washed, mined sand, and seedlings at the two-leaf stage were transplanted to the plastic containers.

The design for these studies was a split plot with Ca level as the main plot and cultivar as the subplot. Treatments were replicated four times. A plot consisted of a single plant in a container.

Seeds for Expt. 1 were planted on 28 Dec. 1989. Seedlings were transplanted into plastic containers on 8 Jan. 1990 and harvested 36 days later. Seeds for Expt. 2 were planted on 29 Jan. 1990. Seedlings were transplanted into plastic containers on 15 Feb. 1990 and harvested 35 days later.

Visual tipburn at the completion of studies was rated on the same scale as that used for the field study. Fresh and dry weights of whole leaves (blade and midrib), petioles, stem, and roots were recorded. Preparation of tissue samples and analysis of tissue samples for Ca content was the same as that described for the field study. Nutrient solution samples were collected each week from each plot before they were changed and then analyzed for Ca as for the field study.

Sand culture study. 'Vates', 'Blue Max', and 'Heavi Crop' collard plants were grown in quartz sand in 4-liter (15 cm in diameter) pots. The nutrient solution, which contained 5 mrvt Ca, was as described for the nutrient solution culture studies. The solutions were applied at 600 ml/pot for the first 3 weeks of the study and 1000 ml/pot thereafter through to harvest. Nutrient solutions were applied on days 1, 3, and 5, with an equal amount of deionized water being applied on the other 4 days of the week; some of the water drained from the sand. Collard seeds were planted on 29 Jan. 1990; plants were harvested 49 days later. The design was a randomized block with six replications. A replicate consisted of one plant in a pot. Data collected included dry weights of whole leaves (blade and midrib), petioles, stem, and roots. Sand was removed from roots by washing with water.

Data from field and sand culture studies were processed by analysis of variance, with mean separation by least significant difference. Data from the nutrient solution culture study were analyzed by analysis of variance, with mean separation between cultivars within a Ca treatment by least significant difference.

Field studies. 'Vates' was more susceptible to tipburn than 'Blue Max' (Table 1); however, for both cultivars, the Ca concentrations "in the young (0.51% and 0.44%) and old (1.12% and 0.95%) leaves were similar. The shoot and root systems of 'Blue Max' had a higher total dry weight than that of 'Vates', but the shoot : root ratio was higher for 'Vates' than for 'Blue Max'. Roots of 'Vates' were less fibrous than 'Blue Max', based on visual observation.

Table 1. Tipburn severity and biomass partitioning for 'Vates' and 'Blue Max' collards; field experiment, 1989.

Cultivar	Tipburn rating ^a	Dry wt (g)		Shoot : root ratio
		Shoot	Root	
Vates	4*	38.0 ^a	3.3*	11.94*
Blue Max	1	55.4	7.7	7.62

^aVisual tipburn rating on a scale of 1 = no tipburn and 5 = severe tipburn.

*Significant mean separation within columns by LSD at $P = 0.05$.

Nutrient solution culture. Results of the two studies were similar; therefore, only results of the second study are presented. Leaf area of 'Blue Max' was highest at both Ca levels. Whole-leaf (blade and midrib), petiole, and root dry weights were higher for 'Blue Max' and 'Heavi Crop' than for 'Vates' when grown in 1 mM Ca nutrient solution (Table 2). The shoot : root ratio was higher for 'Vates' and 'Blue Max' than for 'Heavi Crop' when grown with 1 mM Ca; however, it was similar for the three cultivars when grown with 5 mM Ca. 'Vates' had a lower root dry weight than 'Blue Max' or 'Heavi Crop' when grown with 1 mM Ca, but 'Vates' and 'Blue Max' had a similar and higher root dry weight than 'Heavi Crop' when grown with 5 mM Ca.

'Vates' developed more tipburn than 'Blue Max' or 'Heavi Crop' at both Ca levels (Table 3). Calcium concentration in young leaves was higher for 'Vates' than for 'Blue Max' or 'Heavi Crop' when grown with 1 mM Ca; however, when grown with 5 mM Ca, young leaves of all three contained similar concentrations of Ca (Table 3). Calcium concentration in mature leaves was similar for the three cultivars at 1 or 5 mM Ca, but about twice as high at 5 as at 1 mM Ca. Calcium concentration in petioles was higher for 'Blue Max' than for 'Vates' or 'Heavi Crop' grown with 1 or 5 mM Ca in the nutrient solution. Petioles apparently accumulated more Ca in the susceptible than in the resistant cultivar. Stem Ca concentration was similar for the

Table 2. Biomass partitioning for three cultivars of collards grown with 1 or 5 mM Ca in nutrient solution culture.

Cultivar	Leaf area (cm ²)	Dry wt (g/plant)			Shoot : root ratio
		Leaves	Petioles	Roots	
<i>1 mM Ca</i>					
Vates	4070 c ^z	18.4 b	5.6 b	2.7 b	10.3 a
Blue Max	7070 a	28.3 a	7.9 a	4.3 a	9.8 a
Heavi Crop	5990 b	24.7 a	7.3 a	4.6 a	7.7 b
<i>5 mM Ca</i>					
Vates	4170 b	20.6 b	5.0 b	3.7 a	8.3 a
Blue Max	6410 a	26.1 a	6.5 a	4.4 a	8.6 a
Heavi Crop	3380 b	15.7 c	4.8 b	2.6 b	8.9 a

^aMean separation among cultivars within a Ca treatment by LSD at $P = 0.05$.

Table 3. Calcium distribution in three cultivars of collards with 1 or 5 mM Ca in nutrient solution culture.^a

Cultivar	Tipburn rating [*]	Ca concn (% dry wt)					
		<i>Leaves^r</i>		Petiole ^w	Stem	Roots	
		Young	Old				
<i>1 mM Ca</i>							
Vates	3 a	0.93 a	2.30 a	0.70 b	0.31 a	0.37 a	
Blue Max	2 b	0.51 b	2.33 a	0.94 a	0.30 a	0.29 a	
Heavi Crop	1 c	0.58 b	2.45 a	0.64 b	0.31 a	0.29 a	
<i>5 mM Ca</i>							
Vates	2 a	1.78 a	4.32 a	1.30 b	0.50 c	4.66 a	
Blue Max	1 b	2.01 a	4.80 a	2.25 a	0.60 b	6.06 a	
Heavi Crop	1 b	1.96 a	4.58 a	1.33 b	0.68 a	1.54 b	

^aMean separation among cultivars within a Ca treatment by LSD at $P = 0.05$.

^bYoung leaves (blade and midrib) = terminal five leaves that were 2 to 6 cm long; old leaves (blade and midrib) = all leaves older than fifth leaf from terminal.

^cVisual tipburn rating on a scale of 1 = no tipburn and 5 = severe tipburn.

^dPetiole is a composite sample of petioles from young and old leaves.

three cultivars grown with 1 mM Ca in the nutrient solution. Stem Ca concentration was higher for 'Blue Max' and 'Heavi Crop' than for 'Vates'. Root Ca concentration was similar for the three cultivars in 1 mM Ca, but was lower in 'Heavi Crop' than in the other two cultivars when grown with 5 mM Ca.

Calcium accumulation rate (amount of Ca removed from the nutrient solution per week) was similar for the three cultivars throughout the study for plants with 1 mM Ca (data not shown). This similarity in Ca accumulation for the three cultivars indicates that, for plants grown with 1 mM Ca, factors other than total Ca accumulation determine cultivar susceptibility to tipburn. Other factors that may influence cultivar susceptibility to tipburn may be differences in root growth or moisture relations in the plant. 'Vates' has a more vertical leaf orientation than 'Blue Max' or 'Heavi Crop', which results in the young leaves being somewhat further below the top of the outer leaves in 'Vates' than in the others. This may result in less air movement around the young leaves of 'Vates', which may result in reduced transpiration rate and reduced movement of Ca to the younger leaves. Calcium accumulation during the 2nd week of the study was similar for the three cultivars supplied with 5 mM Ca (Table 4). During the 3rd and 4th weeks, Ca accumulation was higher for 'Blue Max' than for 'Vates' or 'Heavi Crop'. In the 5th week, the sequence was 'Blue Max' > 'Vates' > 'Heavi Crop'. From the 2nd to the 5th week of the study, Ca accumulation rate increased for all cultivars at both Ca levels (50 to 59 mg/plant during week 2, 164 to 233 mg/plant during week 5 for 1 mM Ca; see Table 4 for 5 mM Ca). Tipburn of collards usually does not occur in the field until 3 or 4 weeks before harvest, corresponding to the time when Ca accumulation is increasing. Tipburn may occur during this time of rapid leaf expansion because the plant is unable to move it rapidly enough to the young leaves for normal growth.

'Blue Max' had a higher CaER in young leaves than 'Vates' at 1 mM Ca, but there was no difference among the cultivars at 5 mM Ca (Table 5). CaER for old leaves was similar for all cultivars at the 1 or 5 mM Ca levels, but it was about twice as high at 1 as at 5 mM Ca. CaER for petioles was higher for 'Vates' and 'Heavi Crop' than 'Blue Max' at both levels. The total plant CaER was similar for the three cultivars at the 1 mM Ca level, but 'Blue Max' and 'Vates' had similar total plant CaER at 5 mM Ca. 'Heavi Crop' had a higher total plant CaER than 'Blue Max' when grown at 5 mM Ca.

Sand culture. Dry weights of whole leaves (blade and midrib) and roots were higher for 'Blue Max' than for 'Vates' or 'Heavi Crop' (Table 6). Petiole dry weight was similar for the three cultivars. Shoot : root ratios were similar for the three cultivars.

Calcium accumulation was higher for 'Blue Max' than 'Vates' when grown with 5 mM Ca; however, Ca concentrations in young and old leaves were similar for the two cultivars. CaER in young leaves was higher for 'Blue Max' than 'Vates', indi-

Table 4. Calcium accumulation in leaves of three cultivars of collards grown with 5 mM Ca in nutrient solution culture.

Cultivar	Ca uptake (mg/plant) ^a			
	Uptake period (days after transplanting)			
	7-14	14-21	21-28	28-35
Vates	68 a	124 b	422 b	604 b
Blue Max	44 a	273 a	569 a	791 a
Heavi Crop	63 a	84 b	343 b	392 C

^aMean separation among cultivars by LSD at $P = 0.05$. Calcium uptake during a given week was similar for all cultivars at 1 mM Ca.

Table 5. CaER for three cultivars of collards grown with 1 or 5 mM Ca in nutrient solution culture.

Cultivar	CaER [†]			
	Leaves ^y		Petioles [‡]	Total plant
	Young	Old		
	<i>1 mM Ca</i>			
Vates	107 b	44 a	145 a	69 a
Blue Max	206 a	43 a	107 b	64 a
Heavi Crop	183 a	42 a	158 a	66 a
	<i>5 mM Ca</i>			
Vates	58 a	24 a	79 a	30 ab
Blue Max	50 a	21 a	45 b	26 b
Heavi Crop	51 a	22 a	75 a	33 a

^aMean separation among cultivars within a Ca level by LSD at $P = 0.05$.

^bYoung leaves (blade and midrib) = terminal five leaves that were 2 to 6 cm long; old leaves (blade and midrib) = all leaves older than the fifth leaf from the terminal.

^cPetiole is a composite sample of petioles from young and old leaves.

Table 6. Biomass partitioning for three cultivars of collards grown with 5 mM Ca in sand culture.

Cultivar	Dry wt (g) ^a				Shoot : root ratio
	Leaves	Petioles	Stem	Roots	
Vates	15.4 b	4.5 a	3.0 a	7.8 b	3.0 a
Blue Max	18.1 a	4.4 a	3.1 a	10.3 a	2.7 a
Heavi Crop	13.9 b	3.6 a	1.6 b	7.4 b	2.5 a

^aMean separation within columns by LSD at $P = 0.05$.

eating that young leaves of 'Blue Max' were more efficient in using Ca than were those of 'Vates'. This difference in CaER in young leaves maybe part of the basis for 'Vates' being more susceptible to tipburn than 'Blue Max'. Total plant CaER was higher for 'Heavi Crop' than 'Blue Max'; however, 'Vates' and 'Blue Max' had similar total plant CaER. Cauliflower cultivars also have been found to differ in CaER (Hochmuth, 1984).

'Vates' had a root system with fewer fibrous roots and lower dry weight than 'Blue Max' in field, nutrient solution culture, and sand culture experiments. Root dry weight did not influence Ca accumulation or Ca concentration in the plant. These results are in contrast to those reported for Chinese cabbage, in which restriction of root volume reduced soluble Ca concentration in leaf sap of tips of young leaves and increased incidence of tipburn (Aloni, 1986).

The best method to control tipburn of collards grown during the summer in the southeastern United States is to use tolerant cultivars.

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