Effect of Kaolin (Surround™) on Pepper Fruit and Seed Mineral Nutrients[1]

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ABSTRACT

A kaolin-based particle film, Surround™, was evaluated in 2004 on an anaheim-type pepper (*Capsicum annuum*) for its ability to reduce light induced stresses and mimic shading responses reported in other vegetable crops, with respect to plant pigments and mineral nutrient accumulation. Agronomic attributes, such as yield, were not affected by kaolin applications, but fruit tissue Ca, Na, B, and total carotenoids were increased and Al concentrations reduced by kaolin application. Late season fruit were higher in most mineral nutrients and pigments compared to earlier-harvested fruit. Seed were little affected by kaolin, but were higher in N, P, Mg, S, Fe, Zn, Mn, and Cu and lower in K, Ca, NO_3, B, and Al than corresponding fruit tissue. Kaolin application did not benefit seed yield, size or germination attributes.

RESUMEN

Capas protectoras de kaolin, Surround™ fueron evaluadas en chile tipo anaheim (*Capsicum annuum*) en el 2004. Las particulas protectoras de este producto tienen la habilidad de disminuir los estreses de la luz solar al imitar las respuestas al sobreado. El efecto protector de este producto ya ha sido reportado en cuanto a la acumulación de pigmentos y nutrintes en otras hortalizas. La característica agronómica de rendimiento no fue afectada por las aplicaciones de kaolin, pero el Ca, Na, B, y carotenoides totales en el fruto se incrementaron. Mientras que las concentraciones de Al furon reducidas por las aplicaciones de este producto. Los frutos tardíos tuvieron mayor contenido en casi todos los nutrientes minerales y pigmentos en comparación con los frutos de cosecha temprana. La semilla fue poco afectada por kaolin, pero el contenido de N, P, Mg, S, Fe, Zn, Mn, y Cu fueron altos, mientras que el contenido de K, Ca, NO_3, B, y Al fueron mas bajos que los encontrados en el fruto. Las aplicaciones de Kaolin no afecto el rendimento, tamanio o características de germinación.

Additional index words: Capsicum annuum, particle film

During much of the year the lower Rio Grande Valley of Texas is subjected to both high light intensity and high temperatures, with little relief from night cooling (Orton, et al., 1967). Methods to reduce these sources of plant stresses would be desirable in order to improve fruit and vegetable quality and extend production into less favorable growth periods, such as mid-summer.

Kaolin-based particle films, commercially available as Surround™ have physical properties useful in reducing pest incidence in several crops (Glenn and Puterka, 2005), including beet leafhopper (Creamer et al., 2005) and pepper weevil (Makus, 2005) in peppers. Because kaolin can reflect incident light (Glenn et al. 2002), canopy cooling in cotton (Makus and Zibilske, 2001) and pecan (Lombardini et al.,2005) and a reduction in pomegranate (Melgarejo et al., 2004) and apple fruit temperatures (Glenn et al., 2002) have been reported. Although not as effective as 20% shade or evaporative cooling, kaolin particle film application cooled apple fruit 1.5 to 6.4 C compared to untreated fruit during days with maximum air temperatures of 34 to 37 C (Gindaba and Wand, 2005).

Shading experiments with vegetable amaranth, *Amaranthus tricolor*, (Makus and Hettiarachchy, 2001), and mustard greens, *Brassica juncea*, (Makus and Lester, 2002) have demonstrated that reduced light during plant growth can increase leaf carotenoids and increase mineral nutrients. Kaolin, which increases light reflectance, also was found to reduce cotton leaf temperatures, leaf transpiration, and plant sap flow (Makus and Zibilske, 2001). Seeds deficient in mineral elements can affect seed viability and subsequent germination (Marschner, 1995). Therefore an experiment was conducted to test the hypothesis that kaolin sprayed on pepper plants might benefit fruit yield and produce fruits and seeds with improved levels of mineral nutrients; and that improved seed mineral nutrient levels would improve seed quality attributes.

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MATERIAL AND METHODS

Six week-old 'Sonora Anaheim' pepper (*Capsicum annuum* L.) plants were transplanted on 25 Mar. 2004 into a Hildago sandy clay soil near Weslaco, TX (26° 08' N Lat.). Plants were set by transplanter at 18" (45 cm) in-row spacings. Plots were 30' (9.1 m) in length, but only 20' (6.1 m) were used for yield. There were 4 replications per treatment. Ten cover spray applications of kaolin, a processed clay aluminosilicate marketed as Surround™ (Engelhart Corp. Islin, N.J.), applied at approximately 10 day intervals at 25 kg/ha, were initiated beginning 4 June and were ended on 17 Sept.

Fruit wall temperatures (northern side) were measured by thermocouples (36 gauge at the point of insertion), plant canopy temperatures by IR thermocouples (Apogee, Logan, UT), and photosynthetically active radiation (PAR) with an LI-190SA (LI-COR, Lincoln, NE) sensor every 60 s, and averaged hourly with a datalogger (Model CR-10, Campbell Sci., Logan, UT). Temperature measurements were conducted on fruit and plants in a single rep; however, thermocouples were moved between different fruits and plants over the season.

Fruits were generally harvested when they were about 15 cm long. As the season progressed, fruits tended to grow more isodiametrically, so that lengths approaching 15 cm were also included. Fruits harvested on 23 June, 5 July, 29 Aug., and 19 Sept. were used to estimate treatment yields. On several other dates, fruits were picked and discarded because of loss of kaolin-canopy coverage due to rain or because of scheduling conflicts. During the growing season, no pesticides were applied and weeds were mechanically controlled.

On 23 June, approximately 100 g from 10 fruit sub-samples were washed, seeds removed and frozen, lyophilized, and passed through a 40 mesh (0.36 mm^2) screen with a Wiley Mill. On 19 Sept., the sampling procedure was repeated, but ca. 5 g of seeds were also collected from fruit sub-samples. Pigments were analyzed spectrophotometrically by the procedure of (Wellburn and Lichtenthaler, 1984) on the fruit sub-samples. Mineral nutrients (K, P, Ca, Mg, S, Na, Al, Fe, Mn, Zn, B, and Cu) were determined, after HNO_3 digest, by ICP spectroscopy (Plank, 1992) on all sub-samples. Fruit total-N was determined by dry combustion using a LECO FP428 analyzer and NO_3-N, after water extraction, by a Skalar autoanalyzer (Plank, 1992).

Seeds were removed from 10 fruit per plot from the 19 Sept. harvest. These were air-dried and used to determine seed yield, avg. seed wt., and percent seed germination after 6 and 10 days imbibition (AOSA, 1993).

The experiment was analyzed as a completely randomized design (n=4; total plots=8). Experimental factors consisted of two treatments (kaolin-sprayed and unsprayed), two harvest dates (23 June and 19 Sept.), and on 19 Sept., two fruit parts (edible tissue and seed) from kaolin-sprayed and unsprayed plants. Differences between response means were tested using the PDIFF option of the LSMEANS statement of PROC GLM of SAS Version 8.2 (SAS Institute, Cary, N.C.).

RESULTS

Environmental modification. There was a nominal reduction in both fruit and canopy temperatures from applied kaolin(averaged daily between 1200 and 1800 hrs) in June when cumulative light intensity and solar angle of declination was 87° (Table 1). As the season progressed and as the mid-day solar angle decreased to 68° and finally 60°, there was no temperature reduction of kaolin-sprayed fruits or foliage when compared to the controls. Light irradiance during the three 10-day reporting periods, declined from 266 to 167 to 156 MJ/m^2, respectively.

Table 1. Average fruit and canopy temperatures and their standard errors for unsprayed and kaolin-sprayed plants for three successive ten-day periods in June and Sept. prior to harvests.

	Temperature[z]	
Dates / treatments	Fruit	Canopy
	------------ °C ------------	
June 12-21		
No kaolin	36.7±1.4	39.1±2.2
Kaolin	36.0±1.2	38.3±2.1
Sept. 8-17		
No kaolin	31.4±2.3	34.7±3.5
Kaolin	31.3±2.2	34.3±3.2
Sept. 29-Oct. 8		
No kaolin	31.3±2.3	33.4±2.3
Kaolin	31.3±2.2	33.4±2.9

[z] Mean represents the avg. hourly temperatures between 1200 and 1800 hrs over the dates given.

Yield. Cumulative fruit yield (from four harvests), fruit number per 6.1 m (20 ft.) plot and avg. fruit wt. were not affected by kaolin application (Table 2). Fruit dry matter (%) was not affected by spray treatment, but June-harvested fruit were higher in dry matter (%) than September-harvested fruit (data not shown).

Table 2. Season yield, fruit number, and avg. fruit wt. of control and kaolin-sprayed 'Sonora Anaheim' pepper plants.

	Season totals per plot[Z]		
	Fruit Wt.	Fruit No.	Avg.Fruit wt.
	kg		g
No kaolin	5.72	180	31.6
Kaolin	7.33	244	30.0
Prob. > F	0.31	0.20	0.09
C.V. (%)	32	30	4

[Z] Sum of harvests on 23 June, 5 July, 29 Aug., and 19 Sept. Fruits were harvested from 6.1 m of row length in each of four replications.

Fruit pigment composition. Pepper fruit harvested late in the season (19 Sept.) had higher concentrations of chlorophyll (dry wt. basis) compared to earlier-harvested fruit (Table 3). The chlorophyll a:b ratio was lowest in early-harvested unsprayed fruit. Total carotenoids were highest and the ratio of chlorophyll to carotenoids was lowest in late-season, kaolin-sprayed fruit. The percentage of late season harvested red fruit was more than 3 times greater when plants were sprayed with kaolin.

Macronutrients. Fruit Ca levels (dry wt. basis) were increased on both sampling dates when plants were sprayed with Kaolin (Table 4). Fruit tissue K, P, Ca, Mg, S, and total cations

Table 3. Effect of kaolin applications (C= unsprayed, K= sprayed) on pigment contents of pepper fruits at two harvest dates and on mature fruit color.

	Chlorophyll		Total	Chloro:carot	
	Total	a:b ratio	carotenoids	ratio	Red fruit[Z]
	mg˙g dw		mg•g dw		%
Date:					
23 June	1.03 b	2.26 b	0.38 b	2.12 a	
19 Sept.	1.25 a	2.31 a	0.66 a	2.14 b	
	**[Y]	*	**	**	
Treatment:					
No kaolin	1.12 a	2.26 b	0.42 b	2.69 a	2.8 b
Kaolin	1.16 a	2.31 a	0.63 a	2.17 b	10.2 a
	NS	*	*	**	**
Interactions:					
June - C	1.02 b	2.20 b	0.38 b	2.70 a	
June - K	1.04 b	2.32 a	0.38 b	2.75 a	
Sept. - C	1.22 a	2.32 a	0.45 b	2.68 a	
Sept. - K	1.28 a	2.30 a	0.87 a	1.60 b	
	NS	**	*	**	

[Z] Sept. harvest only.
[Y] NS, *, ** = Not significant or significant at *P*=0.05, *P*=0.01, respectively.

were highest at the late season harvest. Total N was not affected by treatment or harvest date. There were no treatment X harvest date interactions on fruit macronutrients.

There was no effect from late season application of Kaolin on either fruit or seed. Seeds were higher in total N, P, Mg, and S, but lower in K, Ca, and total cations than fruit tissue. There were no treatment X fruit part interactions for any macronutrient.

Micronutrients. Late-season harvested fruit were higher in NO_3, Mn, and Cu and lower in B than early-season harvested fruit (Table 5). Sodium levels were highest in late-season kaolin-sprayed fruit and lowest in early-season unsprayed fruit. Fruit Al was lowest in early-season unsprayed fruit, but highest in late season unsprayed fruit. Boron concentrations in fruit were increased by kaolin application.

Seed concentrations of Fe, Zn, Mn, and Cu were higher and NO_3, B, and Al (*P*=0.06) lower than in fruit tissue. Sodium concentrations were lowest in seeds and Na in unsprayed fruits were lower than in sprayed fruits. Aluminum concentrations were highest in unsprayed fruit and lowest in seeds, regardless of spray treatments compared to fruits.

Table 4. Effect of unsprayed (C) and kaolin-sprayed (K) applications on macro-elements in pepper fruit at two harvest dates and between pepper fruit and seed harvested late in the growing season.

	N	K	P	Ca	Mg	S	Total cations[Z]
	%						
Fruits:							
June – C	1.85 a	1.74 b	0.255 b	0.169 d	0.131 b	0.147 b	2.07 b
June – K	1.86 a	1.77 b	0.267 b	0.187 c	0.137 b	0.148 b	2.12 b
Sept.– C	1.89 a	1.90 a	0.274 a	0.204 b	0.158 a	0.162 a	2.30 a
Sept.– K	1.90 a	1.87 a	0.286 a	0.220 a	0.161 a	0.163 a	2.30 a
Treatment	NS[Y]	NS	NS	*	NS	NS	NS
Date	NS	*	*	**	**	**	**
Trt x Date	NS	NS	NS	NS	NS	NS	NS
Plant Part:							
Fruit – C	1.89 b	1.90 a	0.274 b	0.204 a	0.158 b	0.162 b	2.30 a
Fruit – K	1.90 b	1.87 a	0.286 b	0.220 a	0.161 b	0.163 b	2.30 a
Seed – C	2.96 a	0.85 b	0.536 a	0.070 b	0.236 a	0.227 a	1.20 b
Seed – K	2.93 a	0.89 b	0.530 a	0.073 b	0.237 a	0.213 a	1.24 b
Treatment	NS	NS	NS	NS	NS	NS	NS
Plant Part	**	**	**	**	**	**	**
Trt x Plant Part	NS	NS	NS	NS	NS	NS	NS

[Z] Total cations include: K, Ca, Mg, Na, Fe, Zn, Mn, Cu, and Al.
[Y] NS, *, ** = Not significant or significant at *P*=0.05, *P*=0.01, respectively. Different letters within fruit and plant part columns indicate differences among means.

Table 5. Effect of unsprayed (C) and kaolin-sprayed (K) applications on micro-elements in pepper fruit at two harvest dates and between plant parts (pepper fruit and seed) harvested late in the growing season.

	NO_3	Na	Fe	Zn	Mn	Cu	B	Al
	µg/g							
Fruits:								
June – C	389 b	155 c	88 a	21.5 a	15.9 b	11.6 b	12.6 b	8.1 c
June – K	401 b	170 bc	94 a	16.0 a	16.0 b	11.5 b	13.0 a	6.6 d
Sept.– C	634 a	193 b	71 a	14.2 a	18.7 a	13.1 a	9.9 d	31.6 a
Sept.– K	779 a	261 a	91 a	19.2 a	18.9 a	13.1 a	10.8 c	19.6 b
Treatment	NS[Z]	**	NS	NS	NS	NS	*	**
Date		**	NS	NS	**	**	**	**
Trt x Date	NS	**	NS	NS	NS	NS	NS	**
Plant Part:								
Fruit – C	634 a	193 b	71 b	14.2 b	18.7 b	13.1 b	9.9 a	31.6 a
Fruit – K	779 a	260 a	91 b	19.2 b	18.9 b	13.1 b	10.8 a	19.6 b
Seed – C	78 b	102 d	155 a	43.2 a	26.2 a	37.2 a	6.0 b	4.3 c
Seed – K	91 b	126 c	190 a	47.4 a	26.4 a	32.3 a	6.4 b	10.2 c
Treatment	NS	**	NS	NS	NS	NS	**	0.06[Y]
Plant Part	**	**	**	**	**	**	**	**
Trt x Plant Part	NS	**	NS	NS	NS	NS	NS	**

[Z] NS, *, ** = Not significant or significant at P=0.05, P=0.01, respectively.

[Y] Probability of a greater 'F' value.

Seed yield, average seed wt., and seed germination at 6 and 10 days were not influenced by kaolin application (data not shown).

DISCUSSION

Only a nominal mid-season benefit was obtained in canopy or fruit cooling from kaolin application to pepper plants compared to that reported for tree crops (Glenn et al., 2002; Melgarejo et al., 2003; Lombardini et al.,2005). This may be due to the architectural differences between vegetables and tree crops (e.g. plant height relative to the soil surface), orchard understory such as orchard grasses, and tree shading of the orchard floor. Row crops are generally clean cultivated and soils provide thermal heat sinks during the day, thus pepper fruits growing close to the soil surface may not be well shielded from re-irradiated high soil surface temperatures. Pepper fruit have little mass compared to pome fruits, and may respond more rapidly to both advective and edaphic conditions.

Contrary to the assumption that solar noon would provide maximum temperature differences in canopy and fruit of sprayed vs. unsprayed plants, the highest fruit and canopy temperatures were recorded typically between 1500 and 1800 hrs. When temperature data was analyzed based on hourly temperature maximums, temperature trends between sprayed and unsprayed plants throughout the season were similar to those where temperatures were averaged over the 6 hrs between 1200 and 1800 hrs (data not shown).

Fruit yields were not affected by kaolin sprays in this study or those reported by Russo and Diaz-Perez (2005) and Creamer et al. (2005). In the Creamer et al. study, by accounting for the significant loss of plants to beet curly top virus, vectored by the beet leafhopper, in one year of the two year study, total yields in that year would have been higher in the kaolin-sprayed pepper plots. In another case, when pepper weevil was controlled by kaolin, yields were improved over unsprayed pepper plants (Makus, 2005).

The pigment and mineral nutrient levels found in kaolin-sprayed pepper fruits are similar to those in shaded leafy vegetable crops (Makus and Lester, 2002). In these leafy greens, carotenoid concentrations increased in concert with chlorophylls. Pepper fruit mesophyll cells have chromoplasts which accumulate these carotenoid pigments and probably explain why a higher percentage of red fruit were observed at the 19 Sept. harvest in kaolin-sprayed plants.

Fruit Ca levels were increased by kaolin application at both sampling dates. Calcium is important in cell wall integrity and for maximizing post-harvest life (Toivonen and Bowen, 1999).

Although current levels of Al in food plants are considered safe by the U.S. Food and Drug Administration, concern for reducing concentrations of this element in food and drugs has been expressed (Lione, 1983). Kaolin is an aluminosilicate mineral (Glenn and Puterka, 2005), which would not be expected to release any of the Al. Since shading was reported to reduce Al concentrations in mustard greens (Makus and Lester, 2002), this would suggest that the reduction in tissue Al observed in pepper fruits from plants sprayed with Kaolin are real.

CONCLUSIONS

Kaolin reduced pepper canopy and fruit temperatures during mid-summer, but high temperature abatement was lost as the season progressed. There was no fruit or seed yield or seed quality benefit from kaolin application, but fruit and seed Ca, Na, and B concentrations were higher due to kaolin application. Aluminum tissue concentrations were lower in kaolin-sprayed fruit compared to unsprayed fruit. Kaolin-sprayed, late-season harvested plants, had more red fruit than unsprayed plants. Late season fruit were higher in plant pigments and most nutrients compared to earlier-harvested fruits.

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