Ethephon Improved Pigmentation but Had No Effect on Cayenne Pepper Fruit Yield in Southern New Mexico

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Abstract. In the desert southwest of the United States, cayenne pepper (*Capsicum annuum* L.) is an important crop. It is used in the production of hot sauce mash, the precursor to many hot sauces. Because hand harvest is currently required to accommodate staggered crop development, more uniform maturity is desired to facilitate mechanical harvest to decrease labor costs. This study was performed over 3 years (2009–11) and in two locations in southern New Mexico, resulting in five unique year/location scenarios (environments). Four timings of ethephon (0.56 kg a.i./ha) spray applications were evaluated for their potential to increase red cayenne cv. Mesilla yields and percentage of red pods. If yield increases and pigmentation improvements occur, ethephon may facilitate a once-over mechanical harvest. Ethephon was applied once at four key cayenne growth stages based on heat units accumulated after planting (HUAP): 1400 HUAP (late June to early July), 1800 HUAP (mid-July), 2800 HUAP (late August to early September), and 3100 HUAP (mid- to late September). Application timings corresponded to early bloom, peak bloom, late physiological maturity of plants, and preharvest, respectively. A non-sprayed control was also included. Fresh red, green, and non-marketable pod weights were recorded for each treatment in a once-over simulated machine harvest in October and analyzed for statistical differences. Mid- to late-season (2800–3100 HUAP) ethephon treatments significantly decreased undesirable green pod yield and, therefore, increased red pod percentage in four of five environments. Although a red pod yield increase was only observed in one environment (a drip-irrigated plot in 2010), there were no negative impacts on red pod yield in any environment resulting from ethephon application. In addition, pepper quality (yield of unmarketable pods) was not significantly reduced by ethephon. Previous work has focused on increasing red pod yields with mixed results. The results show that ethephon may synchronize cayenne pepper red fruit maturity necessary for mechanical harvest and reduce the labor involved in removing green pods before processing.

Cayenne pepper (*Capsicum annuum* L.) is one of several chile pepper pod types grown in New Mexico. Other pepper pod types include long red mild, long green mild, paprika, and long green hot [New Mexico Agricultural Statistics (NMAS), 2010]. Cayenne peppers

are the main ingredient in chile mash, the precursor to most Louisiana-style hot sauces (Bosland and Strausbaugh, 2010). Many commercial cayenne pepper cultivars have an indeterminate growth habit and therefore each plant has many pods of different ages that do not ripen to red simultaneously. This necessitates multiple, costly hand harvests of newly matured red pods during the growing season (Funk and Marshall, 2012). Increasing labor costs make it difficult for New Mexico pepper producers to stay competitive with domestic and foreign markets. Labor costs have created a shift toward less costly mechanical harvest (Funk and Walker, 2010). Reducing labor inputs by using mechanical harvest technology is one way that New Mexico producers can maintain a more competitive position in the U.S. and world pepper market (Wall et al., 2003b).

In addition to its indeterminate growth habit, cayenne pepper pods have characteristics indicative of both climacteric and non-climacteric fruits (Biles et al., 1993; Villavicencio et al., 1999). It is therefore designated as semiclimacteric. This characteristic of cayenne limits the efficiency of once-over machine harvest

because green pods harvested before the breaker stage will not turn red. Pod maturity must be at least to the breaker stage at the time of mechanical harvest to ensure proper pod pigmentation. One goal of New Mexico growers is to maximize red pod yield, whereas another is to increase red pod percentage, which will reduce the cost of sorting and removing green pods in a once-over mechanical harvest system.

Traditional plant breeding may be another way to improve the efficiency of mechanical harvest and help change the staggered pod development of cayenne. There are cultivars that exhibit determinate growth characteristics, but the overall quality and yield of these cultivars are inferior when compared with indeterminate cultivars (Arturo Jurado, Jurado Farms, personal communication, 22 Feb. 2009). The release of new determinate cultivars through traditional plant breeding is time-consuming and costly, so this study will focus on managing an indeterminate hybrid cayenne pepper cultivar to synchronize red fruit maturity necessary for mechanical harvest.

One way to manage indeterminate cayenne pepper pod maturity is by using plant growth regulators (PGRs). Ethylene, one of the primary PGRs involved in fruit ripening, has been shown to increase red pod synchronization when applied to paprika pepper before harvest at the rate recommended by the product (ethephon) label (Kahn et al., 1997). However, results involving ethephon and fruit maturation are highly variable (Alexander and Grierson, 2002). Ethephon has been used to enhance the color development rate in cayenne and paprika peppers (Krajayklang et al., 1999), but did not improve color development in other pepper cultivars (Hoyer, 1996). When ethephon is used to synchronize red pod development, it is most effective if pods are allowed to mature to the breaker stage. Ethephon treatments, however, often cause reduced yields and plant vigor (Kahn et al., 1997). Although ethephon can boost red pod percentage, it can also cause leaf yellowing and abscission of young pods and flowers that may reduce the total yield (Kahn et al., 1997). As a result, many pepper producers have chosen not to adopt PGRs as a result of the perceived risk.

Cantliffe and Goodwin (1975) demonstrated that ethephon applied to paprika-type chile peppers before harvest significantly increased the ratio of red to green pods. A once-over mechanical harvest removes all pods from the plant so undesirable green pods must be sorted out later. Therefore, an increased ratio of red pods will reduce both postharvest sorting time and waste of green pods. The practice of applying ethephon before mechanical harvest could increase the percentage of red pepper pods; however, ethephon is not widely used in New Mexico pepper production because results are variable and, in some cases, treatments actually reduce yields (Alexander and Grierson, 2002; Kahn et al., 1997).

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Kahn et al. (1997) also proposed that ethephon applied several weeks before harvest could increase red pod percentage, allowing for a once-over mechanical harvest because the number of undesirable green pods is reduced. Cantliffe and Goodwin (1975) studied ethephon as a ripening agent for red pod synchronization, whereas Kahn et al. (1997) focused on ethephon-induced abscission of young green pods. Kahn's results, similar to Cantliffe and Goodwin (1975), suggest that ethephon treatments increased red pod ratio because of significant green pod abscission. However, because of this significant green pod abscission, total yield was reduced (Kahn et al., 1997).

As a result of its indeterminate growth habit, we suggest that a midseason application of ethephon can also cause immature pod and flower abscission. However, there is no information in the literature regarding an early-season, controlled abscission of cayenne specifically designed to synchronize red pod development and increase red pod yield and percentage by the end of the season. Therefore, the hypothesis for this study is that midseason application timings of ethephon will increase both red pod percentage and total red pod yield for an indeterminate-type cayenne pepper cultivar. Midseason application of ethylene will serve as a controlled abscission agent and will cause flowers and immature pods to abscise. These early-season pods will not contribute greatly to the overall yield, and their removal will help synchronize the cayenne crop. The plants will quickly produce replacement pods in a shorter period of time causing simultaneous ripening at the end of the season. One objective of this study is to evaluate the effects of four different application timings of ethephon on their ability to increase red pod yield and percentage while maintaining market quality. Another objective is to evaluate the impacts of ethephon application on the total fresh weight of green and non-marketable pods.

Materials and Methods

This study was conducted over 3 years and in two different locations for a total of five southern New Mexico field environments near the New Mexico State University (NMSU) main campus in Las Cruces, NM (lat. 32.28° N, long. 106.76° W; elevation 1183 m). The five field environments were selected over 3 years (2009–11) at the NMSU Fabián García Science Center (FGSC) and Leyendecker Plant Science Research Center (LPSRC). Las Cruces is classified as Zone 8a with average annual minimum temperatures between –12.2 °C and –9.4 °C (USDA Plant Hardiness Zone Map, 2012). FGSC and LPSRC typically have the last spring freeze near 22 Mar. and the first fall freeze near 10 Nov. (NMAS, 2010). Soil type and other characteristics of each experimental plot and environment (A–E) are summarized in Table 1. The average annual precipitation for both locations is ≈20 cm; therefore, all plots were irrigated and managed according to

Table 1. Summary of five southern New Mexico (NM) field environments (A–E) at two New Mexico State University research stations [Fabián García Science Center (FGSC) and Leyendecker Plant Science Research Center (LPSRC)] near Las Cruces, NM.

Environment	A	B	C	D	E
Year	2009	2009	2010	2010	2011
Research station	FGSC	LPSRC	FGSC	LPSRC	LPSRC
Irrigation type	Flood	Flood	Drip	Flood	Drip
Soil type ^a	Ge	Bf	Ge	Gf	Bf
Replications	3	3	3	3	4

^aSource: U.S. Department of Agriculture Natural Resource Conservation Service Web Soil Survey (2009). Ge = Glendale loam; Bf = Belen clay loam; Gf = Glendale clay loam.

local practices (Bosland et al., 1999; Walker, 2009; Wall et al., 2003a; Western Regional Climate Center, 2012). All plots were managed as uniformly as possible with respect to water and nitrogen inputs.

'Mesilla' cayenne pepper (*Capsicum annuum*) is an indeterminate hybrid (Monsanto Vegetable Seed Inc., Oxnard, CA) and was selected for this study because it represents a majority of the raw material that is processed into chile mash. Buffer rows of chile pepper 'AZ-20' (*C. annuum*) (Curry Seed and Chile Co., Pearce, AZ), a large New Mexican green chile pod type, were used to separate 'Mesilla' rows in an effort to minimize the drift of ethephon between experimental plots.

Each year, ethephon treatments were replicated three to four times and arranged in a randomized complete block design. Treatment blocks were 6.1 m long with an unplanted 1.52-m buffer at each end. Standard vegetable raised beds with 0.6-m centers were used and peppers were sown in a single line down the center of each bed. In-row spacing for both the cayenne and green chile buffer rows was 0.3 m.

Each year, 'Mesilla' cayenne seeds were sown, one per cell, into 806-seed flat inserts (Grower's Solution, LLC, Cookeville, TN) filled with a coconut fiber blend potting mix (Sunlight Supply Inc., Vancouver, WA) near 22 Mar. Seeding occurred in a controlled-climate greenhouse at the FGSC. The daytime temperature in the greenhouse was maintained at 27 and 13 °C at night. Flats were hand-watered once per day and fertigated with a 24N–8P–16K solution (Scotts Company, LLC, Marysville, OH) once before hardening occurred. Each year, plants were hardened in a lath house for 9 to 14 d and then transplanted by hand into the field near 15 May. The 'AZ-20' border rows were direct-seeded in the field on or near 29 Mar. At sowing, the fungicide mefenoxam (0.57 kg a.i./ha; Syngenta Crop Protection, Greensboro, NC) was injected into the 'AZ-20' direct-seeded rows as well as the transplanted rows of 'Mesilla' to protect against fungal pathogens.

All field environments were managed using standard cultural practices for chile pepper production in southern New Mexico (Bosland et al., 1999; Walker, 2009; Wall et al., 2003a). Three of the five field environments were flood-irrigated (Table 1). The remaining two environments were drip-irrigated using sub-surface drip tape (Toro Agricultural Irrigation, Riverside, CA) set to a depth of 15.2 cm, 20.3-cm emitter spacing, and a flow rate of

1 L·h⁻¹/emitter at 55 kPa. All field environments were irrigated approximately once per week when the top 5 cm of soil dried. Field plots were fertilized once with a urea ammonium nitrate solution (URAN 2.34 L·ha⁻¹, 32% nitrogen; Helena Chemical Co., Mesquite NM) at early bloom (late June). A tractor-drawn cultivator was used early in the season to remove weeds and hand-weeding was used after the crop became too large for mechanical cultivation.

Ethephon was applied at a rate of 2.34 L product in 187.1 L water/ha (0.56 kg a.i./ha). The rate was selected based on the manufacturer's recommendations given New Mexico's unique environmental conditions such as high heat and low humidity. Applications were made using a hand-pumped backpack sprayer (Model SP2; SP Systems, Santa Monica, CA) during pre-dawn hours. Plants were evenly sprayed from 0.3 m above the plant canopy while walking at a steady speed, resulting in complete leaf coverage.

Ethephon was applied at key cayenne developmental growth stages determined by HUAP as calculated by Brown (1989) and using 12.8 °C (55 °F) and 30 °C (86 °F) as lower and upper thresholds, respectively (Soto-Ortiz and Silvertooth, 2008). The study consisted of three to four ethephon application timings and a non-sprayed control. The spray treatments were applied at 1400 HUAP (end of June; early bloom), 1800 HUAP (mid-July; peak bloom), 2800 HUAP (mid- to late Aug.; late physiological maturity), and 3100 HUAP (mid-September; preharvest) (Soto-Ortiz and Silvertooth, 2008). Heat units were calculated using data from NMSU weather stations near the study sites and retrieved with the associated web database (<http://weather.nmsu.edu/en/ws/>). The 2800 HUAP treatment timing was removed from the 2011 field environment as a result of space considerations (Table 2).

In all environments, harvest was done by hand to approximate a once-over mechanical harvest. Plots were harvested in the second to third week of October at ≈3800 HUAP. All pods in a 3.05-m row section, regardless of size, were stripped as if the crop was harvested mechanically. After harvest, pods were sorted into red, green, and non-marketable categories and weighed individually. A "red" pod was defined as a pod with greater than 50% of the surface pigmented red. Pigmentation was determined by a visual assessment. A "green" pod was defined as greater than 50% of the surface appearing green. A "non-marketable"

pod exhibited one or more disorders such as, but not limited to, anthracnose (*Colletotrichum* spp.), *Phytophthora capsici*, and/or bacterial spot (*Xanthomonas campestris* pv. *vesicatoria*). Pod diseases were evaluated immediately after harvest, separated, and weighed separately. Cayenne pods infected with *Beet curly top virus* or other disorders without tissue or pod necrosis were considered marketable. Red pod percentage was calculated as red pod fresh yield divided by total yield (red pod yield + green pod yield + non-marketable pod yield).

Statistical analysis was conducted using SAS software (SAS Institute, Cary, NC). The proc general linear model was used to analyze the data in this experiment. Data were not pooled as a result of the year/location combinations that resulted in five distinct growing environments. Weights were converted to kg-ha⁻¹ and evaluated for analysis of variance. If the main effect of ethephon application timing was significant ($P < 0.05$) fresh red pod yield, fresh green pod yield, and fresh non-marketable pod yield means were separated using Duncan's multiple range test (SAS 9.2, 2009, SAS Institute). Red pod percentage was calculated and analyzed as a separate variable.

Results and Discussion

Early-season application of ethephon produced variable results in each of the five New Mexico environments observed in this study (Table 2). An ethephon application had the most impact by significantly decreasing undesirable green pod yields while not significantly decreasing desirable red pod yields. As a result, plots sprayed with ethephon showed significantly higher red pod percentages over the untreated control in four of the five environments. Ethephon applications did not have a significant impact on the non-marketable pod yield in any environment. Variability between each of the five environments was the result of year, research station location, irrigation type (drip vs. flood), and soil type. Other differences such as moisture and weed management may have also had an impact on the plants grown in each environment.

Environment A. Only the mid- and late-season (2800 and 3100 HUAP) ethephon application timings had a significant impact on green pod yield while not decreasing red pod yields in 2009. As a result, red pod percentage was significantly increased (74% to 77%) as compared with the untreated control (58%). Ethephon applied at 1800 HUAP caused a significant increase in green pod yield compared with all other treatments likely resulting from abscission of immature pods and flowers followed by a flush of new pods that did not have the opportunity to fully mature by harvest (Fig. 1). This significantly decreased the red pod percentage.

Environment B. Overall yields in environment B were relatively low. Factors that may have influenced yields in environment B included water stress and weed competition. Despite yield differences, mid- to late-season ethephon applications (2800 and 3100 HUAP) significantly decreased green pod yields

Table 2. Effect of various ethephon application timings measured in heat units after planting (HUAP) on 'Mesilla' cayenne fresh pod yields (kg-ha⁻¹) in 3 years (2009–11) and in five New Mexico environments (A–E).

Ethephon treatment	Red pod yield (kg-ha ⁻¹) ^z	Green pod yield (kg-ha ⁻¹)	Non-marketable pod yield (kg-ha ⁻¹)	Red pod percent (%) ^y
Environment A^x				
1800	9,500	17,998 a	485	33.9 c
2800	10,278	2,811 c	226	77.2 a
3100	13,216	4,007 c	420	74.9 a
Control	13,571	9,532 b	517	57.5 b
Significance	NS	***	NS	***
Environment B				
1800	4,685	1,454 a	226	73.6 b
2800	2,908	485 c	97	83.3 a
3100	3,425	711 c	97	80.9 a
Control	3,134	1,325 ab	97	68.8 b
Significance	NS	*	NS	**
Environment C				
1400 ^w	18,127 ab	11,471 ab	485	60.3 bc
1800	18,935 a	7,884 b	614	69.0 b
2800	17,643 ab	11,437 ab	743	59.2 c
3100	16,576 ab	4,168 c	808	76.9 a
Control	14,799 b	14,573 a	1,325	48.2 d
Significance	*	**	NS	**
Environment D				
1400	15,381	3,781	420	78.5
1800	8,789	4,621	582	62.8
2800	6,333	1,422	743	74.5
3100	8,692	4,254	873	62.9
Control	11,212	6,430	808	60.2
Significance	NS	NS	NS	NS
Environment E				
1400	22,780	6,979 b	355	69.2 a
1800	22,101	7,529 b	452	74.5 a
3100	19,387	5,364 b	485	75.2 a
Control	15,251	12,311 a	517	52.8 b
Significance	NS	**	NS	**

^zYield was based on a single, destructive harvest in the second to third week of October before a killing frost. Mean separation within columns and environment by Duncan's multiple range test. Significance at $P \leq 0.001$, 0.01, 0.05 designated by ***, **, and *, respectively. NS = nonsignificant effect.

^yRed percentage (%) = red pod yield/(red pod yield + green pod yield + non-marketable pod yield).

^xEnvironment characteristics are described in the "Materials and Methods" section.

^w1400 HUAP treatment was added in 2010.

Fig. 1. Effect of ethephon on 'Mesilla' cayenne pepper flowers and young pods. The image on the left was taken on 14 July (1800 HUAP). The image on the right was taken 14 d later (28 July). All young pods, flowers, and flower buds have abscised in response to the ethephon treatment (photographs taken by Adam Blalock at the New Mexico State University Fabián García Science Center, 2010). HUAP = heat units accumulated after planting.

without decreasing red pod yield. The decrease in green pod yields increased the red pod percentage. The decrease in green pod yield was likely the result of ethephon-induced abscission of immature, green pods in the weeks leading up to harvest (Fig. 1; Kahn

et al., 1997). This effect was observed, but no data were collected from dropped pods or flowers from the soil surface.

Environment C. Late-season ethephon application timing (3100 HUAP) did not significantly increase red pod yield but did

decrease green pod yield as compared with the control. In this field environment, this treatment resulted in the highest numerical red pod percentage (77%). Unique to this field environment, the 1800 HUAP treatment both significantly increased red pod yield and decreased green pod yield with the overall effect of increasing red pod percentage (69%) as compared with the control. However, the 3100 HUAP timing produced a significantly higher red pod percentage.

Environment D. There were no significant changes in red pod, green pod, non-marketable pod, or red pod percentage in environment D. The crop in this field environment experienced significant moisture stress and weed competition resulting from delayed field management operations, which presumably had an impact on our external ethephon treatments.

Environment E. Similar to environments A, B, and C, ethephon applications (1400, 1800, and 3100 HUAP) significantly decreased green pod yields without a negative impact on red pod yield (Fig. 1). As a result, all three treatments showed a significantly higher red pod percentage when compared with the untreated control. This result indicates that ethephon-induced green pod abscission (early or late) can have a positive influence on red pod percentages at harvest.

The results of this study demonstrate that ethephon has the potential to decrease undesirable green cayenne pod yield and therefore increase red pod percentage. The manufacturer recommends late-season (3100 HUAP) treatment timing to increase red pod yields. In our study, mid- to late-season (2800–3100 HUAP) ethephon treatments significantly increased the red pod percentage in four of five environments. Although a red pod yield increase

was only observed in one environment, it is important to note that unlike other studies (Kahn et al., 1997), there were no negative impacts on red pod yield in any environment resulting from ethephon application. In addition, pepper quality (number of unmarketable pods resulting from disorders, disease, malformation, or discoloration) was not significantly reduced with an application of ethephon. The results from this study show that ethephon may synchronize cayenne pepper red fruit maturity necessary for mechanical harvest and reduce the labor involved in removing green pods before processing.

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