Research Reports

Gibberellic Acid Tank Mix and Adjuvant Effects on Peel Quality and Juice Yield of 'Hamlin' Oranges

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SUMMARY. It is desirable to mix gibberellic acid (GA₃) with other commonly applied materials to reduce application cost. However, applying GA₃ with some compounds can reduce its efficacy or cause phytotoxicity. We conducted experiments in 1997–98 and 1998–99 to determine if GA₃ (ProGibb) can be tank-mixed with fosetyl-Al (Aliette), or avermectin (Agri-Mek) and oil, without reducing GA₃ efficacy. In addition, we compared

Silwet and Kinetic adjuvants for enhancement of GA₃ efficacy. Five tank mixes were tested along with a nonsprayed control. These included 1) GA₃; 2) GA₃ and Silwet; 3) GA₃ and Kinetic; 4) GA₃, Silwet, and fosetyl-Al; and 5) GA₃, Silwet, avermectin, and oil. All compounds were applied at recommended concentrations. In September 1997 or October 1998, about 2.5 gal (9.5 L) of each tank mix was applied with a hand sprayer to 14- or 15-year-old 'Hamlin' orange (*Citrus sinensis*) trees on sour orange (*Citrus aurantium*) rootstock. Peel puncture resistance (PPR), color, and juice yield (% juice weight) were evaluated monthly between December 1997 and March 1998, and December 1998 and January 1999. In both years, fruit of treated trees usually had higher PPR and were less yellow in color than fruit from control trees. There were tank mix effects on juice yield in January of both seasons and February 1998. Gibberellic acid was most effective at enhancing juice yield when applied singly or with avermectin and oil. In both seasons there were dates when GA₃ applied singly was superior at enhancing juice yield than a tank mix of GA₃, Silwet and fosetyl-Al, indicating that GA₃ was incompatible with fosetyl-Al. Neither Kinetic nor Silwet adjuvants consistently enhanced GA₃ effects on peel quality or juice yield over GA₃ alone.

Gibberellic acid (GA₃) has been applied to citrus fruit for many years in the late summer or fall to reduce senescence-related peel disorders and thus improve peel quality and extend the fresh-fruit harvest season (Coggins, 1981; Davies, 1986). Recently, growers in Florida have been applying GA₃ to processing oranges because it can increase juice extraction weight (Davies et al.,

1997). Gibberellic acid is applied with an airblast sprayer that costs about \$30/acre (\$74/ha) to operate (Muraro et al., 1998). Other compounds are often sprayed on citrus during the late summer and fall, thus it is desirable to reduce GA₃ application costs by combining it with other compounds in a tank mix (Coggins et al., 1974).

Tank mix composition can alter the efficacy of GA₃ on citrus fruit (Greenberg and Goldschmidt, 1988). Unfortunately, the mechanisms by which these variables enhance or reduce the effect of GA₃ are not understood. At alkaline pH, GA₃ is converted to a less biologically active form of gibberellin. Alkaline well water (pH 8 to 10) did not reduce the beneficial effects of GA₃, but when added to a whitewash mixture (calcium hydroxide, copper sulfate and zinc sulfate plus an adjuvant; pH 12.6) the effect of GA₃ on PPR and peel color was reduced unless the tank mix was neutralized (Coggins et al., 1974). Acidification, which favors a more active form of gibberellin, enhanced GA₃ efficacy in South Africa (Gilfillan, 1986) and Israel (Greenberg et al., 1984) but not in California (Coggins et al., 1992).

Surfactants enhance GA₃ penetration and the effects of GA₃ on the citrus peel, but the mechanism of surfactants in enhancing GA₃ uptake is also unknown (Henning and Coggins, 1988; Greenberg and Goldschmidt, 1988). Surfactants lower the surface tension of the solution, but surface tension of GA₃ solutions did not always relate to GA₃ efficacy (Henning and Coggins, 1988). Some surfactants appear to dissolve selectively certain cuticle waxes of citrus fruit, which might enhance GA₃ uptake (Greenberg and Goldschmidt, 1988). An interaction between surfactants and GA₃ caused necrotic spots in grapefruit (*Citrus paradisi*) rind which indicate that supraoptimal levels of GA₃ can cause phytotoxicity (Coggins and Henning, 1988). Silwet and Kinetic are adjuvants that may increase GA₃ efficacy on citrus (Henning and Coggins, 1988).

Like surfactants, insecticidal oils appear to dissolve certain cuticular waxes (Coggins, 1981) and thus might enhance GA₃ efficacy or cause phytotoxicity. Petroleum oil, avermectin (mite control) and fosetyl-Al [brown rot (*Phytophthora citrophthora*) control] are often applied to oranges during the fall in Florida and thus are compounds that might be included in a tank mix with GA₃. Before GA₃ is used in a tank mix

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Table 1. Chemicals used in tank mix treatments, source, and amount applied, Gainesville, Fla., 1997–99.

Common name	Trade name	Source	Amount applied
Gibberellic acid	ProGibb	Valent BioSciences, Orlando, Fla.	18 g/acre (a.i.) (45 g·ha ⁻¹)
Silwet	Silwet	Helena Chemical Co., Memphis, Tenn.	0.05% v/v
Kinetic	Kinetic	Setre Chemical Co., Memphis, Tenn.	0.05% v/v
Petroleum oil FC-435	OMNI Supreme Spray	Setre Chemical Co., Memphis, Tenn.	5 gal/acre (46.7 L·ha ⁻¹)
Avermectin	Agri-Mek	Novartis, Greensboro, N.C.	10 fl oz/acre (0.74 L·ha ⁻¹)
Fosetyl-Al	Aliette	Rhone-Poulenc, Research Triangle Park, N.C.	5 lb/acre (5.6 kg·ha ⁻¹)

the effectiveness and possible phytotoxicity of each combination should be evaluated. Our objectives were to determine if GA₃ is effective and nonphytotoxic when mixed with fosetyl-Al or avermectin and oil, and to determine if Silwet and Kinetic adjuvants increase GA₃ efficacy.

Materials and methods

TANK MIX TREATMENTS AND EXPERIMENTAL DESIGN. On 9 Sept., 1997, tank mixes were applied to 14-year-old ‘Hamlin’ orange trees on sour orange rootstock: 1) GA₃ (pH = 6.3); 2) GA₃ + Silwet (pH = 6.7); 3) GA₃ + Kinetic (pH = 7.5); 4) GA₃ + Silwet + fosetyl-Al (pH = 3.4); 5) GA₃ + Silwet + avermectin + oil (pH = 6.8). Chemical sources and the amounts applied are shown in Table 1. A backpack sprayer (Solo Inc., Newport News, VA) was used to apply about 2.5 gal (9.5 L) of each tank mix to seven trees, and seven trees remained nonsprayed. Chemicals were applied between 0700 and 1000 HR. Following treatments, all trees were visually evaluated for leaf drop or other signs of phytotoxicity. The experiment was repeated in 1998–99 on different trees in the same grove with 15-year-old ‘Hamlin’ orange trees. The same tank mix treatments were used except that Kinetic was not included in order to increase the number of individual tree replications in the block based on the

previous year’s results. Tank mixes were applied on 20 Oct. 1998, as previously described, using 11 single tree replications per treatment.

In 1997–98, the experiment consisted of a completely randomized design (CRD) with six treatments and seven individual trees per treatment. In 1998–99, the experiment consisted of a CRD with five treatments and eleven individual trees per treatment. Border trees surrounded each experimental tree. Trees were located in Gainesville, Fla.

FRUIT QUALITY MEASUREMENTS. In 1997–98, fruit were harvested monthly between 30 Sept. 1997 and 11 Mar. 1998. In 1998–99, fruit were harvested on 17 Dec. 1998 and 13 Jan. 1999, when the experiment was terminated due to a freeze that damaged the fruit. At each harvest date, fruit were randomly collected at a 3 to 6 ft (0.9 to 1.8 m) height around each tree. One sample of 10 fruit per tree was washed, air dried, and evaluated for peel puncture resistance (PPR) and peel color. Fruit diameter was measured with calipers, and fruit were also visually inspected for phytotoxicity. Peel puncture resistance was determined, using an AccuForce force gauge (Ametek, Largo, Fla.), as the peak force required to puncture the fruit with a cylindrical steel probe of 0.5 mm diameter. Peel color (hue) was measured with a chroma meter (Minolta Inc., Ramsey, N.J.). Average PPR and

peel color for each fruit were determined from three measurements equidistant around the fruit equator. Another fruit sample, about 20 lb (9 kg), was randomly collected at a 3 to 6 ft (0.9 to 1.8 m) height around each tree between 30 Dec. 1997 and 11 Mar. 1998 and 17 Dec. 1998 and 13 Jan. 1999. Fruit were transported to the Department of Citrus at Lake Alfred, Fla. Each sample was juiced according to Florida State test standards (Terry et al., 1999) using a juice extractor (model 091; FMC Corp., Lakeland, Fla.).

STATISTICAL ANALYSIS. All data were subjected to the general linear model procedure (SAS Institute Inc., Cary, N.C.) for analysis of variance (ANOVA). To test whether the variables changed over time, data were subjected to ANOVA as a split plot in time with treatments as the main plot and harvest time as the subplot (juice weight) or using a repeated measures analysis (color and PPR). Effect of harvest time was significant for each variable ($P \leq 0.05$; data not shown) and data were then subjected to analysis of variance by date and treatment. When treatment effects were significant, treatment means were separated within dates using Duncan’s new multiple range test (DNMRT). Peel variables and juice yield data were subjected to regression analysis using PROC REG (SAS) to investigate possible relationships between juice yield

Table 2. Effects of tank mixes on peel puncture resistance (PPR) of ‘Hamlin’ oranges in Gainesville, Fla., 1997–98².

Tank mix	PPR (pounds-force) ³							
	Harvest date							
	30 Sept.	21 Oct.	11 Nov.	9 Dec.	7 Jan.	27 Jan.	17 Feb.	11 Mar.
Gibberellic acid (GA ₃)	1.75 a	1.46 b	1.19 ab	1.06 ab	0.94 b	0.88 b	0.81 ab	0.76 a
GA ₃ + Silwet	1.73 a	1.66 a	1.44 a	1.21 a	1.06 ab	0.94 ab	0.85 a	0.85 a
GA ₃ + Kinetic	1.69 a	1.55 ab	1.30 ab	1.03 ab	1.08 a	0.99 a	0.85 a	0.80 a
GA ₃ + Silwet + fosetyl-Al	1.64 a	1.48 b	1.29 ab	1.10 ab	0.97 b	0.94 ab	0.88 a	0.76 a
GA ₃ + Silwet + avermectin + oil	1.64 a	1.46 b	1.26 ab	1.10 ab	0.97 b	0.90 ab	0.75 b	0.81 a
Nonsprayed	1.42 b	1.12 c	1.01 c	0.81 c	0.81 c	0.81 c	0.76 b	0.75 a

²Means of three measurements taken around the equator of each of 10 fruit per tree. There were seven individual tree replications per treatment. Data were originally analyzed by repeated measures. Time and treatment were highly significant, $P \leq 0.01$. Mean separation within columns by Duncan’s new multiple range test, $P \leq 0.05$. Trees were sprayed on 9 Sept. 1997.

³1 pound force = 4.45 N.

Table 3. Effects of tank mixes on peel color (hue angle) of ‘Hamlin’ oranges in Gainesville, Fla., 1997–98^z.

Tank mix	Color (hue angle°)							
	Harvest date							
	30 Sept.	21 Oct.	11 Nov.	9 Dec.	7 Jan.	27 Jan.	17 Feb.	11 Mar.
Gibberellic acid (GA ₃)	117.0 a	112.0 b	98.7 b	86.7 ab	80.8 ab	77.4 ab	72.1 a	71.3 a
GA ₃ + Silwet	117.3 a	114.5 a	104.3 a	98.4 a	83.7 ab	81.1 a	73.9 a	72.4 a
GA ₃ + Kinetic	117.5 a	114.4 a	102.9 a	85.5 ab	84.4 a	77.6 ab	72.1 a	70.9 a
GA ₃ + Silwet + fosetyl-Al	118.0 a	113.9 a	101.8ab	85.7 ab	80.4 b	76.8 b	71.6 a	69.1 a
GA ₃ + Silwet + avermectin + oil	118.5 a	114.4 a	101.3ab	88.4 ab	82.4 ab	77.4 ab	71.1 a	70.4 a
Nonsprayed	115.5 a	105.1 b	89.5 c	78.9 b	74.1 b	69.6 b	67.6 b	66.6 a

^zMeans of three measurements taken around the equator of each of 10 fruit per tree. There were seven individual tree replications per treatment. Data were originally analyzed by repeated measures. Time and treatment were highly significant, $P \leq 0.01$. 120 = green, 60 = yellow. Mean separation within columns by Duncan's new multiple range test, $P \leq 0.05$. Trees were sprayed on 9 Sept. 1997.

Table 4. Effects of gibberellic acid (GA₃) tank mixes on peel color (hue angle) and peel puncture resistance (PPR) of ‘Hamlin’ orange fruit, Gainesville, Fla., 1998–99^z.

Tank mix	Hue angle (°)		PPR (pounds-force) ^y	
	Harvest date			
	17 Dec. 1998	13 Jan. 1999	17 Dec. 1998	13 Jan. 1999
GA ₃	115.5 a	108.4 a	1.4 a	1.3 a
GA ₃ + Silwet	115.6 a	108.2 a	1.5 a	1.4 a
GA ₃ + Silwet + fosetyl-Al	115.6 a	108.1 a	1.5 a	1.3 a
GA ₃ + Silwet + avermectin + oil	115.6 a	103.7 b	1.5 a	1.3 a
Nonsprayed	112.8 b	95.9 c	1.2 b	1.0 b

^zMeans of three measurements taken around the equator of each of 10 fruit per tree. There were 11 individual tree replications per treatment. Data were originally analyzed as a split plot in time. Time and treatment were highly significant, $P \leq 0.01$. Mean separation within columns by Duncan's new multiple range test, $P \leq 0.05$. Trees were sprayed on 20 Oct. 1998.

^y1 pound force = 4.45 N.

Table 5. Juice yield of ‘Hamlin’ orange fruit sprayed with various gibberellic acid (GA₃) tank mixes or nonsprayed, Gainesville Fla., 1997–98^z.

Tank mix	Juice yield (% wt/wt)			
	Harvest date			
	11 Dec.	8 Jan.	24 Feb.	27 Mar.
GA ₃	58.1 a	58.4 a	55.2 a	47.5 a
GA ₃ + Silwet	57.1 a	56.6 ab	51.0 ab	43.5 a
GA ₃ + Kinetic	58.9 a	56.7 ab	51.7 ab	47.0 a
GA ₃ + Silwet + fosetyl-Al	58.2 a	56.4 ab	49.8 b	45.7 a
GA ₃ + Silwet + avermectin + oil	59.9 a	58.3 a	53.1 ab	45.9 a
Nonsprayed	57.1 a	54.8 b	51.6 ab	43.7 a

^zMeans of a 20-lb (9-kg) fruit sample per tree. There were seven individual tree replications per treatment. Data were originally analyzed as a split plot in time. Time and treatment were highly significant, $P \leq 0.01$. Mean separation within columns by Duncan's new multiple range test, $P \leq 0.05$. Trees were sprayed on 9 Sept. 1997.

and PPR and peel color. Regression analyses were conducted using means from individual trees across all treatments and dates, within treatments, or within dates.

Results and discussion

Increased PPR due to GA₃ was evident by 30 Sept. 1997, about 1 month after tank mix application (Table 2), whereas GA₃ effects on peel color were not observed until the fruit were evaluated on 21 Oct., about 1 week after colorbreak (Table 3). Between October and February, each of the tank mix

treatments resulted in fruit with higher PPR and higher peel hue angles (more green color) than fruit of nonsprayed trees. Peel puncture resistance and peel color was positively correlated both years (1998–99 data not shown). In 1998–99, there were no differences in PPR and color among tank mix treatments, except for the GA₃, avermectin and oil treatment for color (Table 4).

The GA₃ + Silwet + fosetyl-Al tank mix had a much lower pH than the other treatments (pH = 3.4 vs. 6.3 to 7.5, respectively), but its effect on peel quality was similar to that of other tank

mixes. Coggins et al. (1992) also found that an acidic delivery solution did not increase GA₃ effectiveness, but these findings are in contrast with findings by Gilfillan (1986) and Greenberg and Goldschmidt (1989) who found that acidification by a variety of compounds increased GA₃ effectiveness. In contrast with previous findings (Coggins et al., 1992; Greenberg et al., 1987), neither Silwet nor Kinetic enhanced GA₃ efficacy.

Juice yield differed among treatments on 8 Jan. and 24 Feb. 1998 (Table 5) and on 13 Jan. 1999 (Table

Table 6. Juice yield of 'Hamlin' orange fruit sprayed with various gibberellic acid (GA₃) tank mixes or nonsprayed, Gainesville, Fla., 1998–99^a.

Tank mix	Juice yield (% wt/wt)	
	Harvest date	
	17 Dec. 1998	13 Jan. 1999
GA ₃	59.1 a	49.8 a
GA ₃ + Silwet	58.3 a	47.8 ab
GA ₃ + Silwet + fosetyl-Al	57.1 a	46.2 b
GA ₃ + Silwet + avermectin + oil	58.3 a	48.7 ab
Nonsprayed	56.1 a	49.0 ab

^aMeans of a 20-lb (9-kg) fruit sample per tree. There were 11 individual tree replications per treatment. Data were originally analyzed as a split plot in time. Time and treatment were highly significant, $P \leq 0.05$. Mean separation within columns by Duncan's new multiple range test, $P \leq 0.05$. Trees were sprayed on 20 Oct. 1998.

6). On 8 Jan. 1998, fruit treated with GA₃ alone or GA₃ + Silwet + avermectin + oil yielded about 3.6% more juice than control fruit on a percent fruit weight basis, or about 6% more juice standardized to control. On 24 Feb. 1998 and 13 Jan. 1999, the GA₃ only treatment resulted in approximately 10 or 7% more juice, respectively, than did fruit from trees treated with the GA₃ + Silwet + fosetyl-Al tank mix (standardized to the fosetyl-Al treatment). There were no other tank mix effects on juice yield. Thus, GA₃ efficacy was reduced by the addition of fosetyl-Al in some cases. Moreover, Kinetic and Silwet did not increase juice yield compared to GA₃ alone.

In both seasons, juice yield declined as the harvest season progressed, especially into late March 1998. There were no treatment effects by 27 Mar. 1998. Thus, GA₃ per se did not extend the processing season of 'Hamlin' oranges beyond February. However, GA₃ reduced the number of culls by maintaining peel integrity late into the season (J. Keithly, unpublished) thereby potentially extending the harvest season. The large decline in juice yield in Jan. 1999 was likely due to freeze damage, but the effects were consistent across all treatments.

The basis for GA₃-enhanced juice yield is unknown but physiological or physical mechanisms have been proposed. A physiological response seems unlikely because exogenously applied GA₃ did not enhance fruit size (data not shown) and GA₃ did not affect the percent juice (using hand reamers) in several studies (Davies, 1986). Moreover, radiolabeled GA₃ applied to the peel of grapefruit was metabolized there and not recovered from the juice or seeds (Ferguson et al., 1986). Alternatively, GA₃ effects on peel or fruit rheological properties might affect juice

extraction efficiency using an FMC machine because peel failure during squeezing might allow some juice to escape the juice stream. In support of this hypothesis, peel puncture resistance and juice yield had a coefficient of determination (r^2) of 0.30 to 0.80 within harvest dates in 1997–98. When analyzed within treatments across all harvest dates r^2 values ranged from 0.34 to 0.86, indicating that PPR accounted for as much as 86% of variation in the model. Overall r^2 across all treatments and dates using individual tree means was 0.58 in 1997–98 and 0.54 in 1998–99. Peel hue, which would not have any effect on juice extraction, was poorly correlated with juice yield. We are currently testing the effects of GA₃ on various peel and fruit rheological properties to determine if they relate to juice yield.

Fosetyl-Al + avermectin + oil was combined with GA₃ to decrease application costs without reducing the effect of GA₃ on PPR or peel color, and without causing phytotoxicity. However, fosetyl-Al reduced GA₃ efficacy on juice yield at some dates in both seasons and thus should not be added to a GA₃ tank mix for processing oranges. Applying GA₃ alone without Silwet or Kinetic adjuvants can further reduce application costs, although additional research is needed. Effects of GA₃ on juice yield were variable as observed previously (Davies et al., 1997). This inconsistency may be related to time of application (Davies et al., 1999).

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