Some Mechanical Properties of Developing 'Delicious' and 'Golden Delicious' Apple Fruits as Influenced by N-Dimethylaminosuccinamic Acid[1]

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Abstract. Treatment with a 1000 ppm solution of N-dimethylaminosuccinamic acid (DMAS) at 30 days after full bloom to bearing apple trees caused a significant increase in resistance of 'Delicious' both to bruising and to rupture injury. The onset of increased resistance to bruising by DMAS occurred before that of increased resistance to rupture. Such effects were not found on 'Golden Delicious'.

In studies of mechanical properties of biological materials, an apple bruise is referred to as the initial cell-rupture manifestation shown by a distinct break or drop in the force-deformation curve when an apple fruit is subjected to compression. This break in the curve is termed the bio-yield point. If the compression is continued, a second, but more gradual, drop in the curve occurs when the surface of the fruit is ruptured. This is referred to as the rupture point (10).

Mohsenin et al. (12) have shown that fruit firmness as measured with a Magness-Taylor pressure tester was unrelated to bruising resistance (bio-yield force) in the apple. However, a degree of association was found between firmness and rupture force. Although DMAS may increase the firmness of apple fruits, its effect on bruising and rupture resistance is unknown. New methods for determining the point at which bruising and rupture first occur make possible a critical study of the effects of DMAS on the resistance of apple fruits to such injuries (9,10,11,13).

The objective of this research was to determine changes brought about by a foliar treatment of DMAS on the force to bio-yield (bruise), and the force to rupture of developing 'Delicious' and 'Golden Delicious' apple fruits.

Materials and Methods

In the Plant Physiology Block at the University orchard, 6 'Delicious' and 6 'Golden Delicious' apple trees on EM II rootstocks were selected for treatments. These trees of medium vigor, 15 years old, were growing in a sod-mulch culture. Bloom in the spring of 1968 was heavy on all trees, but cool weather prolonged the blooming period and caused a lighter fruit set than the potential indicated. Some hand thinning was done.

The trees of each cultivar were divided into 3 replications of 2 trees, each pair of uniform condition. One tree of each replication received a dilute foliar aqueous spray of DMAS at 1000 ppm of active material, using the Alar-85 formulation. The surfactant, Tween-20, was added to the spray solution at the rate of 1 milliliter per gallon. Application was made on June 14, 1968, 30 days after full bloom, using a hand gun and a high pressure sprayer. Each sprayed tree was wet to the point of runoff. The second tree of the pair was not treated.

Mechanical properties study. The testing instrument used to evaluate mechanical properties of 'Delicious' and 'Golden Delicious' apples was similar to that developed by Mohsenin (9). An 1/8 inch diameter flat steel-plunger was used, and force applied at the rate of 0.8 inch per minute. The pneumatic drive was checked and recalibrated periodically to assure a uniform rate of force application.

Beginning on August 5 for 'Delicious' and on August 10 for 'Golden Delicious', a 2-apple sample was collected approximately every 7 days from each of the 4 quarters of each tree. For the first 2 sampling periods, apples were collected in the evening and stored within half an hour at 34°F. The following day, they were allowed to reach room temperature before being tested. However, for the remaining sampling periods, this procedure was changed from holding fruits in cold storage to keeping them overnight in the laboratory at room temperature (70-75°F). This method allowed more uniform fruit temperature conditions at time of testing than did the first technique, especially during the early morning. All measurements were completed on the same day, usually within 12 hours.

Four sets of measurements, through the point of fruit rupturing, were taken around each fruit to determine the behavior of the apple under a slow rate of compression stress. From each force-deformation curve plotted by the instrument, force of initial bruising (bio-yield point), and force to rupture (rupture point) values were obtained.

Fruit growth measurements. Since a reduction in apple fruit size has been reported in some instances with an early season application of DMAS (1,2,6,8,10,14), fruit growth measurements were obtained to determine if such an effect occurred in this study. Mohsenin et al. (12) have shown that fruit size can influence bio-yield and rupture force readings. A similar negative relationship has been reported by Looney[4] between fruit diameter and firmness of Delicious apples all at the same physiological stage.

On each tree, 10 typical apple fruits were selected and tagged for cross diameter measurements at weekly intervals. Measurements began on June 13, 1 day before DMAS treatment, and terminated on September 13 for 'Delicious' and on October 7 for 'Golden Delicious'.

Statistical analysis. Analysis of variance with sub-sampling was used to evaluate differences between DMAS-treated and non-treated fruits at a given time of observation (3). Covariance analysis was used in the growth study to determine if significant differences found by analysis of variance on certain dates were actual, or caused by size differences among fruits prior to DMAS application (4). Fruit size on June 13 was the independent variable.

The data are means of 8 similar determinations, 4 on each of 2 apples per tree quarter. Sampling variance (i.e., replications x treatment x sampling) was used for determining the F-ratios for main factors.

Results and Discussion

Both 'Delicious' and 'Golden Delicious' apple trees showed

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[4]Looney, N. E. 1966. Some biochemical and physiological aspects of maturation and ripening in climacteric fruits. Ph.D. Thesis, Washington State University, Pullman, Washington.

the responses usually associated with DMAS treatment when applied in the spring. For example, there was a greater resistance to fruit abscission and removal at harvest. A heavier bloom and a greater set of fruit occurred the following spring on DMAS-treated than on non-treated trees for both cultivars. Thus, it appeared that the trees absorbed DMAS in sufficient quantities to cause normal physiological and growth responses which have been observed previously (1,2,6,8,14,15). The date of commercial harvest was determined by the general condition and appearance of the fruit. The optimum date of commercial harvest for 'Delicious' in 1968 was considered to be on September 26, and for 'Golden Delicious' on October 7.

Fruit Size. The fruit of 'Delicious' and 'Golden Delicious' enlarged each at a constant and similar rate, regardless of treatment. Only on the observation dates of July 22 and July 29 for Delicious were differences between treatments significant, but these differences were not significant upon analysis of the data by covariance. Consequently, an apple size difference between treatments which might have been caused by DMAS (1,2,6,8,14,15) did not exist. Thus, at each sampling date, force to bio-yield and force to rupture values were not influenced by apple size differences due to the DMAS application.

Mechanical properties for 'Delicious'. The data for the mechanical properties of 'Delicious' fruits sampled at different intervals between August 5 and October 12, 1968, are given in Figure 1, and Table 1.

BIO-YIELD FORCE. For non-treated fruits, force required to cause initial bruising decreased slightly from August 5 until September 14. On September 21 a sharp increase occurred in the bio-yield force. From September 21 to September 24, the values for this force remained constant and appeared as a plateau on the curve. From September 24 to October 12, the force at the bio-yield point of the fruit decreased, except on September 28 when another increase was evident.

The bio-yield curve for fruit on the DMAS-treated trees followed the same pattern as that for apples on the non-treated trees, but the force at the bio-yield point for treated fruits was consistently and almost uniformly higher at all observation dates.

The plateau for fruit from the DMAS-treated trees appeared to last for 7 days as compared to 3 days for fruit from non-treated trees. When respective treatment means were analyzed, however, from September 21 through October 12, the durations of the plateaus were statistically identical for the 2 treatments, about 7 days. The arrangement of means in descending order and the significance of their differences from the measurement on September 21, are as follows:

DMAS treated			Non-treated		
Date	Means (lb)	Differ from Sep 21	Date	Means (lb)	Differ from Sep 21
Sep 21	5.60	5.4890 lbs	Sep 21	5.02	4.8336 lbs
Sep 28	5.59	NS	Sep 24	5.00	NS
Sep 24	5.57	NS	Sep 28	4.91	NS
Sep 26	5.56	NS	Oct 1	4.82	**
Oct 1	5.29	*	Sep 26	4.81	*
Oct 12	4.90	*	Oct 12	4.51	*

* and **, means differ from Sep 21 mean at 5% and 1%, respectively.

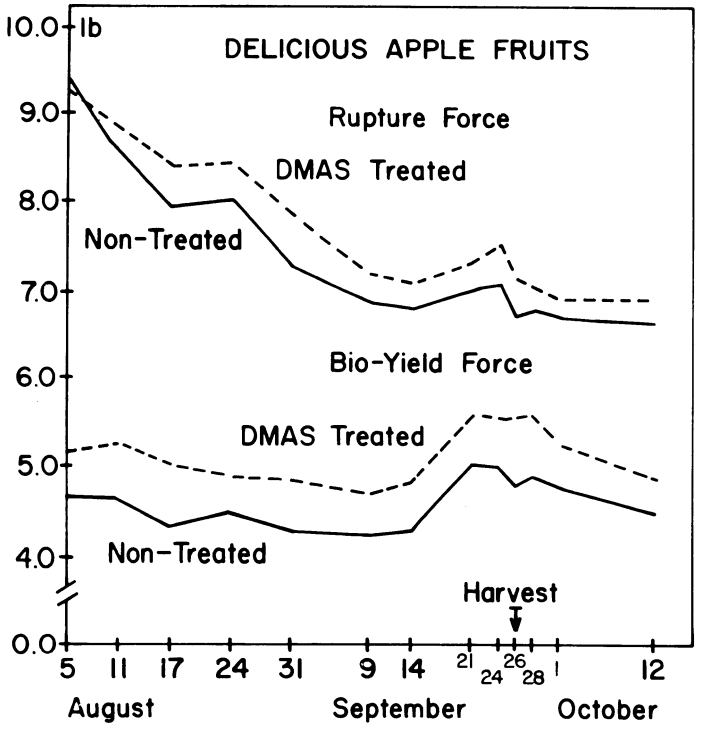

Fig. 1. Comparison of force to bio-yield and force to rupture for developing 'Delicious' apple fruits on non-treated trees with those on trees treated with a foliar aqueous spray of N-dimethylaminosuccinamic acid (DMAS) at 1000 ppm on June 14, 1968, 30 days after full bloom.

Table 1. Some mechanical properties of developing 'Delicious' apple fruits for several weeks before and a few weeks after the time of commercial harvest on trees receiving a foliar aqueous spray of N-dimethylaminosuccinamic acid (DMAS) at 1000 ppm at 30 days after full bloom, as compared to those on non-treated trees, 1968.

Measurement dates	Bio-yield force[x]				Rupture force[x]			
	DMAS treated	Non-treated	Difference and significance[y]		DMAS treated	Non-treated	Difference and significance[y]	
	lb	lb	lb		lb	lb	lb	
Aug 5	5.18	4.67	+0.51	**	9.30	9.41	-0.11	NS
11	5.28	4.64	+0.64	**	9.04	8.58	+0.46	**
17	5.03	4.34	+0.69	**	8.42	7.98	+0.44	*
24	4.91	4.50	+0.41	**	8.47	8.04	+0.42	*
31	4.87	4.31	+0.56	*	7.87	7.30	+0.57	*
Sep 9	4.72	4.24	+0.48	**	7.24	6.90	+0.34	*
14	4.84	4.28	+0.56	**	7.14	6.83	+0.31	*
21	5.60	5.02	+0.58	**	7.36	7.03	+0.33	*
24	5.57	5.00	+0.57	**	7.53	7.13	+0.40	**
26[z]	5.55	4.80	+0.75	**	7.18	6.75	+0.43	**
28	5.59	4.91	+0.68	**	7.08	6.81	+0.27	*
Oct 1	5.29	4.81	+0.48	**	6.94	6.73	+0.21	*
12	4.90	4.50	+0.40	**	6.93	6.67	+0.26	*

[x]Pounds force with an 1/8 inch diameter plunger.

[y]NS, non-significant; * significant at 5% level; ** significant at 1% level.

[z]Date of commercial harvest for 'Delicious'.

However, the data suggested that the length of the plateau for DMAS-treated 'Delicious' apples may have been longer by a few days than for non-treated fruits.

On October 12, 16 days after the commercial harvest date for 'Delicious' apples at University Park in 1968, fruits from DMAS-treated trees were as resistant to initial bruising as were fruits from non-treated trees on September 26. Apparently, the fruit from 'Delicious' trees treated with DMAS at 30 days after full bloom could have been handled over a longer harvesting period with equal or greater resistance to bruising than the fruits from non-treated trees.

The increased resistance of 'Delicious' apples to bruise injury by the DMAS treatment was measurable at the first date of fruit sampling, 82 days after full bloom. The magnitude of the increase varied from 0.40 to 0.75 pounds as the fruit developed. That is, the DMAS treatment did not stimulate an increasing resistance to bruising injury after August 5. The increase in resistance shown for the DMAS-treated fruits must have occurred while they were small, between the date of DMAS application and the date of first sampling, between 30 and 82 days after full bloom.

The sharp increase in bio-yield values from September 14 to September 21 was 0.76 and 0.74 pounds, respectively, for DMAS-treated and non-treated fruits. These values were equal to or greater than the difference brought about by the DMAS treatment. The total increase in resistance to bruising between September 14 for non-treated apples and September 21 for DMAS-treated fruits was 1.32 pounds with a 1/8 inch diameter plunger. Of this total 44% was caused by DMAS and 56% by some other factor(s) occurring between September 14 and 21.

This observed increase in resistance to bruising may have been caused by seasonal weather conditions, since a similar increase was found for 'Golden Delicious' (Figure 2) near the same date, but not at a comparable number of days before harvest. Between September 14 and 21 at University Park, precipitation had been below normal and temperature above normal. Thus, the sharp increase in resistance observed might have been related to warm and dry weather prevalent during this period. Haller (7) has reported firmer apples during the harvest period on non-irrigated trees than on those irrigated.

RUPTURE FORCE. For fruits on the non-treated Delicious trees, the force required to rupture an apple decreased as the fruits developed (Fig. 1 and Table 1). After September 14, a noticeable increase was observed which peaked on September 24. This time of change coincided in general with that for bio-yield force values. Thereafter, rupture force steadily declined.

For fruits on DMAS-treated trees, the same general curve for rupture force values existed (Fig. 1, and Table 1). However, after August 11 rupture forces were significantly greater for fruits from DMAS-treated trees than those from non-treated trees. On the initial sampling date, values were not significantly different between treatments.

Apparently the development or retention of a greater resistance to rupture forces in apples on DMAS-treated trees began around August 5, and continued to increase until about August 17. Thereafter the differences were of about equal magnitude.

The data suggests that changes in some of the mechanical properties of 'Delicious' apples brought about, or caused, by a

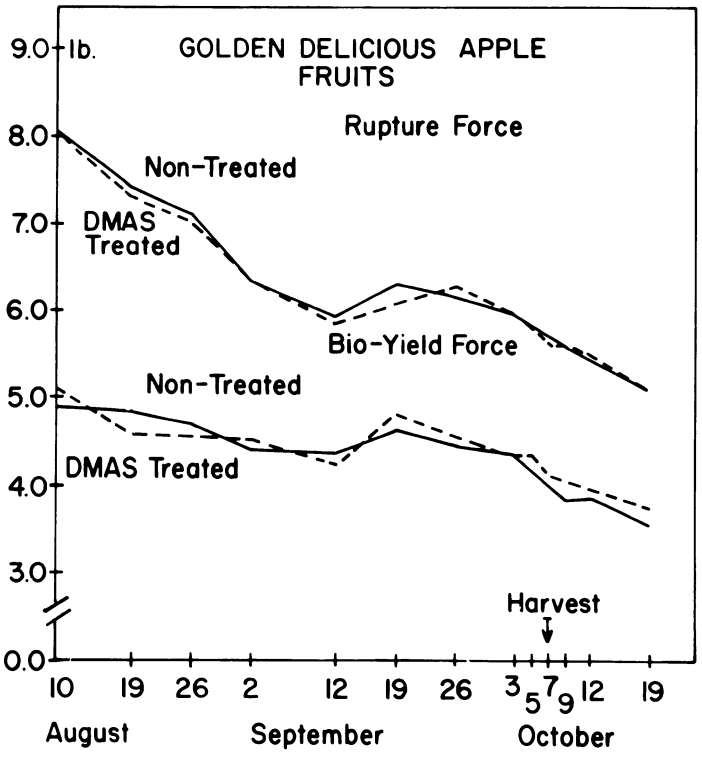

Fig. 2. Comparison of force to bio-yield and force to rupture for developing 'Golden Delicious' apple fruits on non-treated trees with those on trees treated with a foliar aqueous spray of N-dimethylaminosuccinamic acid (DMAS) at 1000 ppm on June 14, 1968, 30 days after bloom.

Table 2. Some mechanical properties of developing 'Golden Delicious' apple fruits for several weeks before and a few weeks after the time of commercial harvest on trees receiving a foliar aqueous spray of N-dimethylaminosuccinamic acid (DMAS) at 1000 ppm on June 14, 1968, as compared to those on non-treated trees.

Measurement dates	Bio-yield force[x]				Rupture force[x]			
	DMAS treated	Non-treated	Difference and significance[y]		DMAS treated	Non-treated	Difference and significance[y]	
	lb	lb	lb		lb	lb	lb	
Aug 10	5.10	4.91	+0.19	NS	8.04	8.06	-0.02	NS
19	4.60	4.81	-0.21	NS	7.34	7.44	-0.10	NS
26	4.55	4.69	-0.14	NS	7.02	7.14	-0.12	NS
Sep 2	4.49	4.43	+0.06	NS	6.34	6.35	-0.01	NS
12	4.25	4.35	-0.10	NS	5.85	5.90	-0.05	NS
19	4.82	4.63	+0.19	NS	6.09	6.23	-0.14	NS
26	4.55	4.47	+0.08	NS	6.21	6.14	+0.07	NS
Oct 3	4.34	4.35	-0.01	NS	5.98	5.94	+0.04	NS
5	4.34	4.16	+0.18	NS	5.80	5.81	-0.01	NS
7[z]	4.13	4.03	+0.10	NS	5.64	5.66	-0.02	NS
9	4.09	3.88	+0.21	NS	5.55	5.56	-0.01	NS
12	4.00	3.88	+0.12	NS	5.43	5.42	+0.01	NS
19	3.77	3.52	+0.25	NS	5.04	5.04	0.00	NS

[x]Pounds force with an 1/8 inch diameter plunger.

[y]NS, non-significant.

[z]Date of commercial harvest for 'Golden Delicious'.

foliar application of DMAS at 30 days after full bloom may not occur at the same stage, or time, as the apple fruits develop. Differences in resistance to bruising injury appeared to occur sooner than that for resistance to rupture. That for greater bruising resistance apparently developed before the first sampling date, August 5, while that for greater rupture resistance appeared to develop shortly afterwards.

Mechanical properties for 'Golden Delicious'. The data for mechanical properties for 'Golden Delicious' fruits are given in Fig. 2, and Table 2.

BIO-YIELD FORCE. In both treatments bio-yield force values decreased from August 10 to September 19. Between September 12 and 19 values rose sharply (as did 'Delicious' during this period) and then decreased until measurement were terminated. Difference between fruits on DMAS-treated and non-treated trees were non-significant for each sampling date. 'Golden Delicious' apple fruits did not respond to the DMAS treatment. A lack of DMAS response on 'Golden Delicious', as compared to other cultivars, has been reported previously (1,5).

RUPTURE FORCE. In both treatments rupture force values decreased steadily until September 12, increased sharply to September 19, and then again decreased steadily through commercial harvest and until measurements were terminated. On each sampling date, almost the same values were obtained for DMAS-treated and non-treated fruits. The sharp increase in rupture force, and bio-yield force as well, for 'Golden Delicious' occurred almost simultaneously as those for 'Delicious'. Thus, some factor other than DMAS treatment, cultivar, and nearness to harvest appeared to be responsible for the observed response, as previously discussed.

Conclusion

A foliar dilute aqueous spray of N-dimethylaminosuccinamic acid (DMAS) at 1000 ppm applied 30 days after full bloom appeared to have the ability to modify favorably the mechanical properties of 'Delicious' apples to cause a greater resistance by the fruit to bruising injury (force to bio-yield) and skin rupture. This effect was not observed on 'Golden Delicious'. Increased resistance to this type of bruise injury appears to develop in apple fruits before that to rupture injury.

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