Fan, X., Mattheis, J.P. Impact of 1-methylcyclopropene and methyl jasmonate on apple volatile production. J. Agric. Food Chem. 47: 2847-2853. 1999.

PROJECT NO.: ARS - 0872

TITLE: Identification of Factors Contributing to 'Fuji' Stain

YEAR INITIATED: 1995
CURRENT YEAR: 1999-2000
TERMINATING YEAR: 1999-2000

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JUSTIFICATION:

The occurrence of 'Fuji' stain is widespread in Washington State orchards. Considerable losses were incurred in 1993, and stain has been reported in all succeeding years. The cause and mechanism of stain development are as yet unknown, however, evidence indicates injury is occurring in the field with visual symptoms developing in most cases during storage. Postharvest investigations indicate controlled atmosphere storage can delay but not prevent stain.

OBJECTIVES:

1. Identify cultural and environmental factors that contribute to stain. Possible contributors include orchard temperatures, sun scald, irrigation/water stress, nitrogen/nutrient availability, tree age, rootstock/scion combination.

2. Identify mechanism of injury.

3. Develop pre- or postharvest management tools to reduce or eliminate stain.

PROGRESS:

Efficacy of Surround for stain reduction

Application of kaolin clay in the field or prior to postharvest UV-B irradiation treatments was evaluated for efficacy in prevention of stain. Control and Surround treated fruit (two applications at 0.5 lb/gallon) were harvested October 20 from a commercial orchard near Malott with a history of stain and stored at 32 ^{o}F. No stain developed on control or Surround treated fruit from this orchard.

Apples from the WSU-USDA Columbia View orchard were harvested November 1 and stored at 33 ^{o}F in air. Surround was applied by dipping fruit in solutions at 0, 0.5, 1 or

1.5 lbs/gallon. After drying, apples were exposed to UV-B irradiation from 4-foot bulbs (FS40, Bulbtronics) for 4 days at 40 or 77 ^{o}F. After treatment, apples were stored at 33 ^{o}F for 3 months.

The incidence of stain induced in the field was low (Tables 1,2). Irradiation with UV-B at either temperature induced a high incidence of stain in control fruit, while incidence and severity decreased with increased rate of Surround. While Surround at 0.5 lb/gallon was ineffective for stain prevention, the higher rates showed efficacy to reduce stain development and severity.

The use of Surround at 1 or 1.5 lb/gallon contributed to abnormal red color development during UV-B treatment. At these rates, the coating of clay on the apple fruit surface was not uniform with less clay in a vertical orientation up and down the fruit. The non-uniform coating allowed more UV-B to contact the fruit surface in some areas, resulting in enhanced red color development and the appearance of vertical red streaks. This phenomena appears similar to that occurring in the field where multiple applications or high rates of Surround have been used.

Table 1. Average stain rating and incidence of 'Fuji' apples exposed to postharvest UV-B irradiation at 77 ^{o}F. Fruit were irradiated for 4 days then stored at 33 ^{o}F for 3 months.

Stain Rating 1-4	Control No UV-B	Control UV-B	Surround 0.5 lb/gallon	Surround 1.0 lb/gallon	Surround 1.5 lb/gallon
Stain rating All fruit	1.1	2.4	3.1	1.8	1.4
Stained fruit only	2	2.9	3.2	2.3	2
Incidence %	6	78	94	67	17

Table 2. Average stain rating and incidence of 'Fuji' apples exposed to postharvest UV-B irradiation at 40 ^{o}F. Fruit were irradiated for 4 days then stored at 33 ^{o}F for 3 months.

Stain Rating 1-4	Control No UV-B	Control UV-B	Surround 0.5 lb/gallon	Surround 1.0 lb/gallon	Surround 1.5 lb/gallon
Stain rating All fruit	1.1	2.1	2.1	1.6	1.3
Stain rating Stained only	2	2.3	2.3	2.4	2
Incidence %	11	89	83	39	33

Table 3. Incidence (%) of abnormal red color development (streaks) on 'Fuji' apples following UV-B irradiation. Fruit were irradiated at 40 or 77 ^{o}F for 4 days then stored at 33 ^{o}F for 3 months.

Treatment temperature	Control	Surround lb/gallon		
		0.5	1.0	1.5
40	0	0	28	35
77	0	0	0	100

Efficacy of field application of ascorbic acid for stain reduction.

Ascorbate sprays reduced stain development and appeared to enhance fruit quality in 1998. This experiment was repeated in 1999. An ascorbic acid solution was applied on two dates in a commercial 'Fuji' block near Orondo. The solution contained 0.5% ascorbic acid and 0.1% Tween 20 as surfactant. Control trees were sprayed with a 0.1% Tween 20 solution. Trees were sprayed on September 29 and October 6. Fruit were harvested October 20 and stored at 33 ^{o}F. Fruit quality and the incidence of stain and other physiological disorders were evaluated after 3 and 6 months storage.

The incidence of stain, superficial scald and core flush were low, therefore, no meaningful conclusions as to the effectiveness of ascorbate application can be made from this data set. No differences in fruit quality due to treatment were apparent.

SUMMARY OF RESULTS 1995-2000

At the beginning of this project, little was known of the etiology of this disorder. Although previously reported in Japan as "sunnyside scald", factors that contribute to induction and development of the symptoms of stain had not been identified. Our research has identified several pre- and postharvest factors that contribute to stain development and while a number of questions remain, some management strategies to reduce stain development can be suggested.

The symptoms of stain typically develop on the blush side of the fruit, often on the margin of sunburned areas. Light and scanning electron microscopy confirmed that symptoms are present only in peel tissue and stain does not lead to internal breakdown. The well-defined, often ribbon-like appearance of stain is typically present when the disorder is first observed out of storage and symptoms do not worsen during warm room incubation. Symptoms appear after a relatively brief period of storage (1-12 weeks after harvest). These factors indicate that stain is different from another peel disorder, superficial scald. We subsequently demonstrated that DPA treatment at harvest did not reduce the incidence or severity of stain, this indicates the mechanism of stain development is likely different from that of superficial scald. Although mechanistically different from superficial scald, stain incidence and severity can be reduced somewhat by CA storage.

The appearance of symptoms on the blush side of the fruit and in some cases with non-affected areas present where exposure to light was prevented by trellis wires or leaves indicates light exposure is important for stain development. We performed a series of experiments using commercial Fuji bags to test the light hypothesis and our results indicate that fruit bagged until harvest do not develop stain. Additionally, by varying the time fruit are bagged during the season, the late September – October period is the likely period stain induction occurs. In an experiment where fruit were bagged using transparent Mylar film that filters UV-B, a technique developed by Drs. Preston Andrews and Jim Johnson, stain development was substantially less when fruit were bagged with the Mylar film. These fruit also developed less red color than unbagged controls.
To test the hypothesis that UV-B irradiation was involved in stain induction, Dr. Fan evaluated postharvest UV-B treatments as a means to induce stain. He showed exposure to UV-B light could induce symptoms that were visually indistinguishable from stain originating in the field. To test whether susceptibility to UV-B changed during fruit development, Dr. Fan harvested apples from July through October and exposed fruit to UV-B light prior to cold storage. The incidence of stain in response to this treatment was highest in fruit harvested in late September through October, similar to results with bags in the field. The results also indicated cold storage was necessary for symptom development as UV-irradiated apples stored at 68 ^{o}F did not develop symptoms while fruit stored at 32 ^{o}F after UV treatment did develop symptoms. Tests of delayed cooling up to 8 days using fruit from orchards with a history of stain did not, however, reduce stain development. Dr. Fan also showed UV-B treatment could induce symptoms much more rapidly when applied at low temperature (40 versus 70 ^{o}F). When irradiated at 40 ^{o}F, fruit exhibited symptoms after 48 hours, while fruit irradiated at 70 ^{o}F required cold storage before symptoms developed. This result was consistent with our initial interest in UV-B which was based on injury that occurs in photosynthetic tissues of some plants (i.e. tomato) when exposed to high irradiance or UV-B under cold temperatures. As the injury symptoms are often a greenish color indicative of chlorophyll, we evaluated the use of chlorophyll fluorescence as a possible means to segregate symptomless fruit as well as to study the possible involvement of chloroplasts in disorder development. The results indicated that while the technique could detect differences due to stain, values for symptomless fruit were similar. The results from bagging and UV experiments indicate that light exposure is critical to stain induction, that the damage occurs in the field during the late season, and that UV-B may play a role in inducing the damage under field conditions as well as providing a means to induce similar damage on harvested fruit.

Results from our research as well as industry experience indicate that storage in CA is a means to delay development of stain. We also evaluated a number of materials applied after harvest prior to storage for efficacy in reducing stain as well as to investigate mechanistic characteristics for the disorder. In 1997 and 1998, a number of postharvest treatments were applied including a hot water dip, 1-aminoethyoxyvinylglycine (AVG, Retain), 1-methylcyclopropene (MCP), ethephon, methyl jasmonate (MJ), ascorbic acid and $CaCl_2$. During the two seasons, vacuum infiltration with a 2% CaCl2 solution significantly reduced the incidence of stain compared to controls. Dip treatments in 2 or 4% $CaCl_2$ were also effective but less than the vacuum infiltration. While no evidence of

phytotoxicity from these Ca treatments occurred, large scale tests of these treatments have not been conducted. The lack of response from treatments that promote (ethephon, MJ) or inhibit (AVG, MCP) ethylene production or action indicates stain symptom development may occur independently of ethylene regulation.

During the course of this project, the incidence of stain on Fuji apples from Washington orchards has decreased. While still present in some years and some orchards, the high incidence of stain that occurred in the 1993 and 1994 crop years has diminished. When the disorder was first recognized as a wide spread problem in Washington Fuji orchards, most of the affected fruit was produced on young trees, often the first crop. Those trees were small and not much canopy was present to reduce sun exposure. As the trees were also being managed to increase size, nitrogen fertilizer was applied at relatively high rates to promote growth. The orchard characteristics that consistently produced fruit with stain in our experience were young trees with very exposed fruit, or older trees with low vigor and high N use. Fuji apples are known to be efficient accumulators of N, and like other varieties, high N delays ripening and loss of green ground color. During the 1995-1999 period, Fuji trees planted in the early 1990's have grown to full size in many orchards. Increased tree size alone may have reduced stain development by providing more canopy to shield fruit during the late season period when fruit appear most susceptible to the damage that results in stain. As tree size has increased, the rate of nitrogen application has also decreased allowing in many cases for earlier harvest based on the ground color change from green to yellow. While other more direct relationships between stain susceptibility and nitrogen content were not demonstrated by this project, the benefits of lower N use in Fuji orchards has been recognized by Washington growers through improved fruit quality.

The results of this project indicate Fuji apples that are produced under conditions that receive high irradiance during the late portion of development may be at highest risk for stain. Factors that delay maturation, such as high N use, may contribute to stain development by keeping fruit on the tree later into the season. The use of bags can reduce but not eliminate the incidence of stain as the bags are removed prior to harvest. Increased tree size and reduced N use are two factors that may help to reduce injury that results in stain. The use of a postharvest Ca treatment may reduce the development of stain although more research is necessary to assure the safety of postharvest Ca use. Storage in CA can delay but does not prevent stain development.

PUBLICATION