Influence of Sampling Time on Elemental Composition of Strawberry Leaves and Petioles[1]

Matt K. John[2], Hugh A. Daubeny[3] and Fred D. McElroy[3]
Agriculture Canada

Abstract. Concentrations of 13 macro and micro elements in leaves and petioles of 3 strawberry (*Fragaria* X *ananassa* Duch.) cultivars were determined biweekly during the growing season. Concentrations of most elements changed rapidly during flowering and fruiting. For most elements, leaf analysis was preferred since markedly greater concentrations occurred in leaves than petioles. These sampling dates and tissue factors, and significant cultivar differences must be considered in interpreting foliar analysis data. Concentrations were relatively stable during the 6 weeks following harvest and this period appeared optimum for sampling.

The relationship between nutrient content of leaves, deficiency symptoms, and yields of fruit indicates the value of foliar analyses of strawberries (*Fragaria* X *ananassa* Duch.) (3). Strawberry nutrition has been widely studied but much of the literature is contradictory. Many inconsistencies clearly result from variations in climate, soil and culture, but others result from tissue sampling techniques.

Ballinger and Mason (1) reported that leaves were superior to crowns, petioles and roots in reflecting the status of 5 elements in the strawberry. Kwong and Boynton (11) and Kwong (10) found significant differences in elemental composition between leaves and petioles, and between leaves of different age. Sampling the youngest mature leaves minimized the effect of age so that seasonal changes in N, P, K, Ca and Mg content were small (11). However, Bould (2) found marked seasonal changes in fully expanded non-senescent leaves at flowering, at fruit ripening, and after harvest,. The N, P, and K content decreased while Mg and Ca increased, indicating that samples must be taken at identifiable physiological stages of plant growth.

The seasonal changes warranted further investigation to determine an optimum sampling time and to interpret the analysis data. Since current knowledge is largely based on greenhouse sand culture studies, 3 field-grown strawberry cultivars were sampled to determine the macro and micro element composition of leaves and petioles at 2-week intervals during the growing season.

Materials and Methods

The experiment was conducted on an Acid Brown Wooded silt loam of the Abbotsford series in the lower Fraser Valley, B.C. During the sampling year of 1973, the soil-test values for surface samples were: 5.5% oxidizable organic matter, pH 5.8, 55 ppm exchangeable Mg, 830 ppm exchangeable Ca, 160 ppm exchangeable K, 135 ppm available P as determined by the Bray P_1 method (12), and 0.40 ppm water-soluble B extracted by the method of John (7).

Three replicate plots of 'Shuksan', 'Totem' and 'Northwest' were established in a randomized complete block in the field in 1972. Ten plants were spaced at 60 cm within matted rows maintained 120 cm apart. In both 1972 and 1973, 13-16-10 fertilizer was applied at 224 kg/ha (200 lb/A) in late March, 16-20-0 at the same rate in early May and 34-0-0 at 112 kg/ha at the beginning of August. In 1973, plants flowered during the first 2 weeks of May and harvest was completed by the first week of July.

Tissue samples were collected at 2-week intervals from May 9 to October 10, 1973. Fifteen 'youngest mature' leaves were detached at the crown to include petioles. Samples were immediately washed in deionized distilled water for 1 min, blotted, separated into leaf and petiole, oven-dried at 70°C, and ground to 20 mesh.

A portion of each tissue sample was digested with HNO_3-$HClO_4$ mixture (6). Phosphorus was determined by the vanadomolybdate method (5). Sulphur was determined by the turbidimetric method of Tabatabai and Bremner (13), modified by the use of 0.025% gelatin in the reagent. Aluminum was determined by the pyrocatechol method (14). Calcium, Mg, K, Na, Mn, Cu, Zn and Fe were determined by atomic absorption spectrophotometry. A second sample portion was used for micro-digestion (8) and subsequent colorimetric N determination (4). Sufficient petiole tissue, however, was available for only 6 sampling dates. A third portion of leaf samples (insufficient petiole tissue available) was extracted with *N* HCl, using an adaption of the method of Yoshida and Yoshida (16), for subsequent colorimetric determination of B using azomethine-H (15).

Computer methods (9) were used to collect instrumental data and transform these to concentrations in oven dry tissue. Results were subjected to analyses of variance and Duncan's multiple range tests. Leaf and petiole data were considered separately to determine the effects in each and were combined to elucidate any tissue effect or interaction.

Results

Effects of sampling date. Elemental concentrations in strawberry leaves and petioles were significantly affected by sampling date (Table 1). Means of 3 cultivars (Table 2) indicated elemental concentrations differed significantly at various times throughout the season. For most elements, similar sampling date effects on the concentration in a particular tissue were evident for the individual cultivars (Fig. 1 and 2), such that sampling date and cultivar effects seldom interacted significantly despite significant cultivar differences (Table 1).

Nitrogen concentration (Fig. 1a), particularly in leaves, decreased until harvest. Leaf N remained relatively unchanged after harvest except for an increase during early fall, possibly a response to the August 1 fertilization. Phosphorus concentration (Fig. 1b) in both tissues decreased in May, was relatively stable during the summer and decreased again in the fall. Potassium concentrations (Fig. 1c) declined throughout May and June, but levelled off somewhat during July, August and September, although petiole K increased significantly at the end of August. Sulphur (Fig. 1d) and Zn (Fig. 2b) concentrations decreased rapidly during flowering and fruiting, were relatively stable for the remainder of the summer, and tended to rise again in the fall. Similarly, Mg and Ca concentrations (Table 2) were highest at the beginning and the end of the sampling period and concentrations in leaves were minimum at the end of August. Sodium concentration also decreased until harvest but varied in both tissues during the rest of the study period. Leaf Na was lowest on August 1 but showed a small significant increase in the fall. Copper concentration in leaves was relatively stable until October, but petiole Cu decreased during flowering and fruiting, stabilized, and then increased slightly in early fall. Boron concentration in leaves (Fig. 2d) declined until harvest, levelled off temporarily, declined sharply at the end of

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[2] Formerly Research Scientist, Agriculture Canada, Agassiz, B.C. and presently with the Science Policy Branch of Environment Canada, Ottawa, Ontario, K1A 0H3.
[3] Research Scientists, Agriculture Canada, Vancouver, B.C. V6T 1X2.

Table 1. Significance of effects in analyses of variance for elemental concentrations in oven dry strawberry leaves and petioles.[z]

Element	Leaf data			Petiole data			Combined data[y]					
	D	C	D×C	D	C	D×C	D	C	D×C	T	D×T	C×T
% N[x]	***	***	ns	***	ns	ns	***	***	ns	***	***	***
% P	*	ns	ns	***	**	*	***	ns	**	***	ns	**
% K	***	***	ns	***	ns	ns	***	ns	*	***	***	**
% Mg	***	***	ns	***	***	ns	***	***	ns	***	***	***
% S	***	ns	ns	***	**	ns	***	ns	ns	***	**	ns
% Ca	***	ns	ns	***	ns	ns	***	ns	ns	***	***	ns
ppm Na	***	***	ns	***	ns	ns	***	**	ns	***	***	ns
ppm Mn	***	***	ns	**	***	**	***	***	**	***	***	***
ppm Zn	***	**	ns	***	**	ns	***	***	*	***	***	ns
ppm Cu	***	*	ns	***	ns	ns	***	ns	ns	***	***	**
ppm Al	***	***	ns	***	***	ns	***	***	*	***	***	**
ppm Fe	***	***	*	***	***	ns	***	***	**	***	***	ns
ppm B[w]	***	***	ns									

[z] Sources of variation: D = date of sampling. C = cultivar, T = tissue and x = interaction.
Significance of F-ratios: ***, $P < 0.001$; **, $P < 0.01$; *, $P < 0.05$; ns, non-significant at $P = 0.05$.
[y] In combined analyses of variance, the D×C×T interaction was non-significant at $P = 0.05$ for all elements.
[x] Petiole N was determined for only 6 sampling dates and only leaf and petiole data for these dates were combined.
[w] Petiole B was not determined.

Table 2. Effect of sampling date on elemental concentrations in oven dry strawberry leaves and petioles.[z]

Element	Tissue[y]	9/5[x]	23/5	6/6	20/6	4/7	18/7	1/8	15/8	29/8	12/9	26/9	10/10	24/10
% N	L	4.15h	3.58g	3.19f	2.71de	2.49bcd	2.25a	2.29ab	2.46abc	2.45abc	2.88e	2.85e	2.81e	2.54cd
	P[w]		1.29c		0.88b		0.70a		0.67a			0.71a		0.63a
% P	L	.352d	.311c	.273ab	.286bc	.294bc	.294bc	.291bc	.312c	.300c	.285bc	.256a	.252a	.249a
	P	.213f	.181e	.141bc	.154cd	.153cd	.164de	.159cd	.158cd	.164de	.144c	.121a	.125ab	.108a
% K	L	2.45e	2.06d	1.97d	1.76c	1.65bc	1.70bc	1.61abc	1.73c	1.56ab	1.49a	1.57ab	1.46a	1.50a
	P	4.72h	4.39g	3.60f	3.43f	2.91e	2.57de	2.31bcd	2.31bcd	2.90e	2.46cd	2.15bc	1.98b	1.56a
% Mg	L	.312e	.277cd	.267cd	.240ab	.259bc	.259bc	.268cd	.261bcd	.231a	.270cd	.276cd	.283d	.285d
	P	.308e	.214ab	.184ab	.185ab	.191ab	.177a	.185ab	.208ab	.219bc	.247cd	.266d	.299e	.301e
% S	L	0.18f	0.16ef	0.15de	0.12abc	0.14cd	0.12abc	0.11ab	0.10a	0.12abc	0.12abc	0.12bc	0.12bc	0.13c
	P	0.08e	0.07d	0.06cd	0.05bc	0.04a	0.04a	0.04a	0.04a	0.04a	0.04a	0.04a	0.04a	0.04ab
% Ca	L	1.00bcd	0.95bcd	0.90bc	0.87ab	0.99bcd	1.03cd	1.02bcd	1.07d	0.75a	0.90bc	0.94bcd	0.95bcd	1.07d
	P	1.34c	1.06ab	0.98a	0.98a	1.00a	1.00a	1.08ab	1.07ab	1.01a	1.23bc	1.19bc	1.33c	1.36c
ppm Na	L	40.6f	36.0e	34.9e	28.8bc	28.2bc	29.1cd	23.7a	30.1cd	28.7bc	24.3a	25.0ab	32.9de	32.8de
	P	76.5g	64.1f	57.7ef	53.4de	43.3cd	43.8cd	30.4a	42.0bc	39.5abc	39.7abc	31.8ab	40.8abc	39.7abc
ppm Mn	L	141bc	116a	117a	116a	159cd	155cd	175de	162cd	126ab	169d	193ef	210f	234g
	P	70.0a-d	57.1a	65.8abc	67.6a-d	83.2de	76.5b-e	73.4a-e	62.4ab	69.0a-d	77.8b-e	80.2cde	88.3e	79.4cde
ppm Zn	L	31.8e	28.5d	25.7c	25.7c	26.5cd	20.5ab	19.8ab	20.0ab	18.0a	19.8ab	20.4ab	20.3ab	21.2b
	P	25.0e	19.0d	16.7a-d	14.7ab	15.8abc	17.6bcd	15.8abc	15.2abc	14.0a	15.4abc	16.5a-d	19.2d	17.9bcd
ppm Cu	L	8.8bc	8.8bc	8.7bc	8.4bc	9.7c	8.2b	8.9bc	9.1bc	8.3f	9.4bc	8.7bc	6.6a	7.0a
	P	6.2de	6.3e	5.6d	4.0ab	4.0ab	3.6a	3.7a	4.1abc	4.7bc	4.7bc	4.8c	4.7bc	4.5bc
ppm Al	L	46.8b	20.0a	25.4ab	13.1a	44.3b	34.0ab	109.8d	89.3c	26.1ab	46.8b	76.7c	74.3c	109.8d
	P	29.1c	14.0ab	12.5a	11.2a	16.3ab	16.2ab	19.3ab	29.0c	15.6ab	16.9ab	28.4c	21.4bc	28.2c
ppm Fe	L	120bc	103a	125c	91a	122bc	107ab	154de	145d	122bc	158de	162e	152de	186f
	P	46.5cd	39.9abc	32.2a	34.8a	33.3a	44.8bcd	37.0ab	39.9abc	38.1ab	34.2a	49.4d	40.3abc	43.7bcd
ppm B[v]	L	57.5f	53.3e	47.2d	39.4c	39.7c	35.9c	36.4c	37.7c	22.0a	27.1b	27.1b	29.9b	27.8b

[z] For each tissue elemental analysis, sampling date means (3 cultivars × 3 replicates) followed by a common letter did not differ significantly at the 5% level according to Duncan's multiple range test.
[y] L = leaf, P = petiole.
[x] Day/Month.
[w] Petiole N was determined for only 6 sampling dates.
[v] Petiole B was not determined.

August and stabilized once more at a slightly lower level. Manganese (Fig. 2a), Fe (Fig. 2c), and Al (Table 2) concentrations were highest in the fall. Leaf Mn and Al, and petiole Al and Fe, decreased significantly during spring. Their concentrations were relatively unstable and significantly elevated levels were observed at various times during the post-harvest summer period.

Effects of cultivar and tissue. Cultivar effects were significant for leaf concentrations of all elements, except P, S and Ca, and petiole P, Mg, S, Mn, Zn, Al and Fe (Table 1). Differences between specific cultivars were found among mean tissue concentrations over all

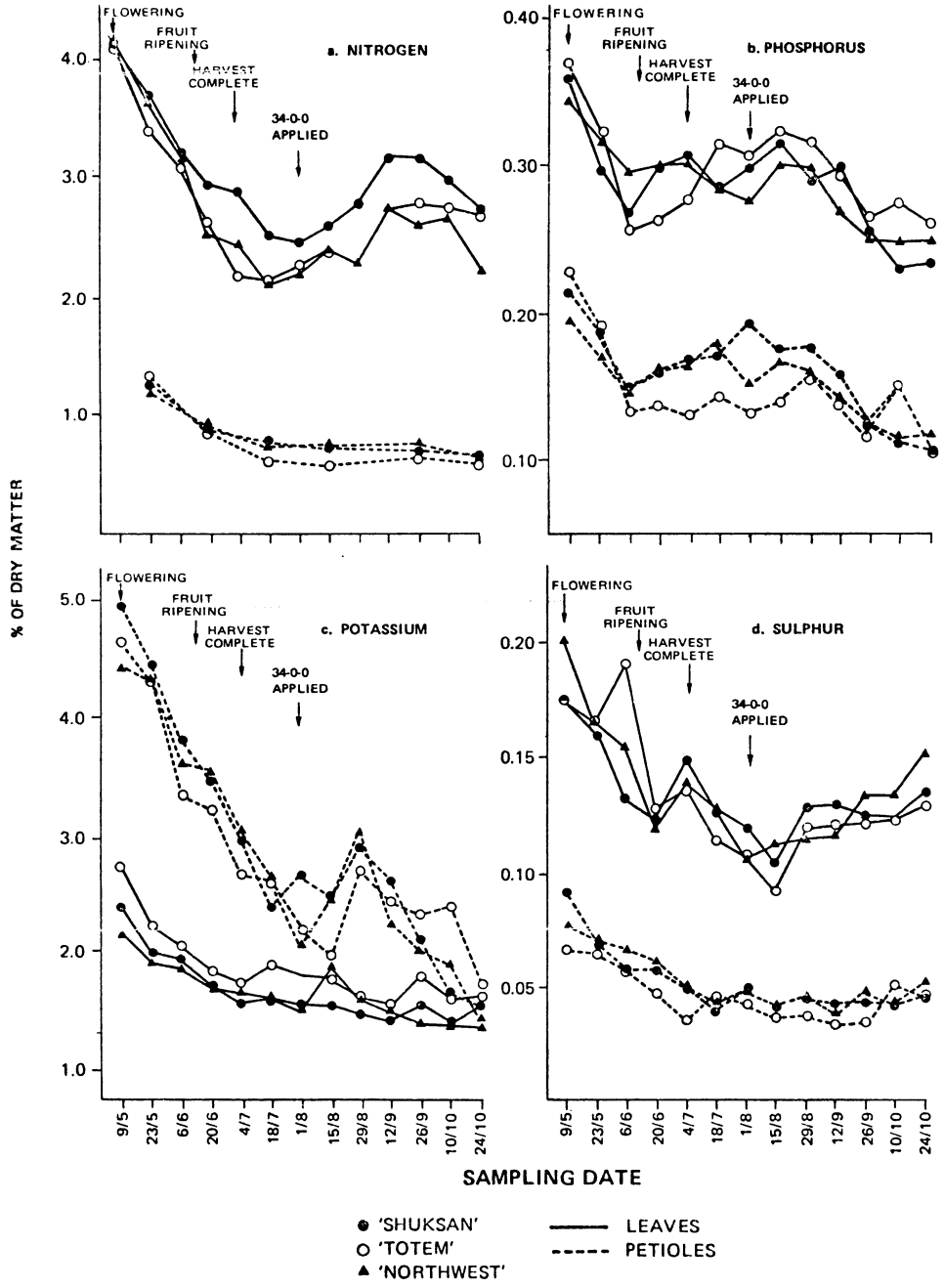

Fig. 1a–d. Effect of sampling date on concentrations of N, P, K and S in leaves and petioles of 3 strawberry cultivars.

Table 3. Effect of cultivar on elemental concentrations in oven dry strawberry leaves and petioles.[z]

Cultivar	% N	% P	% K	% Mg	% S	% Ca	ppm Na	ppm Mn	ppm Zn	ppm Cu	ppm Al	ppm Fe	ppm B
						Leaves							
Shuksan	3.02b	.287a	1.67a	.254a	0.13a	0.94a	28.2a	199 b	21.9a	8.8b	42.3a	130 a	40.2c
Totem	2.73a	.293a	1.86b	.300b	0.13a	1.00a	31.3b	144 a	23.9b	8.1a	48.9a	129 a	37.3b
Northwest	2.71a	.287a	1.66a	.251a	0.13a	0.98a	31.7b	136 a	23.0ab	8.6b	74.2b	144 b	33.5a
						Petioles[y]							
Shuksan	0.83a[x]	.160b	2.94a	.255b	0.05b	1.10a	44.3a	82.0c	15.9a	4.6a	12.8a	35.7a	
Totem	0.77a	.145a	2.83a	.221a	0.04a	1.14a	45.2a	72.2b	18.2b	4.8a	16.8b	37.1a	
Northwest	0.83a	.153ab	2.84a	.213a	0.05b	1.14a	49.6a	65.3a	17.3b	4.6a	29.9c	45.8b	

[z] For each tissue elemental analysis, cultivar means (13 sampling dates × 3 replicates) followed by a common letter did not differ significantly at the 5% level according to Duncan's multiple range test.
[y] Petiole B was not determined.
[x] Petiole N was averaged for only 6 sampling dates.

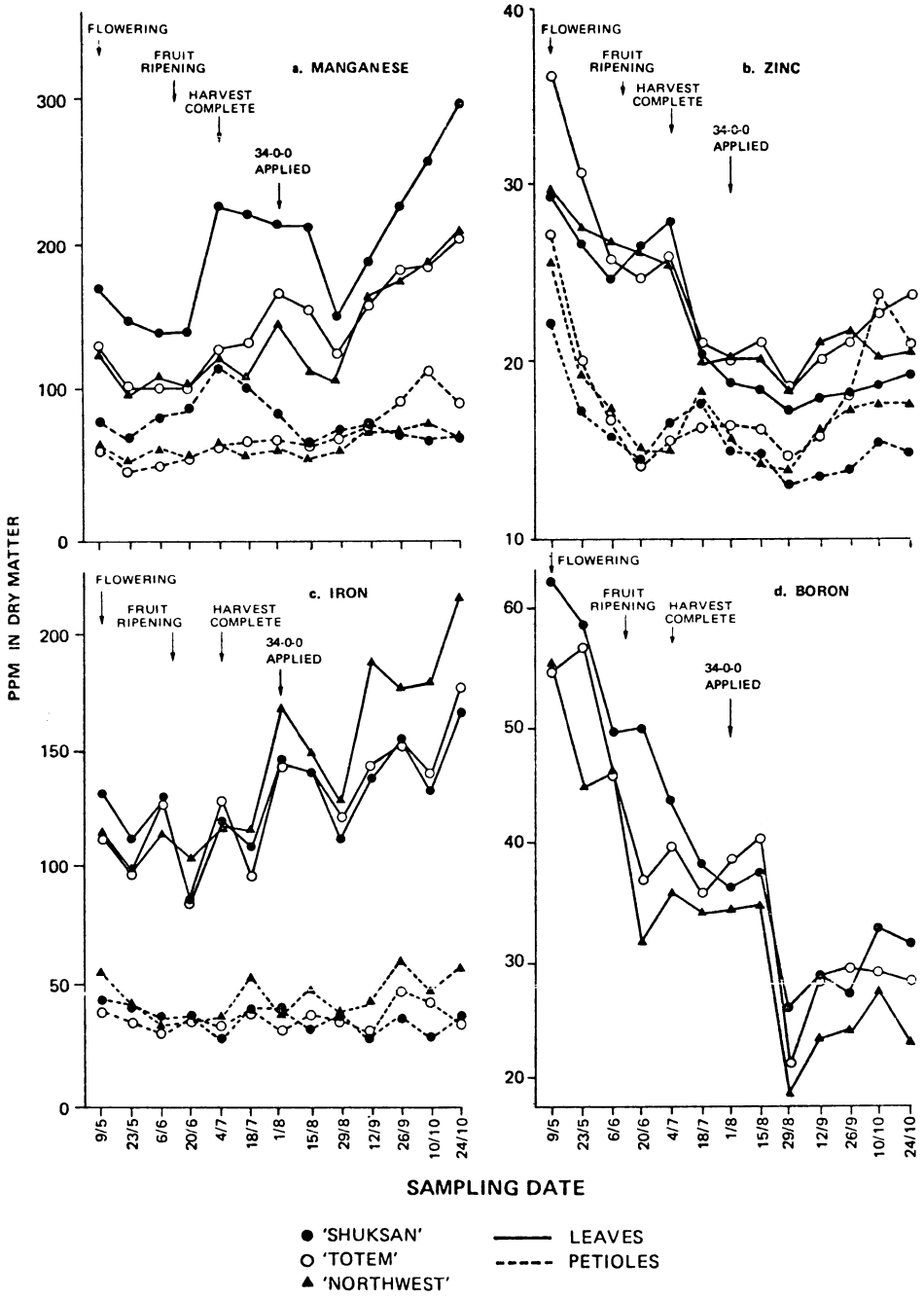

Fig. 2a–d. Effect of sampling date on concentrations of Mn, Zn, Fe and B in leaves and petioles of 3 strawberry cultivars.

sampling dates (Table 3). These results indicated differences in cultivar requirements and/or their abilities to assimilate the specific nutrient elements.

Analyses of variance for combined data indicated leaf and petiole concentrations differed significantly for all elements (Table 1). Concentrations of N, P, S, Mn, Zn, Cu, Al and Fe were significantly greater in leaves than petioles. Petiole concentrations of K and Na were greater than in leaves.

Interaction effects. Whereas sampling date and cultivar seldom interacted significantly, interactions of sampling date or cultivar effects with tissue effect were significant for most elements (Table 1). Significant interaction between sampling date and tissue effects reflected variations in nutrient transport between petioles and leaves. The concentration of an element in one tissue often decreased as an increase occurred in the other. For example, the relative magnitude of leaf and petiole Mg or Ca concentrations depended upon sampling date (Table 2). Tissue and cultivar interactions indicated differing abilities to translocate elements.

Discussion

Sampling date had a critical bearing on elemental concentrations in strawberry petioles, confirming that strawberry plants should be sampled at identifiable physiological stages (2). Concentration of most elements changed rapidly during periods of high metabolic activity such as flowering and fruiting. Concentrations were most stable during the 6 weeks following harvest although Mn, Al and Fe concentrations were exceptions. Sampling during this 6-week period was feasible for the majority of elements and is therefore recommended.

For most elements, greater concentrations occurred in leaves than petioles. This finding was in agreement with previous reports (1, 2, 11), except that Ballinger and Mason (1) found petioles to be superior for K determination. A greater stability of peptiole K than leaf K was observed and may warrant the selection of peptiole tissue when specifically concerned with K status. Nonetheless, leaf analysis was better suited for the greater number of elements.

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Maturation and Ripening of 'Canino' Apricot as Affected by Combined Sprays of Succinic Acid 2,2-Dimethylhydrazide (SADH) and 2,4,5 Tri-chlorophenoxypropionic Acid (2,4,5-TP)[1]

Sylvia Guelfat-Reich and Ruth Ben-Arie

Agricultural Research Organization, The Volcani Center, Bet Dagan, Israel

Abstract. SADH affected color enhancement of 'Canino' apricot (*Prunus armeniaca* L.) thereby increasing the percentage of fruit harvested during the first 2 harvests. The sprays at and after pit hardening had a greater effect on color than "after bloom" spray. Other parameters of ripening, however, were unaffected, or were even retarded, indicating the different effects of SADH on various species of stone fruits.

It is known that 2,4,5-T and 2,4,5-TP both increase the size of apricot fruits and advance their maturation (7, 8, 9). Thus, 2,4,5-TP sprays at pit hardening have become general practice in apricot orchards in Israel. Fruit not treated with 2,4,5-TP is smaller and ripens 2–3 weeks after treated fruit. There are many reports that SADH accelerates ripening of stone fruits (1, 3, 4, 13). These experiments were conducted with peaches and cherries but not with apricots.

We report effects of SADH sprays on maturation and ripening of 'Canino' apricot when applied before, with, or after 2,4,5-TP, with the aim of further advancing the harvest.

Materials and Methods

SADH was applied in different orchards to 'Canino' apricot at concentrations of 2000–4000 ppm 2 weeks after petal fall, at pit hardening, or 2 weeks after pit hardening. Control and SADH-treated trees were sprayed at pit hardening with 20 ppm 2,4,5-TP this is a routine orchard treatment. Trees were sprayed to run-off (*ca.* 7 liters/tree) with a motorized knapsack in the early morning before the dew had evaporated. Each experiment comprised 3 single-tree replicates per treatment, distributed in blocks. The criterion for harvest was that used commercially; the change in color from green to pale yellow. The fruit was weighed at each harvest. Samples of 50 fruits per tree from the first harvest were held in the laboratory for 3–9 days at 20°C. In 1972 and 1973, fruit from the second harvest was also examined in the laboratory.

Ripening parameters evaluated at harvest and during shelf life included fruit color, determined by light reflection with a Bausch and Lomb Spectronic 20 at 670 nm, or with a Gardner color instrument (value a); fruit firmness, measured with a Hunter Penetrometer (1.14-cm tip); tangible softening (hard, slightly soft, or soft) evaluated by hand; total soluble solids (TSS) content measured with a hand refractometer; and acidity measured by titration of the juice with 0.1N NaOH. Carbon dioxide production was measured either by the Claypool and Keefer method (6) or by sampling air from a closed system with a Packard gas chromatograph equipped with a Propack C column and a thermal conductivity detector. A Packard gas chromatograph with an activated alumina column served for measuring ethylene evolution, also sampled from a closed system.

Results

SADH treatment induced an earlier harvest when applied with 2,4,5-TP to 'Canino' apricot at pit hardening or 2 weeks later (Fig. 1a), at a concn of 3000 or 4000 ppm (Fig. 1b), as compared with the 2,4,5-TP spray alone. The post-bloom spray was not always effective and the effect of lower concn of SADH was erratic. Enhancement of harvest time resulted from the accelerating effect of SADH on change in fruit color, which is the principal criterion for the beginning of fruit harvest.

The measurable difference in fruit color at harvest was maintained during shelf-life (Fig. 2). The effects of time of application and of

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