Control of Sucrose Loss in Sugarbeet During Storage by Chemicals[1] and Modified Atmosphere and Certain Associated Physiological Changes

M. T. Wu,[2] B. Singh,[2] J. C. Theurer,[3] L. E. Olson,[2] and D. K. Salunkhe[2]

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Introduction

The loss of sucrose during the storage of sugarbeet is a problem of major concern in the sugar industry. In the year 1966-1967 alone, the loss of sucrose in stored sugarbeets in North America was over $30 million.[4] The loss has been attributed principally to the respiration of sugarbeet roots (15)[5].

In 1950, Stout suggested ventilating storage piles of sugarbeet roots to lower the high rate of respiration associated with high temperature build-up inside the pile. Other workers have used metabolic inhibitors and growth regulators as preharvest foliar sprays or post-harvest treatments of the sugarbeet roots with varying results. The chemicals tested include amino triazole, 2,4-dinitrophenol, sodium arsenate, sodium azide, iodoacetamide, hydroxylamine, sodium fluoride, maleic hydrazide, etc. (5,6,9,14,17).

We have applied preharvest foliar sprays of several pesticides and plant growth regulators, postharvest dips of the sugarbeet roots in solutions of pesticides and growth regulators, and modified atmosphere to control sucrose losses during the storage of the roots. The effects of these treatments on the chemical composition and the rate of respiration of the roots during storage are reported here.

Material and Methods

Preharvest foliar application of the chemicals

Test plots of sugarbeet (cultivar: Utah-Idaho No. 7) planted in 22-inch rows at Utah State University's experimental farm, Logan, Utah, were sprayed 10 days before harvest with one of the following test chemicals: Randox (α-Chloro-N, N-Diallylacetamide) 200 ppm; maleic hydrazide (1,2-Dihydro-3, 6-pyridazinedione) 10, 100, and 1000 ppm; simazine [2-Chloro-4,6-bis(ethylamino)-s-triazine], 5, 50, 500 ppm; N^6-benzyladenine, 10, 100, and 1000 ppm; mixture of N^6-benzyladenine, 1000 ppm, and indoleacetic acid (3-indoleacetic acid) 1000 ppm; mixture of

[1] Mention of a specific commercial product does not constitute endorsement by the U. S. Department of Agriculture or by the Utah State University.

[2] Department of Food Science and Industries, Utah State University, Logan, Utah.

[3] Crops Research Division, Agricultural Research Service, Department of Agriculture, Logan, Utah.

[4] An estimate given by G. Rush at "Storage and Respiration" symposium of the American Society of Sugar Beet Technologists, Phoenix, Arizona, February, 1968.

[5] Numbers in parentheses refer to literature cited.

N^6-benzyladenine, 1000 ppm and α-naphthaleneacetic acid, 1000 ppm; Vegadex (2-Chloroallyl diethyldithiocarbamate) 200 ppm; chloro-IPC [Isopropyl-N-(3-chlorophenyl) carbamate] Falone [tris-([2,4-Dichlorophenoxy] ethyl)phosphite], 200 ppm; Na-hexametaphosphate, 1000 ppm; Malathion, [S-(1,2-dicarbethoxy-ethyl)-0,0-dimethyl dithiophosphate], 1000 ppm; Telone (1,3-hexametaphosphate, 1000 ppm; Malathion, [S-(1,2-dicarbethoxy-4-cyclohexene-1,2-dicarboximide, 100 and 1000 ppm. Triton B-1956 was used as a surfactant. The control plants were sprayed with the surfactants. After harvest in October, 1968, the beets from each test plot were washed, leaves were trimmed away, the crowns were removed, and the roots were stored at 10°C. A sample from the control plot was analyzed for concentration of sucrose, reducing sugar, raffinose, and the rate of respiration at the beginning of storage.

Postharvest dips of the roots in the chemicals

Each unit containing 25 sugarbeet roots was dipped for either 5 minutes or 1 hour in water solutions of one of the following chemicals: Randox, 500 ppm; maleic hydrazide, 500 ppm; chloro-IPC, 500 ppm; Falone, 500 ppm; Vegadex, 500 ppm; N^6-benzyladenine, 500 ppm; 2-aminobutane, 250 ppm; and Difolatan, [N-(1,1,2,2-tetrachloroethylthio)-4-cyclohexene, 1,2-dicarboximide, 50 ppm]. One untreated unit served as a control. Subsequent to the treatment, all units were stored at 10°C.

Modified environment

Units of 25 washed beet roots were stored in sealed polyethylene bags at 10°C and compared with similar samples stored in air. Relatively high CO_2 concentrations were maintained inside each bag because of the respiratory CO_2 evolution and O_2 utilization by the roots.

Beet root samples from each treatment were taken out periodically for chemical analyses and measurement of respiration rates. The latter was measured by the method of Claypool and Keefer (3). The method of Shaffer and Somogyi (10) was used in determining the contents of sucrose and reducing sugars. Raffinose was determined by an adaptation of the paper chromatography method of Brown (2).

Statistical analysis

Analysis of variance and comparison of means were carried out according to Tukey's *w*-procedure (13).

Results and Discussion

Preharvest chemical treatments

The effects of the preharvest foliar sprays on the contents of reducing sugars, sucrose, and raffinose, and on the rate of respiration were tabulated (Tables 1 and 2; and Figure 1). Of all the 13 chemicals used, only Randox significantly reduced sucrose loss

Table 1.—Effects of preharvest foliar sprays of some chemicals on sucrose content and respiratory rate of sugarbeet roots during storage[a].

Chemical	Concentration (ppm)	Sucrose (%)				Respiratory rate mg CO_2/Kg/hr			
		Oct. 68	Dec. 68	Feb. 69	Apr. 69	Oct. 68	Dec. 68	Feb. 69	Apr. 69
Control		14.51[b]	13.34	12.18	11.14	8.1[c]	7.7	7.6	6.9
Maleic hydrazide	10	.....	13.32	12.13	11.19	....	7.9	7.5	7.0
	100	.....	13.28	12.23	11.33	....	8.0	7.5	6.7
	1000	.....	13.61	12.31	11.20	....	7.8	7.6	6.7
Simazine	5	.....	13.46	12.22	11.19	....	8.1	7.4	7.0
	50	.....	13.42	12.23	11.07	....	7.9	7.4	6.7
	500	.....	13.27	12.10	11.26	....	7.6	7.5	7.0
N^6-benzyladenine	10	.....	13.29	12.22	11.12	....	7.7	7.5	6.8
	100	.....	13.31	12.12	11.09	....	7.8	7.4	7.0
	1000	.....	13.39	12.17	11.08	....	7.6	7.6	6.8
N^6-benzyladenine + indoleacetic acid	1000	.....	13.10	11.64**	10.35**	....	7.7	7.5	6.9
N^6-benzyladenine + α-Naphthalene-acetic acid	1000	.....	13.38	12.28	11.04	....	8.1	7.9	7.4
Vegadex	200	.....	13.36	12.10	11.08	....	7.9	7.4	7.2
Chloro-IPC	200	.....	12.95**	11.74**	10.24**	....	7.8	7.5	7.2
Falone	200	.....	13.23	12.22	10.96	....	8.3	7.5	7.4
Na-hexametaphosphate	1000	.....	13.46	11.01**	9.99**	....	8.8	7.9	7.1
Malathion	1000	.....	13.47	12.28	11.06	....	7.6	7.7	7.2
Telone	1000	.....	12.70**	11.12**	9.69**	....	7.9	7.8	7.6
Captan	100	.....	13.23	12.12	11.03	....	7.8	7.8	7.0
	1000	.....	13.39	12.18	11.33	....	7.9	7.6	6.8
Randox	200	.....	13.74**	13.09**	12.29**	....	6.7	6.2	5.4

[a] Analysis of variance and comparison of means by Tukey's *w*-procedure.
* Significant at .05 level; ** Significant at the .01 level.
[b] Concentration of sucrose at the beginning of storage.
[c] Rate of respiration at the beginning of storage.

Table 2.—Effects of preharvest foliar sprays of some chemicals on reducing sugar and raffinose content of sugarbeet roots during storage.

Chemical	Concentration (ppm)	Reducing sugar (%)				Raffinose (%)			
		Oct. 68	Dec. 68	Feb. 69	Apr. 69	Oct. 68	Dec. 68	Feb. 69	Apr. 69
Control		0.07[a]	0.19	0.30	0.50	0.06[b]	0.21	0.44	0.49
Maleic hydrazide	10	.....	0.27	0.33*	0.54	.....	0.26*	0.39	0.53
	100	.....	0.23	0.35*	0.64**	.....	0.11**	0.18**	0.46
	1000	.....	0.21	0.36*	0.52	.....	0.27*	0.35*	0.48
Simazine	5	.....	0.17	0.26*	0.47	.....	0.19	0.38	0.50
	50	.....	0.21	0.44*	0.56*	.....	0.17	0.44	0.52
	500	.....	0.15	0.26*	0.50	.....	0.21	0.38	0.55*
N^6-benzyladenine	10	.....	0.13	0.30	0.57*	.....	0.23	0.38	0.46
	100	.....	0.18	0.35*	0.52	.....	0.18	0.44	0.55*
	1000	.....	0.19	0.28	0.53	.....	0.21	0.43	0.56*
N^6-benzyladenine +Indoleacetic acid	1000 +1000	.....	0.31**	0.45**	0.81*	.....	0.20	0.34**	0.55*
N^6-benzyladenine +α-Naphthalene acetic acid	1000 +1000	.....	0.22	0.32	0.55	.....	0.26*	0.41	0.47
Vegadex	200	.....	0.19	0.31	0.49	.....	0.28*	0.33**	0.55*
Chloro-IPC	200	.....	0.14	0.42**	0.57*	.....	0.26*	0.33**	0.48
Falone	200	.....	0.17	0.32	0.51	.....	0.17	0.39	0.54*
Na-Hexametaphosphate	1000	.....	0.22	0.29	0.58*	.....	0.19	0.41	0.57**
Malathion	1000	.....	0.20	0.36*	0.58*	.....	0.19	0.37*	0.54*
Telone	1000	.....	0.44**	0.51**	0.73**	.....	0.13**	0.28**	0.46
Captan	100	.....	0.14	0.40**	0.57*	.....	0.24	0.46	0.53
	1000	.....	0.24	0.29	0.43*	.....	0.22	0.38	0.47
Randox	200	.....	0.16	0.33*	0.56*	.....	0.16*	0.37*	0.44

[a]Concentration of reducing sugar at the beginning of storage.
[b]Concentration of raffinose at the beginning of storage.
*Significant at .05 level.
**Significant at .01 level.

in stored roots (Figure 1). The sucrose contents of Randox-treated beets exceeded those of the control beets in all samples. The increased sucrose coincided with a considerable reduction in the rate of respiration and in the content of raffinose. The reducing sugar content of the Randox-treated beets was lower than that of the control beets through one month of storage. In the second and third month, however, the situation was reversed.

The sucrose content of the beets treated with a mixture of N^6-benzyladenine and indoleacetic acid, chloro-IPC, Na-hexametaphosphate or Telone was lower than those of the untreated control roots (Table 1 and Table 2). The reducing sugars of the beet roots treated with a mixture of N^6-benzyladenine and indoleacetic acid, or Telone was higher than the control beets. Contrary to the results of other workers (5,18), we did not encounter a reduced loss of sucrose in the sugarbeet roots treated with maleic hydrazide.

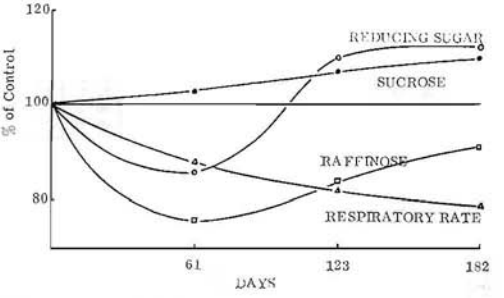

Figure 1.—Effects of preharvest foliar sprays of Randox (concentration: 200 ppm) on sucrose, reducing sugar, and raffinose content and respiratory rate of sugarbeet roots during storage.

Postharvest dips of the roots in the chemicals

Two (N^6-benzyladenine and Randox) of the six chemicals used as dips limited sucrose losses in the stored roots (Tables 3 and 4; and Figures 2 and 3). In roots treated for 1 hour with N^6-benzyladenine, the sucrose content was higher while the raffinose content and the rates of respiration were lower than those of the control beets. The 5-minute treatment with N^6-benzyladenine, however, had no significant influence on the contents of sucrose, reducing sugars, raffinose, or on the rates of respiration. N^6-benzyladenine has been reported to inhibit senescence in plants (11) and respiration of fruits and vegetables (4). Respiration inhibition by N^6-benzyladenine has been attributed to its ability to inhibit kinases of the glycolytic pathway (16).

A 1-hour dip in Randox also considerably reduced sucrose losses and the rate of respiration (Figure 2).

Table 3.—Effects of postharvest treatments on sucrose content and respiratory rate of sugarbeet roots during storage.

Chemical	Concentration (ppm)	Time for dipping	Sucrose (%)				Respiratory rate mg CO_2/Kg/hr			
			Nov. 67	Dec. 67	Jan. 68	Feb. 68	Nov. 67	Jan. 68	Dec. 68	Feb. 68
Control	.....	.....	14.34[a]	13.69	12.98	12.24	6.9[b]	6.7	6.2	5.2
N^6-benzyladenine	500	5 min	.....	13.75	12.90	12.33	....	6.6	6.3	5.0
2-aminobutane	250	2 min	.....	13.67	13.04	12.19	....	6.9	6.1	5.3
Difolatan	50	5 min	.....	13.81	13.07	12.20	....	6.6	6.2	5.2
Modified atmosphere	.....	.....	.....	13.91*	13.66**	13.37**	....	5.2	5.0	4.1
			Oct. 68	Dec. 68	Feb. 69	Apr. 69	Oct. 68	Dec. 68	Feb. 69	Apr. 69
Control	.....	.....	14.51[a]	13.34	12.18	11.14	8.1[b]	7.7	7.6	6.9
Maleic hydrazide	500	1 hr	.....	13.48	12.53	11.34	....	7.9	7.5	7.0
Chloro-IPC	500	1 hr	.....	13.39	12.24	11.17	....	7.7	7.4	7.0
Falone	500	1 hr	.....	13.23	12.28	10.92*	....	7.7	7.7	6.8
Vegadex	500	1 hr	.....	13.53	12.23	11.02	....	7.6	7.5	7.1
N^6-benzyladenine	500	1 hr	.....	13.85**	13.01**	12.17**	....	7.1	7.0	6.2
Randox	500	1 hr	.....	13.81**	13.06**	12.28**	....	7.4	7.1	6.1

[a]Concentration of sucrose at the beginning of storage.
[b]Rate of respiration at the beginning of storage.
*Significant at .05 level.
**Significant at .01 level.

Table 4.—Effects of postharvest treatments on reducing sugar and raffinose content of sugarbeet roots during storage.

Chemical	Concentration (ppm)	Time for dipping	Reducing sugar (%)				Raffinose (%)			
			Nov. 67	Dec. 67	Jan. 68	Feb. 68	Nov. 67	Dec. 67	Jan. 68	Feb. 68
Control	.....	.....	0.04[a]	0.07	0.12	0.32	0.06[b]	0.22	0.39	0.52
N^6-benzyladenine	500	5 min	.....	0.06	0.14	0.31	.....	0.20	0.36	0.49
2-aminobutane	250	5 min	.....	0.07	0.10	0.35*	.....	0.21	0.41	0.47*
Difolatan	50	5 min	.....	0.07	0.11	0.30	.....	0.24	0.38	0.54
Modified atmosphere	.....	.....	.....	0.12**	0.18**	0.35*	.....	0.17*	0.38	0.51
			Oct. 68	Dec. 68	Feb. 69	Apr. 69	Oct. 68	Dec. 68	Feb. 69	Apr. 69
Control	.....	.....	0.07[a]	0.19	0.30	0.50	0.06[b]	0.21	0.44	0.49
Maleic hydrazide	500	1 hr	.....	0.23	0.39**	0.55	.....	0.15	0.36*	0.47
Chloro-IPC	500	1 hr	.....	0.17	0.44**	0.62*	.....	0.19	0.37*	0.55*
Falone	500	1 hr	.....	0.25*	0.35*	0.54	.....	0.21	0.29**	0.43*
Vegadex	500	1 hr	.....	0.14	0.32	0.44	.....	0.26	0.33**	0.51
N^6-benzyladenine	500	1 hr	.....	0.25*	0.37*	0.59*	.....	0.18	0.30**	0.45*
Randox	500	1 hr	.....	0.20	0.35*	0.57*	.....	0.18	0.37*	0.50

[a]Concentration of reducing sugar at the beginning of storage.
[b]Concentration of raffinose at the beginning of storage.
*Significant at .05 level.
**Significant at .01 level.

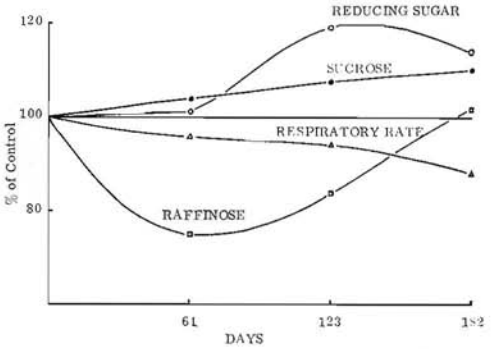

Figure 2.—Effects of postharvest treatment of Randox (concentration: 500 ppm; time for dipping: 1 hour) on sucrose, reducing sugar, and raffinose content and respiratory rate of sugarbeet roots during storage.

Modified environment

A modified atmosphere storage of sugarbeet roots also resulted in reduced sucrose losses (Figure 4). The data given in Figure 4 do not represent the value for respiration of the roots during storage. It is evident, however, that the high CO_2 concentration inhibits respiratory rate which could even be observed after removal of the roots from the storage. The residual effect may well be due to a high concentration of CO_2 left out in beet root cells stored under modified atmosphere. The larger sucrose and reducing sugar content observed in the roots of the sugarbeet stored under modified atmosphere for 30 to 90 days also attests

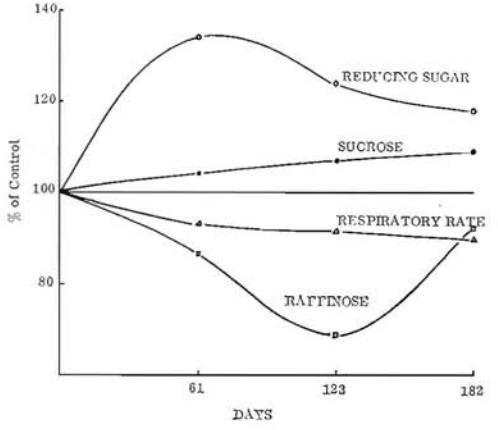

Figure 3.—Effects of postharvest treatment of N^6-benzyladenine (concentration: 500 ppm; time for dipping: 1 hour) on sucrose, rdeucng sugar, and raffinose content and respiratory rate of sugarbeet roots during storage.

to a decreased ability to carry out sugar-consuming metabolic processes (respiration) by the root cells.

Figure 4 indicates an inverse relationship between the raffinose and the reducing sugar contents of the roots. The increase in reducing sugars may have been due to their lowered utilization in the biosynthesis of raffinose, or to raffinose being degraded under modified atmosphere conditions.

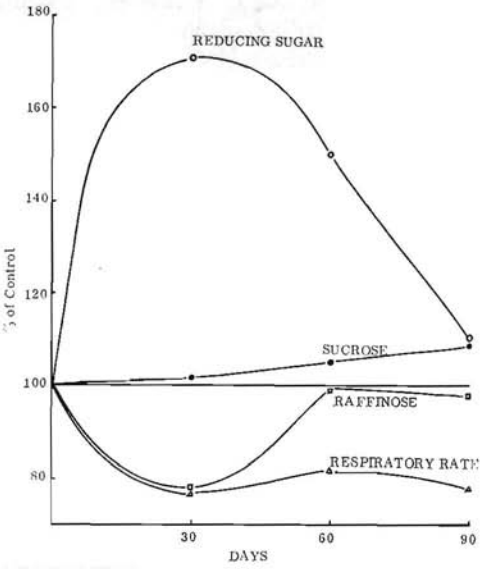

Figure 4.—Effects of modified atmosphere on sucrose, reducing sugar, and raffinose content and respiratory rate of sugarbeet roots during storage.

Inhibition of respiration and reduction of sugar loss in a modified atmosphere (high CO_2 and low O_2 concentration) has been observed in several fruits and vegetables (1,7,8). The work of Littlefield (8) with apples, pears, and cherries suggests that controlled atmosphere storage conditions increase the shelf-life of the fruits by inhibiting synthesis of proteins and of enzymes, especially the respiratory enzymes. The lower rate of respiration we noted in the sugarbeet roots, in modified atmosphere storage, thus may have resulted from an inhibition of the relevant enzymes.

Summary

Preharvest foliar sprays of the plants, postharvest dips of the roots, and modified (high CO_2 and low O_2) atmosphere storage of roots were tested for effectiveness in reducing the loss of sugar in sugarbeet roots during storage. The preharvest foliar application of Randox, the postharvest dips in N^6-benzyladenine and Randox solutions, and the modified atmosphere storage of

roots each produced similar responses: 1) reduced loss of sucrose, 2) reduced concentration of raffinose, and 3) reduced rate of respiration.

The sucrose content of the beets treated before harvest with a mixture of N^6-benzyladenine and indoleacetic acid, chloro-IPC, Na-hexametaphosphate, or Telone was lower than those of the untreated control roots. The application of maleic hydrazide, simazine, naphthaleneacetic acid, Vegadex, Falone, malathion, and Captan as preharvest foliar spray or postharvest dips of the roots in maleic hydrazide, chloro-IPC, Telone, Vegadex, 2-aminobutane, and Difolatan had no significant effect on sucrose content of the roots.

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