4. Ben-Yehoshua, S. 1984. Transpiration and water stress. In: G. Weichmann (ed.). Postharvest physiology of vegetbles. Marcel Dekker, New York. (In press)
5. Ben-Yehoshua, S., B. Shapiro, Z. Even-Chen, and S. Lurie. 1983. Mode of action of plastic film in extending life of lemon and bell pepper fruit by alleviation of water stress. Plant Physiol. 73:87–93.
6. Borochov, A., A.H. Halevy, H. Borochov, and M. Shinitzky. 1978. Microviscosity of plasmalemmas in rose petals as affected by age and environmental factors. Plant Physiol. 61:812–815.
7. Borochov, A., A.H. Halevy, and M. Shinitzky. 1982. Senescence and the fluidity of rose petal membranes. Plant Physiol. 69:396–399.
8. Bradford, M.M. 1976. A new method of protein determination. Anal. Biochem. 72:248–251.
9. Chiamori, I. and R. Henri. 1959. Study of a method of determination of total cholesterol and cholesterol esters. Amer. J. Clin. Pathol. 31:305–309.
10. Eilan, Y. 1965. Permeability changes in senescing tissue. J. Expt. Biol. 16:614–627.
11. Even-Chen, Z. and C. Itai. 1975. The role of abscisic acid in senecence of detached tobacco leaves. Physiol. Plant. 34:97–100.
12. Goldschmidt, E.E., R. Goren, Z. Even-Chen, and S. Bittner. 1973. Increase in free and bound abscisic acid during natural and ethylene-induced senescence of citrus fruit peel. Plant Physiol. 51:879–882.
13. Lurie, S. and R. Ben-Aire. 1983. Microsomal membrane changes during the ripening of apple fruit. Plant Physiol. 73:636–638.
14. Lurie, S., B. Shapiro, and S. Ben-Yehoshua. 1986. Effects of water stress and degree of ripeness on rate of senescence of harvested bell pepper fruit. J. Amer. Soc. Hort. Sci. 111:880–885.
15. McGlassan, W.B. and I. Adato. 1976. Changes in the concentration of abscisic acid in fruits of normal and Nr, rin and nor mutant tomatoes during growth, maturation and senescence. Austral. J. Plant. Physiol. 3:809–817.
16. McKersie, B.D. and J.E. Thompson. 1979. Phase properties of senescing plant membrane: role of the neutral lipids. Biochim. Biophys. Acta 550:48–58.
17. Nooden, L.D. 1980. Senescence in the whole plant, p. 219–258. In: K. Thimann (ed.). Senescence in plants. CRC Press, Boca Raton, Fla.
18. Rhodes, M.J.C. 1980. The maturation and ripening of fruits, p. 151–205. In: K. Thimann (ed.). Senescence in plants, CRC Press, Boca Raton, Fla.
19. Sacher, J.A. 1957. Relationship between auxin and membrane integrity in tissue senescence and abscission. Science 125:1199–2000.
20. Saltveit, M. 1977. Carbon dioxide, ethylene and color development in ripening mature green bell peppers. J. Amer. Soc. Hort. Sci. 102:523–525.
21. Shinitzky, M. and Y. Barenholz. 1978. Fluidity parameters of lipid regions determined by fluorescence polarization. Biochim. Biophys. Acta 515:367–394.
22. Siminovitch, D., H. Therrien, F. Gfeller, and B. Rheaume. 1964. The quantitative estimation of frost injury and resistance in black locust, alfalfa, and wheat tissues by determination of amino acids and other ninhydrin reacting substances released after thawing. Can. J. Bot. 42:637–649.
23. Wright, S.T.C. 1978. Phytohormones and stress, p. 495–536. In: D.S. Letham, P.B. Goodwin, and T.J.V. Higgins (eds.). Phytohormones and related compounds. Elsevier, Amsterdam.

J. Amer. Soc. Hort. Sci. 111(6):889–892. 1986.

Weight Loss in Sweet Potatoes During Curing and Storage: Contribution of Transpiration and Respiration

David H. Picha
Department of Horticulture, Louisiana Agricultural Experiment Station, Louisiana State University Agricultural Center, Baton Rouge, LA 70803

Additional index words. *Ipomoea batatas*, root quality

Abstract. **Cured sweet potatoes [*Ipomoea batatas* (L.) Lam] were stored successfully at 15.6°C and 90% RH for up to a year without sprouting. Contribution of respiration and transpiration to total weight loss was determined during curing and storage in 6 cultivars. Respiration rate was highest the day of harvest, decreased during curing, and continued to decrease at a slower rate during the first several months of storage, whereafter it remained constant (except for slight increases during the last several months in 2 cultivars). Respiration contributed more to total weight loss during the latter periods of storage than during curing or the first months in storage. Transpiration, however, was the major source of weight loss. The highest rate of weight loss occurred during curing, followed by a gradual rate of loss during storage. Total weight loss of cured roots after 50 weeks of storage ranged from 6.7% ('Rojo Blanco') to 16.1% ('Travis').**

Successful storage of sweet potatoes after harvest depends on proper curing for suberization and wound-periderm formation (3) and proper storage temperature and humidity to prevent sprouting and chilling injury (11). Storing sweet potatoes is generally an economically beneficial practice, resulting in fresh product availability over the entire year. Farm price is usually lowest in the fall after harvest, and gradually increases during the winter and spring months (16).

Significant metabolic changes that affect internal composition and texture occur during curing and storage (11). Respiration and transpiration contribute to loss in weight and alteration of internal and external appearance (10). Little information exists on the respiration and weight loss rates during curing and storage of currently grown cultivars. Most previous work indicated that respiration was higher after harvest than during curing or storage (1, 2, 4, 6, 10, 12); but, in one study, no decline in respiration was found over a 9-day period after harvest (15).

Received for publication 30 Sept. 1985. The cost of publishing this paper was defrayed in part by the payment of page charges. Under postal regulations, this paper therefore must be hereby marked *advertisement* solely to indicate this fact.

Total weight loss rate was higher during curing than storage (7–10). No information exists on the relative contribution of respiration and transpiration to total weight loss in currently grown cultivars.

The objectives of this study were to characterize the respiration rate and total weight loss of 6 sweet potato cultivars during curing and over one year of storage and to determine the contribution to total weight loss from respiration vs. transpiration.

Materials and Methods

Six sweet potato cultivars (Centennial, Jewel, Jasper, Travis, Rojo Blanco, and Whitestar) were grown at the LSU Hill Farm in Baton Rouge, La., in 1981 and 1982, following commercially recommended cultural practices (14). All roots were hand-harvested with the aid of a turn plow in mid-October prior to any adverse cool or wet weather.

A total of 60 disease-free U.S. #1 size roots per cultivar, plus alternates, were washed and divided into 4 replications of 15 roots. Each individual root was weighed the day of harvest, after 10 days of curing at 32°C and 90% RH, and after every 2 or 4 weeks of 15.6° and 90% RH storage for up to 50 weeks. Any root that developed decay during storage was discarded and replaced by a sound alternate root. Cumulative weight loss was determined in reference to the initial weight at harvest.

Additional roots, which were not part of the weight loss study, were cut longitudinally in halves every 4 weeks to monitor the development of internal pithiness and discoloration.

Moisture content of the roots at harvest was determined by drying duplicate 10.0-g samples of flesh tissue from 6 different roots at 70°C for 48 hr in a forced-air oven.

Respiration rates (fresh weight basis) of 8 randomly selected sound U.S. #1 size roots per cultivar were determined during the same time intervals as weight loss measurements. Several additional determinations were made during the curing period. Two roots per cultivar, replicated 4 times, were put in 4-liter glass jars, which were then sealed. Carbon dioxide content in the head space was determined after 1 hr by gas chromatography. All respiration measurements were made at a 15.6°C root temperature, which required a temporary transfer of the roots from curing to 15.6° for several hours before analysis. Displaced air inside the jar due to root volume was taken into account in all respiration calculations. The CO_2 buildup inside the jars never exceeded 0.4%, and respiration rates were similar after 1-, 2-, or 4-hr incubation periods.

Weight of C loss (mg of C present in CO_2) during curing or storage was calculated by converting the total milliliters of CO_2 generated during the curing period or 50-week storage interval into milligrams of CO_2 and then multiplying the weight of CO_2 evolved by 0.273 (atomic weight of C ÷ molecular weight of CO_2). The difference between C loss and total weight loss was assumed to be transpiration loss, even though the ultimate source of some of the H_2O loss was probably generated during respiration. Weight loss was expressed in milligrams (C or total) lost per gram of root fresh weight.

Results and Discussion

Root appearance. No pithiness (hollow cavities within the root) or internal discoloration was found in any 'Travis', 'Jewel', 'Whitestar', or 'Rojo Blanco' root in either year during the 50-week storage period. Pithiness was first observed in 'Jasper' roots after about 28 weeks of storage and after 38 weeks in 'Centennial'. The amount of pithiness increased in both cultivars with continued storage. Pithiness previously was shown to develop during storage when weight loss exceeded volume loss (10). Noticeable, but not objectionable, external shrinkage symptoms occurred in 'Travis' roots after about 10 weeks. Slight internal root darkening was observed in 'Centennial' roots after 38 weeks in the 1981–82 study.

Respiration. All cultivars had the highest respiration rate the day of harvest, followed by a steep decline during the first few days of curing, followed by a more gradual decline over the last few days of curing (Fig. 1). Respiration rate continued to decline gradually in all cultivars during the first 14–18 weeks of storage. Other workers also reported highest respiration rates at harvest followed by a decline during curing or storage (1, 2, 4, 6, 10, 12). The respiration rates reported herein for 'Centennial' and 'Jewel' agree with the values of others (1, 10), with the exception of one study that reported extremely low rates (15). Respiration rates changed only slightly after 18 weeks of storage, except in 'Centennial' and 'Jasper', which increased gradually after 26 weeks. Respiration rates at any one storage time within a cultivar were similar both years. 'Rojo Blanco' and 'Whitestar' had the lowest respiration rates during storage, while 'Jasper' and 'Centennial' had the highest.

Slight differences in root wounding due to vine detachment may explain the occasional difference in the order of respiration rate ranking between cultivars during curing compared to storage. Respiration rate differences between the curing and storage periods and between cultivars probably were not due to different internal gas diffusion rates within the roots. Studies with potato tubers showed that metabolic activity was not limited by an O_2 deficiency or CO_2 buildup inside the tissue (5, 13).

Weight loss. The contribution of respiratory C loss to total weight loss during curing was slight (Table 1). 'Jasper' lost the most respiratory C (2.1% of total weight loss) while in 'Travis' C loss contributed only 1.4% of the total weight loss during curing. The contribution of respiratory C loss to total weight loss was greater during storage than during curing, and ranged from 5.7% ('Travis') to 11.2% ('Jasper' and 'Centennial') of total weight loss over the entire storage period. Respiration contributed more to total weight loss during the latter periods of storage than during the first months. Transpiration was the ma-

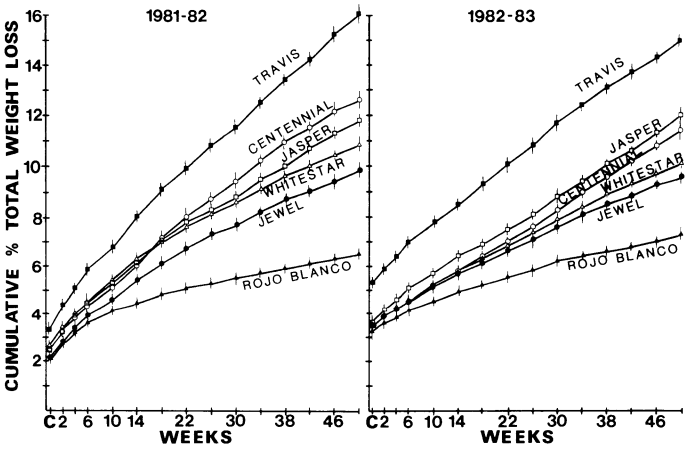

Fig. 1. Respiration rate (fresh weight basis) of 6 sweet potato cultivars at harvest (H), after curing (C), and during 50 weeks of storage at 15.6°C, 90% RH. Each point represents the average of 8 roots. Vertical bars represent SE of the mean and, when absent, fall under the symbol.

Table 1. Total weight loss and respiratory C loss from 6 sweet potato cultivars during curing and storage.

	Weight loss[z] (mg·g^{-1} root fresh wt)											
	'Rojo Blanco'		'Jewel'		'Whitestar'		'Jasper'		'Centennial'		'Travis'	
Period	Total	C	Total	C	Total	C	Total	C	Total	C	Total	C
Curing[y]	27.0	0.50	28.0	0.52	30.5	0.48	30.0	0.64	29.5	0.59	42.5	0.59
Storage[x]	43.0	4.40	69.0	6.98	74.0	5.48	89.0	9.92	91.0	10.18	113.0	6.41
Total	70.0	4.90	97.0	7.50	104.5	5.96	119.0	10.56	120.5	10.77	155.5	7.00

[z]Average values of 1981–82 and 1982–83 tests.
[y]Curing = 10 days at 32°C, 90% RH.
[x]Storage = 50 weeks at 15.6°C, 90% RH.

jor source of total weight loss during storage, which was in agreement with previous reports (2, 10). The cultivars with the highest C losses did not always have the highest water losses, a response consistent with a previous study that found C and H_2O were lost independently (10).

The highest rate of weight loss occurred during curing. 'Travis' roots had the most weight loss of all cultivars during curing in both years and 'Rojo Blanco' had the least (Fig. 2). 'Jewel' weight loss during curing in the 1981 test was similar to that of 'Rojo Blanco'. 'Travis' had the highest percentage of moisture content (about 82%) among all cultivars and the highest amount of H_2O loss during curing (Table 1). Transpiration is expected to be high immediately after harvest due to the unavoidable skinning and wounding created when separating the root from the vine. All cultivars were harvested in a similar manner, minimizing differential amounts of harvest injury as a factor contributing to differences in cultivar H_2O loss. Suberization and wound periderm formation in the outer cell layers establishes an effective H_2O loss barrier, but it takes several days to be initiated and slightly longer to become developed (3). Cultivar differences in H_2O loss during curing may be due to anatomical differences in amount and rate of cell suberization and wound periderm formation along with initial root moisture content.

The rate of weight loss was lower during storage than during curing, consistent with previous reports (7–10). The rate of storage weight loss in all cultivars was highest during the first 8 weeks of storage and lowest during the last 20 weeks. 'Travis' continued to lose the most weight and 'Rojo Blanco' the least among all cultivars during storage (Fig. 2). 'Jasper' and 'Centennial' had a higher weight loss rate than 'Jewel' and 'Whitestar' during weeks 18 to 50. Total weight loss values within the same cultivar after curing and 50 weeks of storage were usually within 1% between years and ranged from 15.0–16.1% in 'Travis', 11.5–12.6% in 'Centennial', 11.8–12.0% in 'Jasper', 10.1–10.8% in 'Whitestar', 9.6–9.8% in 'Jewel', and 6.7–7.3% in 'Rojo Blanco'.

Total weight loss was not determined solely by initial root moisture content at harvest. 'Rojo Blanco' had about 71% moisture and 'Jewel' 76%, but both cultivars had less weight loss than 'Whitestar', which had 67% moisture. 'Jewel' roots also had a higher moisture content than 'Centennial' (73%), but less total weight loss. 'Travis', however, had the highest root moisture content and highest weight loss.

Rate of weight loss or total weight loss could not be used to predict which cultivars would develop internal pithiness. 'Travis' had the highest rate of weight loss and total weight loss, but did not develop pithiness. Pithiness developed in 'Jasper' and 'Centennial' roots, even though they had less weight loss than 'Travis'.

Respiration rate expressed on a fresh weight basis was not a good indicator for predicting weight loss. 'Travis' had the highest weight loss but not the highest respiration rate, while 'Jewel' had a higher respiration rate than 'Whitestar' or 'Travis', but less total weight loss.

The 2 white-flesh cultivars ('Whitestar' and 'Rojo Blanco') and 'Jewel' were best suited for long-term storage because of their low rates of weight loss and absence of internal pithiness. The high rate of storage weight loss in 'Travis' would result in more dollar value loss compared to other cultivars, since sweet potatoes are sold on a weight basis. 'Jasper' was best suited for short-term storage because of pithiness susceptibility with increasing storage duration. 'Centennial' was well-adapted for storage up to 38 weeks, whereafter slight pithiness and internal discoloration were found to detract from product appearance.

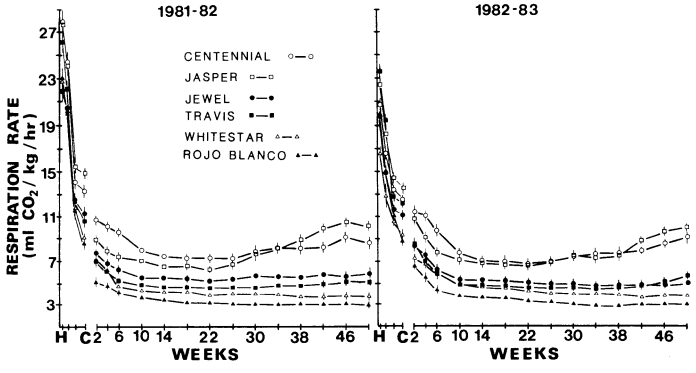

Fig. 2. Cumulative percentage of total weight loss in 6 sweet potato cultivars after curing (C) and during 50 weeks of storage at 15.6°C, 90% RH. Each point represents the average of 60 individual roots. Vertical bars represent SE of the mean.

Literature Cited

1. Ahn, J.K., W.W. Collins, and D.M. Pharr. 1980. Influence of preharvest temperature and flooding on sweet potato roots in storage. HortScience 15:261–263.
2. Appleman, C.O., H.G. Shrirk, P.H. Heinze, and R.G. Brown. 1943. The curing and storage of Maryland Golden sweet potatoes. Maryland Agr. Expt. Sta. Bul A22.
3. Artschwager, E. 1931. Suberization and wound-periderm formation in sweet potato and gladiolus as affected by temperature and relative humidity. J. Agr. Res. 43:353–364.
4. Buescher, R.W., W.A. Sistrunk, and P.L. Brady. 1975. Effects of ethylene on metabolic and quality attributes in sweet potato roots. J. Food Sci. 40:1018–1020.
5. Burton, W.G. 1950. Studies on the dormancy and sprouting of potatoes: I. The oxygen content of the potato tuber. New Phytol. 49:121–134.
6. Chang, L.A. and S.J. Kays. 1981. Effect of low oxygen storage on sweet potato roots. J. Amer. Soc. Hort. Sci. 106:481–483.

7. Hammett, L.K. and C.H. Miller. 1982. Influence of mineral nutrition and storage on quality factors of 'Jewel' sweet potatoes. J. Amer. Soc. Hort. Sci. 107:972–975.
8. Hammett, L.K. and T.J. Monaco. 1981. Effect of oryzalin and other herbicide treatments on selected quality factors of sweet potatoes. J. Amer. Soc. Hort. Sci. 107:432–436.
9. Kushman, L.J. 1975. Effect of injury and relative humidity during curing on weight and volume loss of sweet potatoes during curing and storage. HortScience 10:275–277.
10. Kushman, L.J. and D.T. Pope. 1972. Causes of pithiness in sweet potatoes. N.C. Agr. Expt. Sta. Tech. Bul. 207.
11. Kushman, L.J. and F.S. Wright. 1969. Sweet potato storage. Agr. Hdbk. 358, USDA, Washington, D.C.
12. Kushman, L.J. and M.T. Deonier. 1959. Relation of internal gas content and respiration to keeping quality of Porto Rico sweet potatoes. Proc. Amer. Soc. Hort. Sci. 74:622–641.
13. Laties, G.G. 1962. Controlling influence of thickness on development and type of respiratory activity in potato slices. Plant Physiol. 37:679–690.
14. Montelaro, J., W.J. Martin, and E.J. Kantack. 1966. Sweet potatoes in Louisiana. LSU Coop. Ext. Publ. 1450.
15. Saltveit, M.E. and R.D. Locy. 1982. Cultivar differences in ethylene production by wounded sweet potato roots. J. Amer. Soc. Hort. Sci. 107:1114–1117.
16. USDA. 1985. Vegetable outlook and situation report TV-235. Econ. Res. Serv. USDA, Washington, D.C.

J. Amer. Soc. Hort. Sci. 111:(6):892–896. 1986.

Application of Flavonoid Glycosides and Phenolic Acids to Suppress Firmness Loss in Apples

P.D. Lidster[1], A.J. Dick[2], A. DeMarco[3], and K.B. McRae[4]

Agriculture Canada Research Station, Kentville, Nova Scotia, Canada B4N 1J5

Additional index words. *Malus domestica*, quercetin, rutin, chlorogenic acid, catechin, postharvest dip, vacuum infusion

Abstract. **Vacuum infusion or dipping fruit in solutions of an apple (*Malus domestica* Borkh.) extract containing chlorogenic acid, catechins, and quercetin glycosides (isolated from 'Spartan' apples) suppressed fruit softening of 'Spartan' and 'Golden Delicious' apples held at 20°C. Quercetin or rutin [0.01% or 0.05% (w/v)], applied by postharvest vacuum infusion or dipping, reduced softening of 'Golden Delicious' apples held at 20° and 0°. Structurally related compounds (catechin, coumaric acid, and chlorogenic acid) showed some potential for retarding fruit softening but the effects were inconsistent. Additions of 0.25% (w/v) thickener plus 0.1% surfactant to the dipping solution containing the above compounds further reduced fruit firmness loss in storage. When quercetin or rutin were vacuum-infused either before or after CA storage, fruit were firmer than control fruit over a 25-day period at 20°.**

Apple softening, in refrigerated storage and at shelf temperatures, has been retarded by the application of an apple extract containing compounds with β-galactosidase inhibitory properties (1, 3). Several of these compounds have been identified as chlorogenic acid, catechins, and quercetin glycosides (2). Vacuum infusion of chlorogenic acid or a mixture of quercetin glycosides to 'Golden Delicious' apples retarded fruit softening, but a low concentration of quercetin was not as effective in maintaining fruit firmness at 20°C (2). This evidence suggests that fruit firmness may be maintained by the addition of flavonoid compounds. The present investigation examined the efficacy of several structurally related flavonoid and phenolic acid compounds, applied by several methods, to reduce fruit softening at 0° and 20°.

Materials and Methods

Apple extract application study. Preclimacteric 'Spartan' apples were harvested from each of 5 trees (replicates) in a commercial orchard near Kentville, N.S. Apples (50 per replicate) were either dipped for 1 min in, or were vacuum-infused with, distilled H_2O or the purified apple extract (200 units/ml) used in previous studies (2, 3). For infusion, apples were held for 2.5 min in glass desiccators containing either solution and a vacuum (final pressure 5.1 kPa) drawn for 2.5 min. The vacuum then was released and the fruit pressure allowed to equilibrate for 0.5 min to ambient atmosphere in solution. Apples were cooled to 0°C within 24 hr, and placed in 38-μm perforated polyethylene bags that maintained relative humidity at 90–95% during storage at 0°. Ten apples from each polyethylene bag were removed at 50-day intervals. Fruit firmness was determined, on opposite pared sectors of the apples, using a Ballauf penetrometer with an 11.1-mm tip.

Effects of inhibitor compounds at shelf temperature. 'Golden Delicious' apples, which had been stored for 205 days in a commercial controlled atmosphere (CA) storage at 3% CO_2 plus 2.5% O_2 at 0°C, were randomly divided into 56 groups of 50 apples each for a factorial experiment of 7 treatments × 2 dilutions × 4 replicates. Apples were warmed to 20°, and then each of 4 replicates was immersed in one solution of: 0.01 or 0.002% (w/v in 10% EtOH) quercetin; 0.01% or 0.002% (w/v in 10% EtOH) catechin; 0.3% or 0.06% (v/v in H_2O) glycoside fraction; 0.3% or 0.06% (w/v in H_2O) chlorogenic acid; 0.005% or 0.001% (w/v in 10% EtOH) epicatechin; 0.01% or 0.002% (w/v in 10% EtOH) rutin; 10% (v/v) EtOH; or in H_2O (controls). All fruit were submerged and then vacuum-infused with the appropriate solution, as previously described. Fruit then were held at 20° and 80% RH; firmness of 10 apples from each treatment–replicate was determined by the previously described method, at 3, 7, 10, 14, and 20 days.

Vacuum infusion of flavonoid glycosides, phenolic acids, and related compounds. Preclimacteric 'Golden Delicious' apples were harvested from a commercial orchard in Kingston, N.S.

Received for publication 21 Jan. 1985. Contribution no. 1867, Agr. Canada Res. Sta., Kentville, N.S. B4N 1J5. The cost of publishing this paper was defrayed in part by the payment of page charges. Under postal regulations, this paper therefore must be hereby marked *advertisement* solely to indicate this fact.

[1]Research Scientist.
[2]Associate Professor, Chemistry Dept., Acadia Univ., Wolfville, N.S., Canada B0P 1X0.
[3]Technician, Chemistry Dept., Acadia Univ., Wolfville, NS, Canada B0P 1X0.
[4]Regional Statistician (Atlantic).