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Effects of nitrogen, phosphorus and potassium fertilizer treatments on weight loss and changes in chemical composition of potato tubers stored at 4 °C

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Summary

Pot and field experiments were carried out to test fertilizer treatments on the behaviour of potato tubers stored at 4 °C and ≥90% relative humidity for 6 months. Weight losses (separated into water and dry matter) were enhanced after N and K fertilization and decreased by increasing P supply. Glucose and fructose contents were reduced at harvest by high-N-fertilizer rates compared to no or low fertilization, but throughout storage reducing sugar accumulation was increased, sucrose reduction was decreased and ascorbic acid was increased. K fertilization affected the chemical composition of the tubers somewhat similar to that of nitrogen fertilization. High initial nitrate content of the tubers seemed to be increased and low nitrate values were decreased during storage. The tubers from pot experiments showed similar changes but of greater magnitude.

Introduction

The storage behaviour of potato tubers involves many factors. The physiological age of the seed tuber, the cultivar, the soil type, climatic conditions during the growing period as well as agronomic factors like foliage killing before maturity and date of harvest, influence weight losses and changes in the chemical composition of stored tubers (Köhler, 1964; Stricker, 1985; Iritani et al., 1977; Hunnius, 1977; Mica, 1977; Putz, 1978; Grassert et al., 1984). Early investigations, e.g. by Berkner & Schlimm (1933), showed that different fertilizer regimes caused a change in tuber quality. Subsequently much research has been done, especially into the effect of N fertilization on tuber weight losses and decay, and on starch or sugar levels (Swiniarsky & Ladenberger, 1970; Stricker, 1974; Zgorska & Frydecka-Mazurczyk, 1977; Schnieder, 1978; Rogozinska, 1985; Kolbe, 1990). Nevertheless, the results obtained were often inconsistent, or other main nutrients were not included. Moreover, in these fertilizer trials changes in concentration of only a few ingredients were examined.

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Therefore, pot and field investigations were done to analyze weight losses and to observe changes in the important chemical compounds of potato tubers throughout storage to obtain information on the influence of agricultural practices on storage.

Materials and methods

In 1981 and 1982 potato tubers of cvs Désirée and Semenic were planted as part of complex trials in outdoor Mitscherlich-pots and field plots in Brasov (Romania) and Göttingen (Germany), as described by Kolbe (1990). Treatments included several combinations of various amounts of NPK-fertilizers given before planting (cf. Figures 1 and 3). Plants were harvested at full maturity and tubers were stored in plastic baskets under controlled conditions at 4 °C and ≥90% relative humidity.

Concentrations of dry matter were analyzed by calculating weight losses during freeze drying, including the determination of remaining moisture after 4 h at 105 °C. Glucose, fructose, sucrose and citric acid were analyzed enzymatically according to Bergmeyer (1974), using test sets from Boehringer, Mannheim, Germany; ascorbic acid with dichlorphenolindophenol by titration (Franke, 1955) and nitrate by an ion selective electrode (Kolbe & Müller, 1985). Tuber weight (data from 1982 inclusive of sprouts, but exclusive of rot), dry matter (as percentage of fresh matter, FM) and chemical compounds (as percentage of dry matter, DM) were analyzed just before storage (time I) and after 6 months' storage during winter (time III). Tuber weight, dry matter content and ascorbic acid were also measured after 3 months' storage (time II).

Water and dry matter were then calculated as the amounts contained in 100 g of fresh matter, others in 100 g of dry matter. Differences in the observed values were tested by variance analysis and F-test, and those between fertilizer treatments by variance analysis and Duncan's range test separately for times I and III. Different small letters mean significant differences for $p \leq 0.05$ (Duncan, 1955; Weber, 1980).

Results

Pot experiments. The effect of storage on weight loss and quantitative changes in the chemical composition of the tubers are shown in Table 1. Between times I and III the mean weight loss was 2.47%, the concentration of dry matter decreased by 0.82% and that of citric acid by 0.19%. The content of nitrate did not change during storage, but ascorbic acid decreased by about 45%. Sucrose decreased by about 75% and reducing sugars (glucose and fructose) increased threefold, from 2.32% to 7.06%.

In the 1982 season tubers of low N fertilization (Fig. 1, treatment 1) initially contained 80.56 g water in 100 g FM, but after 6 months' storage this dropped to 78.37 g. Increasing N fertilization (Fig. 1, treatments 1–3) resulted in decreased water loss. In contrast to the water balance, a continuous increase of dry matter losses in the stored tubers was observed through increasing N-supply of the plants (Fig. 1, treatments 1–3). The loss in dry matter after high N fertilization was at 6.3% more than twice as high as in the low nitrogen plots. There was a proportionally greater increase in weight losses in stored potato tubers after N fertilization. Increasing P

Table 1. Weight and chemical composition of tubers at harvest (time I) and after 3 months (time II) and 6 months (time III) storage (Averages of 2 years, 2 cultivars and 2 locations).

	Time			Time III minus Time I	F-value[a]
	I	II	III		
Pot trials					
Tuber weight[b] (g FM)	100.00	99.05	97.53	-2.47	–
Dry matter (% FM)	19.23	18.96	18.41	-0.82	55.3***
Glucose (% DM)	1.37	–	4.26	+2.89	1681***
Fructose (% DM)	0.95	–	2.80	+1.85	1342***
Sucrose (% DM)	3.07	–	0.66	-2.41	983***
Ascorbic acid (μg g-1 DM)	802.60	526.00	443.80	-358.80	3679***
Citric acid (% DM)	2.36	–	2.17	-0.19	47.7***
Nitrate (μg g-1 DM)	519.95	–	519.38	-0.57	0.0 n.s.
Field trials					
Tuber weight[b] (g FM)	100.00	98.98	97.69	-2.31	–
Dry matter (% FM)	21.15	21.27	20.40	-0.75	48.8***
Glucose (% DM)	0.94	–	3.34	+2.4	2379***
Fructose (% DM)	0.78	–	2.54	+1.76	3591***
Sucrose (% DM)	1.83	–	0.60	-1.23	852***
Ascorbic acid (μg g-1 DM)	758.50	432.00	412.30	-346.20	1679***
Citric acid (% DM)	1.82	–	2.07	+0.25	39.6***
Nitrate (μg g-1 DM)	434.39	–	438.99	+4.6	0.1 n.s.

[a] F-value: n.s. not significant, *** $p \leq 0.001$.
[b] Data from 1982.

fertilization (Fig. 1, treatments 4–6) led to decreasing losses in dry matter. A low N supply or high P nutrition (treatments 3 or 6, A) gave the lowest reduction in dry matter in the trial. Higher K fertilization (Fig. 1, treatments 7–9) resulted in a similar but smaller change in dry matter losses compared to N fertilization. High K fertilization gave the lowest dry matter content at harvest and a further reduction in the stored tubers.

A considerable increase in reducing sugars after storage at 4 °C was observed (Fig. 1). The relative increase in fructose (B) was slightly higher than that of glucose, but changes in absolute values (A) were much lower. Thus increasing N fertilization (Fig. 1, treatments 1–3) lead to a decrease in the glucose and fructose levels at harvest, and to decreasing effects on glucose and somewhat increasing effects on fructose accumulation in the stored potatoes. Increasing N fertilization gave an overall relative increase in the amounts of reducing sugars in the stored tubers.

The levels of sucrose were reduced by a mean of 90.8% from the original values at harvest (Fig. 2). Whereas there was no direct effect of varying P and K fertilization, increasing N gave a slight reduction in the loss of sucrose in the stored tubers.

Ascorbic acid was reduced by about 50%, largely independent of fertilizer treatments, but after high N fertilization a slight increase in losses of ascorbic acid was observed during 6 months' storage (Fig. 2, treatments 1–3). Citric acid levels

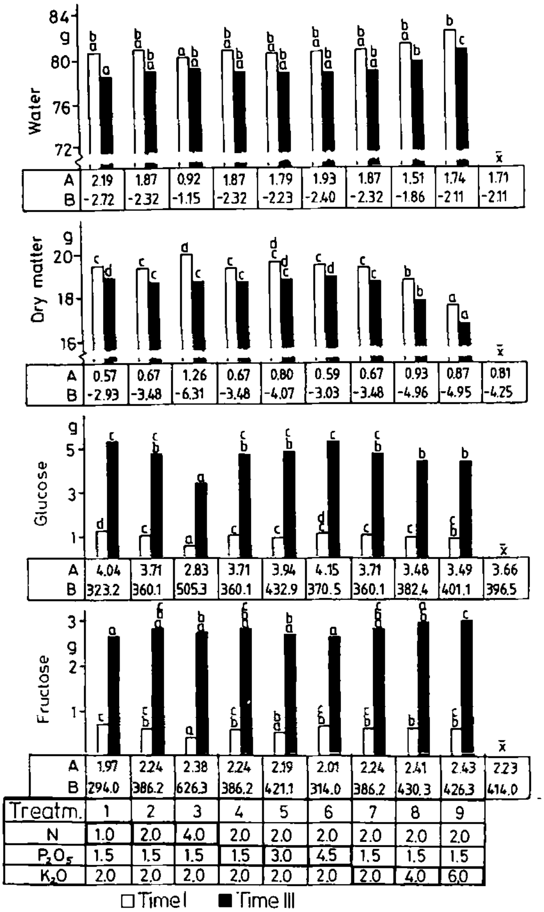


Fig. 1. Effect of NPK fertilization (g/pot) of pot-grown plants on chemical composition of tubers (g/100 g) at harvest (time I), and after 6 months storage at 4 °C (time III). Water and dry matter based on fresh weight, reducing sugars on dry weight. Data from 1982.
(A = change in absolute values; B = relative values, time I = 100%. Small letters indicate statistical differences for $p \leq 0.05$).

varied relatively independently of the NPK treatments, and were reduced by a fairly constant amount of 0.4 g during storage. Relatively high original values were reduced to a smaller extent than relatively low values.

The nitrate content of the tubers changed little compared with the other compounds throughout storage, but was greatly increased by increasing N fertilization (Fig. 2, treatments 1–3) and slightly influenced by K fertilization (treatments 7–9). This effect of nitrogen was also observed in the field trials (Fig. 4).

Field trials. Weight losses and chemical changes were somewhat smaller in the tubers from field trials (Table 1). Except for citric acid the results of both trials were in close

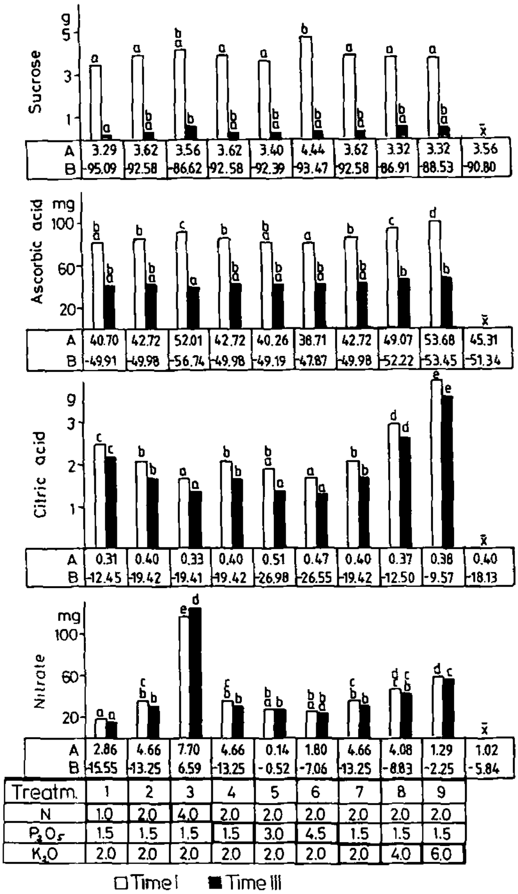
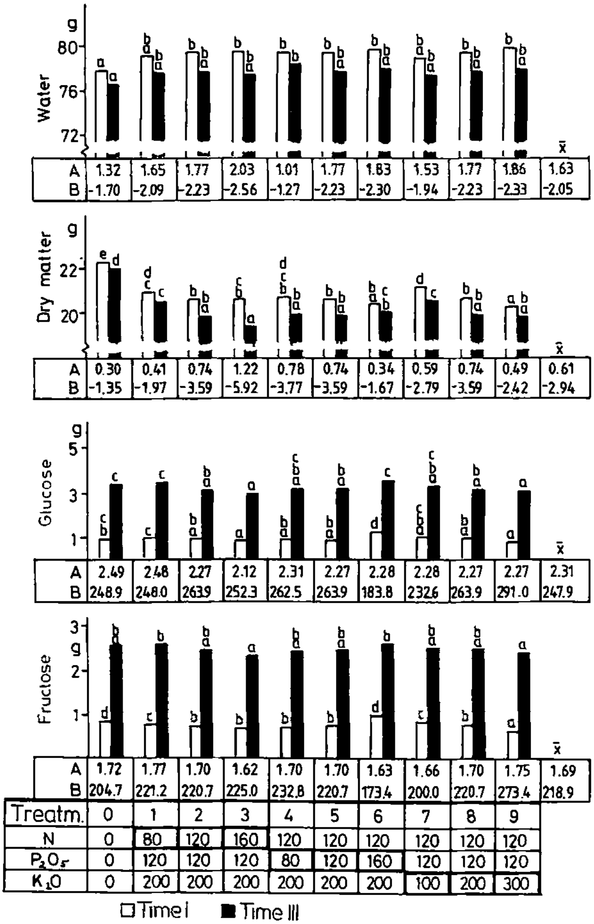


Fig. 2. Effect of NPK fertilization (g/pot) of pot-grown plants on chemical composition of tubers (g or mg/100 g DM) at harvest (time I), and after 6 months storage at 4 °C (time III). Data from 1982.
(A = change in absolute values; B = relative values, time I = 100%. Small letters indicate statistical differences for $p \leq 0.05$).

agreement. Figures 3–4 show the effects of fertilizer treatments on changes in tuber composition during storage, in the 1982 season.

Water loss during storage was higher for field-grown potatoes, which lost more water as the nitrogen supply was increased (Fig. 3, treatments 0–3). Dry matter decreased at harvest with increasing N fertilization, as did relative losses during storage. The effects of nitrogen on dry matter during storage were similar for pot- or field-grown tubers; however, the degree of change of the analyzed compounds appeared to be larger in the pot-grown tubers.

Apart from citric acid, the effect of NPK fertilization was similar in both pot and



Water	0	1	2	3	4	5	6	7	8	9	x̄
A	1.32	1.65	1.77	2.03	1.01	1.77	1.83	1.53	1.77	1.86	1.63
B	-1.70	-2.09	-2.23	-2.56	-1.27	-2.23	-2.30	-1.94	-2.23	-2.33	-2.05

Dry matter	0	1	2	3	4	5	6	7	8	9	x̄
A	0.30	0.41	0.74	1.22	0.78	0.74	0.34	0.59	0.74	0.49	0.61
B	-1.35	-1.97	-3.59	-5.92	-3.77	-3.59	-1.67	-2.79	-3.59	-2.42	-2.94

Glucose	0	1	2	3	4	5	6	7	8	9	x̄
A	2.49	2.48	2.27	2.12	2.31	2.27	2.28	2.28	2.27	2.27	2.31
B	248.9	248.0	263.9	252.3	262.5	263.9	183.8	232.6	263.9	291.0	247.9

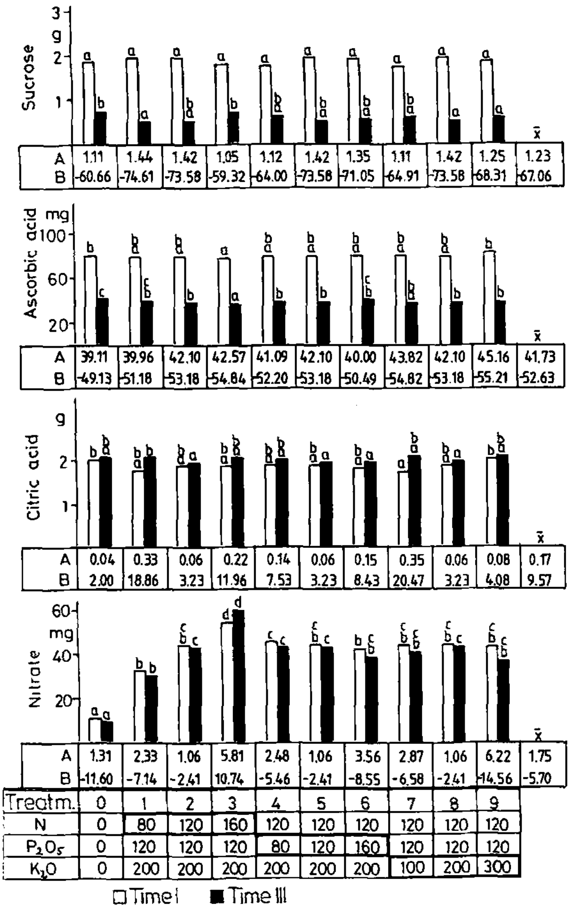
Fructose	0	1	2	3	4	5	6	7	8	9	x̄
A	1.72	1.77	1.70	1.62	1.70	1.70	1.63	1.66	1.70	1.75	1.69
B	204.7	221.2	220.7	225.0	232.8	220.7	173.4	200.0	220.7	273.4	218.9

Treatm.	0	1	2	3	4	5	6	7	8	9
N	0	80	120	160	120	120	120	120	120	120
P_2O_5	0	120	120	120	80	120	160	120	120	120
K_2O	0	200	200	200	200	200	200	100	200	300

Fig. 3. Effect of NPK fertilization (kg/ha) under field conditions on chemical composition of tubers (g/100 g) at harvest (time I), and after 6 months storage at 4 °C (time III). Water and dry matter based on fresh weight, reducing sugars on dry weight. Data from 1982. (A = change in absolute values; B = relative values, time I = 100%. Small letters indicate statistical differences for $p \leq 0.05$).

field experiments. The amount of citric acid in pot-grown tubers decreased during storage but increased in field-grown material (Figs 2 and 4). Changes in sugar content were smaller in field-grown tubers. N fertilization gave reduced glucose and fructose contents at harvest and increased reducing sugar accumulation during storage (Fig. 3, treatments 0–3).

At low N the original mean amount of glucose was 1.00 g per 100 g DM (Fig. 3, treatment 1). Increasing N to 160 kg ha^{-1} reduced the glucose by 0.16 g (treatment 3) at time I. After 6 months of storage treatment 1 gave 3.48 g. The mean glucose content in this trial increased by about 2.3 g after 6 months storage, while N



		0	1	2	3	4	5	6	7	8	9	x̄
Sucrose	A	1.11	1.44	1.42	1.05	1.12	1.42	1.35	1.11	1.42	1.25	1.23
	B	-60.66	-74.61	-73.58	-59.32	-64.00	-73.58	-71.05	-64.91	-73.58	-68.31	-67.06
Ascorbic acid	A	39.11	39.96	42.10	42.57	41.09	42.10	40.00	43.82	42.10	45.16	41.73
	B	-49.13	-51.18	-53.18	-54.84	-52.20	-53.18	-50.49	-54.82	-53.18	-55.21	-52.63
Citric acid	A	0.04	0.33	0.06	0.22	0.14	0.06	0.15	0.35	0.06	0.08	0.17
	B	2.00	18.86	3.23	11.96	7.53	3.23	8.43	20.47	3.23	4.08	9.57
Nitrate	A	1.31	2.33	1.06	5.81	2.48	1.06	3.56	2.87	1.06	6.22	1.75
	B	-11.60	-7.14	-2.41	10.74	-5.46	-2.41	-8.55	-6.58	-2.41	-14.56	-5.70

Treatm.	0	1	2	3	4	5	6	7	8	9
N	0	80	120	160	120	120	120	120	120	120
P_2O_5	0	120	120	120	80	120	160	120	120	120
K_2O	0	200	200	200	200	200	200	100	200	300

Fig. 4. Effect of NPK fertilization (kg/ha) under field conditions on chemical composition of tubers (g or mg/100 g DM) at harvest (time I), and after 6 months storage at 4 °C (time III). Data from 1982.
(A = change in absolute values; B = relative values, time I = 100%. Small letters indicate statistical differences for $p \leq 0.05$).

fertilization decreased it by about 0.52 g. The different levels of reducing sugars at harvest and after storage resulted in a variation in the glucose/fructose ratio in the stored tubers, especially in pot-grown material (Table 2). Storage at 4 °C led to a higher relative increase in the glucose concentration compared to fructose. The relative values varied more at storage time III than at time I, because the mean glucose contents at harvest were higher than fructose and also because glucose accumulation from relative high initial values is greater than from lower values. Fructose levels varied inversly to those of glucose (Table 2).

Table 2. Effect of NPK fertilization on the glucose/fructose ratio (fructose = 1.0) at harvest (time I) and after 6 months storage (time III) (Averages of 2 cultivars and 2 locations; data from Figures 1 and 3).

	Treatment[a]									
	0	1	2	3	4	5	6	7	8	9
Pot trials										
Time I	-	1.87	1.78	1.47	1.78	1.75	1.75	1.78	1.63	1.53
Time III	-	2.02	1.69	1.23	1.69	1.80	2.00	1.69	1.48	1.45
Field trials										
Time I	1.17	1.25	1.12	1.17	1.21	1.12	1.32	1.18	1.12	1.22
Time III	1.33	1.36	1.27	1.27	1.32	1.27	1.38	1.31	1.27	1.28

[a] See Figures 1 - 4.

Discussion

Even under optimal storage conditions, considerable changes in chemical composition and in respirational losses occur (cf. Burton, 1978, 1982; Grassert et al., 1984). Storage at 4 °C leads to minimal losses through sprouting, respiration and tuber rot (Burton 1966, 1982; Boe et al., 1974; Stricker, 1985).

Between 75 and 85% of the relative variation in tuber weight, sugar and ascorbic acid levels are explained by storage conditions and only 1–5% by differences in NPK application (Kolbe, 1990). For other parameters such as dry matter, citric acid and nitrate, 40–50% of the variation can be explained by fertilization and only a minor proportion directly by the storage conditions. Fertility conditions throughout the growing period have a pronounced influence on the storage behaviour of the tubers, particularly in relation to dry matter losses.

High N fertilization resulted in an increase in weight loss during storage, as reported by Fehmi (1933), Bömig et al. (1975) and Zgorska & Frydecka-Mazurczyk (1977). In contrast, high P fertilization gave a reduction in weight loss.

Dry matter losses of tubers grown in the hot summer of 1982 reached a mean value of 0.71% per month of storage from pot trials and 0.49% per month from tubers grown in the field (see Figs 1 and 3). According to Iritani et al. (1977), a warm climate leads to higher weight losses throughout storage. But after increasing N nutrition the following results were obtained (see Kolbe, 1990; Fig. 3). No fertilization led to a mean N concentration of 1.40% DM of the tubers and relative dry matter losses of 0.23% during storage. Applying 80 kg ha^{-1} of nitrogen gave 1.55% N in the DM, and the relative dry matter losses increased to 0.33% per month. These losses are similar to those found by Burton (1982) of 0.3% per month. Applying 120 kg ha^{-1} of nitrogen gave 1.7% N and a loss of 0.60%; 160 kg N ha^{-1} (1.90% N in DM) gave a relative loss of 0.99% DM per month.

Although these experiments showed that increasing K fertilization increased weight losses during storage, as did Berkner & Schlimm (1933), others have reported a decrease (Amberger, 1968 cit. by Mengel, 1969). Weight losses after increasing K fertilization are mainly caused by loss of water, for the dry matter and starch content are not much affected (Rogozinska & Pinska, 1991).

Although reducing sugar concentrations were relatively low both at harvest and after storage following high N and high K fertilization, their relative accumulation, especially of fructose, was higher than in tubers from low N-, K- and high P-fertilized plots. Increasing P nutrition gave an increase of reducing sugars at harvest and very high sugar contents after storage (especially glucose), but the lowest accumulation rates, especially of fructose. Zgorska & Frydecka-Mazurczyk (1977) and Putz (1978) found no relationship between N fertilization and sugar accumulation throughout storage. Stricker (1974) and Hughes & Fuller (1984) found that sugar enrichment in high N-fertilized tubers was only high if they were stored at relatively low temperature. Storage at higher temperature often reduces sugar accumulation because of higher rates of starch resynthesis or respiration.

Low storage temperatures lead to a lower enrichment of fructose than glucose (Arreguin-Lozano & Bonner, 1949; Samotus et al., 1974; Mica, 1977). Our results disagree, for 4 °C storage gave a higher mean accumulation of fructose. In contrast, only high P nutrition gave a relatively high glucose accumulation. The glucose/fructose ratio is also influenced by variety, weather conditions late in the season until harvest and date of harvest, as reported by Miller et al. (1975) and Mica (1977). Cultivars with a relatively low percentage of glucose are preferable for making fried products, because glucose causes a more intensive Maillard reaction than fructose (cf. Weaver & Timm, 1983; Sachs et al., 1988).

The decrease in the ascorbic acid is subject to what is known as a "self-dynamic process", which can be calculated by the use of logarithmic functions (Saguy et al., 1978; Nour, 1979). Thus using data from Polensky (1979) the time during which 50% of ascorbic acid is lost is 180 days for potatoes. This value is comparable to our results.

Ascorbic acid and sucrose behave similarly, for high N fertilization reduces losses on storage. Tubers over-fertilized with nitrogen, as well as unfertilized tubers (which mature earlier) showed comparably high sucrose values after 6 months' storage.
A minor reduction in sucrose was observed in stored tubers in 1981 (Kolbe, 1990), whereas the high temperatures in 1982 reduced starch synthesis and increased sucrose concentrations (Kolbe, 1994). Throughout storage, the sucrose level is then quickly reduced to a medium level of 0.6–0.65% DM in pot- and field-grown tubers (see Table 1). Reducing sugars accumulated to a greater extent in stored tubers from the warm year 1982 compared to the cooler 1981 (Kolbe, 1990). Grassert et al. (1984) found sugars accumulated more when tubers were grown under higher precipitation and in cool climates late in the season.

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