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The sugar content and sprout growth of tubers of potato cultivar Record, grown in different localities, when stored at 10, 2 and 20°C

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Summary

Mature tubers, from 13 centres between 211 and 837 km N of 50° N, were stored at 10° C in 1966 and 1967, and always showed an initial rise in reducing sugar. In 1966 this obliterated the effect of latitude upon sugar content. At harvest, 20 crops had a sugar content acceptable for processing. A few weeks later only 2 were acceptable. The increased sugar decreased on transfer to 20° C, the samples behaving similarly, and thus showing no effect of latitude of growing centre after 'conditioning'. Such treatment, being slow, would be commercially practicable only if the desired changes were small. The start of sprout growth at 10° C, and accompanying start of carbohydrate mobilization, showed no effect of latitude. Nor did the amount of sugar accumulated at 2° C, despite a suggestion of an effect on initial rate of sweetening. The initial rate of subsequent de-sweetening at 20° C was positively correlated with the amount of accumulated sugar.

Introduction

The greater part of the potatoes used in the processing industry are potatoes from store. Their suitability depends not only upon their quality at harvest but upon their response to storage conditions. These last must be a compromise between the varying claims of avoiding low-temperature sweeting, senescent sweetening, rotting, water-loss and sprout growth. The latter is normally suppressed chemically but the difficulty and expense of effective control increases with the temperature. Rotting, water-loss and senescent sweetening are all encouraged by high storage temperatures, but below 10° C low-temperature sweetening can become a problem, the more so the lower the temperature. The normal compromise reached is to store potatoes for processing in the short term at 10° C. More prolonged storage is at 7–8° C, after initial wound-healing at a higher temperature, this being a compromise between the more rapid sprout growth and senescent sweetening at 10° C and the low-temperature sweetening at 5° C. If the sugar content after storage is too high to be acceptable, some adjustment is possible by storing the tubers at about 20° C. Such treatment should be as

brief as possible because of the dangers and losses associated with storage at this temperature.

The response to storage conditions is in part a varietal characteristic. For example, although there may be large differences in the amount of sugar accumulated at a low temperature by the tubers of any one cultivar in different years, the ranking of cultivars in this respect remains much the same from year to year (van Vliet & Schriemer, 1960; Rønsen & Frogner, 1969). It is in fact possible to breed potato varieties which will give acceptable fried products immediately after taking from 4 C storage (Lauer & Shaw, 1970).

Apart from varietal differences in the response to storage conditions, differences between samples, perhaps resulting from different growing conditions, might be expected. The work on the apparent effect of latitude of cultivation on the sugar content of potatoes, reported previously (Burton & Wilson, 1970), provided the opportunity to store several samples of the same cultivar, grown under normal commercial conditions, from the same stock of seed tubers, but in widely different locations. The original intention was to carry out a comprehensive study of storage behaviour, but the closing of the Ditton Laboratory in 1968 for work other than on top fruit, with consequent loss of reliable constant temperature facilities, and the transfer of staff to other work, precluded this. The present paper thus relates only to changes in the content of sugar, and to sprout growth, during storage at 10 C in two years, and to one preliminary experiment on sweetening and de-sweetening. The results, however, are of sufficient interest to be reported, particularly those relating to storage at 10 C.

Material and methods

In 1966 and 1967 the cv. Record was grown at 15 centres distributed between 211 and 837 km N of 50° N, certified stock seed from the same crop being used at each centre. Details are given in Burton & Wilson (1970). At the final lifting date (Sept.–Oct.) about 100 kg of tubers were taken to the Ditton Laboratory from each of 13 of the centres* and stored in a constant temperature room at 10 C. The sugar content of 20-tuber samples was determined at intervals during storage at this temperature until 24 May 1967 (1966 crop) and 4 June 1968 (1967 crop). Methods of sub-sampling, extraction and analysis were as described by Burton (1969).

On 25 January 1967, 200 tubers from each centre (1966 crop) were placed at 2 C and 100 tubers at 20 C, 20-tuber samples of these being analysed at intervals until 24 May. 60 tubers were placed at 20 C from 2 C on 7 March to de-sweeten, three 20-tuber samples being analysed during the ensuing 4 weeks. The tubers remaining at 2 C on 24 May were also placed at 20 C to de-sweeten and analysed twice during the ensuing 4 weeks. By this time some of the samples stored for the whole time at 10 C were showing signs of senescent sweetening. Those remaining after the

* In each year two growers harvested the experimental rows with the commercial crop in which they were included, and the produce was thus lost.

analysis on 24 May were transferred from 10 to 20°C and analysed twice in the following 12 days.

Sprouting occurred during storage and the tubers were desprouted before analysis, the sprouts being weighed to provide information on possible differences in sprouting behaviour.

Results and discussion

Sugar content during initial storage at 10°C

Apart from any regional differences in sugar content, Burton & Wilson (1970) noted a number of general trends during tuber development. These included a fall in the content of surcrose throughout tuber growth; a fall in the reducing sugar/sucrose ratio to a minimum of around 0.2 in the middle of the tuber growing period, followed by a rise to a value which could be greater than 1.0 at maturity; and a content of reducing sugars which also fell to a minimum about the middle of the tuber growing period, there being quite frequently, thereafter, a tendency for a slight rise as maturity was approached. These general trends continued after harvest, during the first few weeks of storage at 10°C, as shown in Tables 1 and 2.

The increase in the content of reducing sugars is of particular interest. An increase also occurs in freshly harvested immature tubers, but this appears to be at the expense of the sucrose (see e.g. Burton, 1965), the total content of sugar remaining much the same. In our results with mature tubers, illustrated in Tables 1 and 2, there was an increase in the total content of sugar, although there was some decrease in sucrose and a considerable increase in the reducing sugar/sucrose ratio. This reached a peak, some 5 times greater than the value at harvest, early in the storage season, and thereafter declined.

The conclusion of Burton & Wilson (1970) as to the increase in the content of reducing sugars during the latter part of the growing period was rather tentative, and the increase was not always noticeable except in the far north. There was even perhaps the possibility that it could have been attributed to a local spell of cold weather about the time of harvest. The increase in the harvested tubers stored at 10° is, however, beyond doubt, and suggests that there is a real trend towards a higher content of reducing sugars starting, though almost unnoticeably, about the middle, and accelerating towards the end, of the growing season, and continuing during the first few weeks of storage.

Rønsen & Frogner (1969) noticed similar rises in reducing sugar in tubers placed at 7°C after harvest. It has often been assumed that these were entirely due to slight low-temperature sweetening, and if that fully mature potatoes with a low content of reducing sugars are harvested and stored at 10°C then the low content is maintained. Barker (1950) in fact had noted, in experimental samples of cv. King Edward, an increase in the content of reducing sugars, during the first four weeks at 10°C, from 50 to 230 mg/100 g fresh weight. This observation is fully confirmed by our results. In every case, in our experiments, there was a marked increase in the content of re-

Table 1. Changes in the content of sugar during storage of mature tubers, cv. Record, at 10°C, 1966–1967.

Location of growing centre, km N of 50° N[1]		Content of reducing (RS) or non-reducing (NRS) sugar (mg/100 g F.W.)[3]													
		211	213	217	345	356	359	458	464	654	655	831	833	837	Av.
At harvest*[2]	RS:	39	30	48	35	19	59	76	48	171	86	184	187	125	85
	NRS:	95	126	78	85	118	118	113	143	129	137	129	127	100	115
25.1.67	RS:	192	187	287	309	220	288	297	200	268	194	247	259	221	244
	NRS:	72	67	35	84	65	116	88	95	64	77	91	55	34	73
8.2.67	RS:	–	211	357	247	272	–	372	270	261	146	229	299	290	269
	NRS:	–	96	84	87	117	–	124	112	100	64	59	94	70	92
21.2.67	RS:	172	172	190	213	218	233	261	173	203	178	226	254	205	208
	NRS:	59	86	50	66	99	82	94	51	195	99	68	66	80	84
7.3 67	RS:	146	120	194	181	145	232	219	221	225	162	221	143	211	186
	NRS:	47	41	65	57	51	93	66	51	83	71	50	24	26	56
21.3.67	RS:	172	128	217	178	156	204	194	220	277	177	261	186	288	204
	NRS:	71	88	80	48	85	142	94	112	75	89	85	41	78	84
24.5.67	RS:	129	101	145	139	158	186	260	191	238	139	233	215	213	181
	NRS:	87	152	123	113	216	242	154	79	126	111	51	57	95	124

* Various dates from 1 September to 19 October – *Verschiedene Daten vom 1. September bis 19. Oktober – Différentes dates du 1er septembre au 19 octobre.*

[1] *Lage des Anbauzentrums, km N des 50.° N – Localisation du centre de culture, km au nord du 50e de latitude nord;* [2] *Bei der Ernte – A la récolte;* [3] *Gehalt an reduzierenden (RS) oder nichtreduzierenden (NRS) Zuckern, mg/100 g F.G. – Teneur en sucres réducteurs (SR) et non réducteur (NRS), mg/100 g de matière fraîche.*

Tabelle 1. Aenderungen im Zuckergehalt während der Lagerung von reifen Knollen der Sorte Record bei 10 °C, 1966–1967.

Tableau 1. Evolution de la teneur en sucres durant le stockage de tubercules mûrs, variété Record, à 10 °C, 1966–1967.

ducing sugars during the early part of the storage period. This would have had practical implications for the processor. If he purchased potatoes with the low content of reducing sugars which he regarded as desirable, and stored them at 10°C, they could have had a much higher content within a few weeks. In our experiments, if we take 0.1% of reducing sugar as being the limit of acceptability, then at the time of harvest 20 out of 26 samples were acceptable; but at the time of the first analysis of stored samples only 2 out of 25 were acceptable (Table 3). If a less stringent standard were adopted, 0.25% of reducing sugar being taken as the limit of acceptability, then all the freshly harvested samples, and 16 of the 25 stored samples would have been acceptable.

In the case of the 1966/67 results it could be objected that, as will be mentioned later, sprout growth had already started at the time of the first analyses (Table 5) and the sweetening could have been related to this. This objection does not apply

Table 2. Changes in the content of sugar during storage of mature tubers, cv. Record, at 10 C, 1967–1968.

Location of growing centre, km N of 50 N[1]		Content of reducing (RS) or non-reducing (NRS) sugar (mg/100 g F.W.)[3]													
		211	213	217	344	360	458	469	654	655	659	831	833	837	Av.
At harvest*[2]	RS:	26	43	32	82	61	54	32	30	20	63	121	67	114	57
	NRS:	112	146	118	169	122	102	178	104	127	107	130	108	101	125
22.11.67	RS:	118	122	89	–	198	132	137	150	68	198	335	273	364	168
	NRS:	67	73	67	–	84	61	112	79	68	50	68	74	40	70
18.12.67	RS:	152	82	55	180	130	107	100	122	79	267	227	177	255	149
	NRS:	77	64	52	135	86	80	72	61	64	41	94	45	70	72
12.2.68	RS:	109	68	64	109	71	85	74	124	77	194	304	194	232	136
	NRS:	73	79	102	77	79	74	77	74	104	67	95	51	67	78
18.3.68	RS:	104	97	64	92	115	112	116	203	79	183	279	204	211	143
	NRS:	65	86	89	106	56	79	72	119	126	81	130	82	59	88
8.4.68	RS:	87	66	92	60	134	126	117	109	67	202	225	216	252	139
	NRS:	87	90	141	101	121	113	92	99	157	76	75	114	115	106
6.5.68	RS:	127	74	60	56	98	116	111	135	58	258	242	215	284	141
	NRS:	119	127	145	133	111	137	142	166	133	148	157	116	153	137
4.6.68	RS:	115	80	59	86	93	70	158	125	60	210	341	218	315	148
	NRS:	118	208	183	170	151	237	170	212	276	158	205	198	267	196

* Various dates from 12 September to 18 October – *Verschiedene Daten vom 12. September bis 18. Oktober – Différentes dates du 12 septembre au 18 octobre.*

[1, 2, 3] *Siehe Tabelle 1 – Voir tableau 1.*

Tabelle 2. Aenderungen im Zuckergehalt während der Lagerung von reifen Knollen der Sorte Record bei 10 C, 1967–1968.

Tableau 2. Evolution de la teneur en sucres durant le stockage de tubercules mûrs, variété Record, à 10 C, 1967–1968.

to the 1967/68 results. In this year the first analyses were done two months earlier and sprout growth had not started (Table 6).

As an indication of the general applicability to other cultivars of the above obser-observations on cv. Record, the results of analyses of single 20-tuber samples of five cultivars grown together on trial plots at East Craigs, Scotland, are given in Table 4. It will be noticed from this table, as well as from Tables 1 and 2, that the increase in reducing sugars had taken place by the time of the first analyses of stored tubers and had thus occurred during the first one or two months following harvest, and prior to the start of sprout growth (Table 7).

As shown in Tables 1 and 2, the changes in sugar content which may occur during the early weeks of storage at 10 °C are variable, and, as we have seen, can result either in tubers which are still acceptable for processing, even if the most stringent criteria are applied, or in tubers which are totally unacceptable. It would be important to relate this variable behaviour to some characteristic which is determinable at harvest.

Table 3. Number of samples, cv. Record, having a content of reducing sugars within specified limits at the time of harvest and at intervals during storage at 10 °C.

Crop season[1]	Date of analysis[2]	Number of samples at a content of reducing sugars (% of F.W.) of:[3]		
		< 0.1	0.1–0.25	> 0.25
1966	At harvest*[4]	9	4	0
	25.1.67	0	7	6
	8.2.67***	0	4	7
	21.2.67	0	11	2
	7.3.67	0	13	0
	21.3.67	0	10	3
	24.5.67	0	12	1
1967	At harvest**	11	2	0
	22.11.67***	2	7	3
	18.12.67	3	8	2
	12.2.68	6	6	1
	18.3.68	4	8	1
	8.4.68	5	7	1
	6.5.68	5	6	2
	4.6.68	6	5	2

* Various dates – *Verschiedene Daten – Différentes dates* 1.9–19.10.
** Various dates – *Verschiedene Daten – Différentes dates* 12.9–18.10.
*** Smaller number of samples because of loss during analysis – *Wegen Verlust während der Analyse kleinere Anzahl Muster – Plus petit nombre d'échantillons à cause de pertes durant les analyses.*

[1] *Jahr – Année de culture;* [2] *Datum der Analysen – Date des analyses;* [3] *Anzahl Muster bei einem Gehalt an reduzierenden Zuckern (in % des Frischgewichtes) von – Nombre d'échantillons à un teneur en sucres réducteurs (en % de la matière fraiche) de;* [4] *Bei der Ernte – A la récolte.*

Tabelle 3. Anzahl Muster der Sorte Record, die zur Zeit der Ernte und in Intervallen während der Lagerung bei 10 °C einen Gehalt an reduzierenden Zuckern innerhalb der aufgeführten Grenzen aufwiesen.
Tableau 3. Nombre d'échantillons, variété Record, classés en fonction de leur teneur en sucres réducteurs sans spécification de durée entre la récolte et la conservation à 10 °C.

We have not found this possible from our data, although if the 1967/68 results alone are considered, there might appear to be some prospect of it in that there was a positive relationship, significant at the 0.1% level ($r = 0.946$), between reducing sugar content at harvest and after storage for a few weeks. The relationship was still highly significant ($r = 0.857$) in February, when sprout growth was appreciable (Table 5). By contrast the 1966/67 results showed no such relationship, and reducing sugar content at harvest thus provides no reliable basis for predicting the content which will be found after storage for a few weeks or months at 10 °C.

It follows from the above that the apparent effect of latitude upon sugar content,

Table 4. Changes in the content of sugar, during storage at 10°C, of mature tubers of five cultivars, 1967–1968.

Date of analysis[1]	Content of reducing (RS) or non-reducing (NRS) sugar (mg/100 g fresh wt.)[2]									
	Bintje		Monona		Orion		Record		Woudster	
	RS	NRS	RS	NRS	RS	NRS	RS	NRS	RS	NRS
5.10.67 (harvest)[3]	63	127	30	81	49	76	30	129	35	119
22.11.67	164	112	137	186	155	43	134	60	95	115
18.12.67	119	87	72	144	104	37	146	80	93	115
12.2.68	142	134	74	122	74	97	107	97	130	138
18.3.68	109	107	44	66	95	76	113	100	136	158
8.4.68	172	134	26	83	130	116	134	160	104	115
6.5.68	113	126	36	111	180	175	121	205	140	154
4.6.68	138	187	–	–	159	190	100	313	91	278

[1] *Datum der Analysen – Date des analyses;* [2] *Gehalt an reduzierenden (RS) oder nicht-reduzierenden (NRS) Zuckern (mg/100 g Frischgewicht) – Teneur en sucres réducteurs (RS) ou non-réducteurs (NRS) (mg/100 g de matière fraîche);* [3] *Ernte – Récolte.*

Tabelle 4. Aenderungen im Zuckergehalt während der Lagerung von reifen Knollen von fünf Sorten bei 10 C, 1967–1968.
Tableau 4. Evolution de la teneur en sucres, durant le stockage à 10 C, de tubercules mûrs de cinq variétés, 1967–1968.

Table 5. Sprout growth on samples of the 1966 crop, cv. Record, during storage at 10 C.

Growing centre[1] km N of 50 N	Sprout growth (% w/w)[2]					
	25 Jan	8 Feb	21 Feb	7 Mar	21 Mar	24 May
211	1.56	2.31	2.79	3.89	4.89	12.70
213	0.09	1.34	1.56	1.93	2.83	9.99
217	0.15	2.16	3.44	3.77	5.55	13.26
345	0.69	1.75	1.18	1.68	2.43	9.95
356	0.70	1.20	1.93	1.36	3.88	13.42
360	1.02	1.14	1.88	2.72	3.16	13.66
458	0.87	1.66	2.34	2.24	3.35	11.98
464	0.58	0.95	1.38	1.85	2.67	11.36
654	0.71	1.45	1.66	2.57	3.51	12.54
655	0.74	1.27	1.63	2.33	2.92	12.24
831	0.44	1.24	1.29	1.37	2.18	7.86
833	0.64	0.95	1.35	1.73	2.40	7.85
837	0.50	0.85	0.88	1.53	2.12	8.98
Average[3]	0.67	1.41	1.79	2.23	3.22	11.21

[1] *Anbauzentrum – Centre de culture;* [2] *Keimwachstum, Gew. % – Croissance des germes, % en poids;* [3] *Mittel – Moyenne.*

Tabelle 5. Keimwachstum an Mustern der Ernte 1966, Sorte Record, während der Lagerung bei 10 C.
Tableau 5. Croissance des germes des lots cultivés en 1966, variété Record, durant le stockage à 10 C.

Table 6. Sprout growth on samples of the 1967 crop, cv. Record, during storage at 10 C.

Growing centre[1] km N of 50° N	Sprout growth (% w/w)[2]						
	22 Nov	18 Dec	12 Feb	18 Mar	8 Apr	6 May	4 Jun
211	–	0.45	2.46	2.55	4.42	6.91	9.00
213	–	0.16	1.17	1.90	3.88	7.25	11.09
217	–	0.66	2.25	4.27	8.00	7.56	13.83
344	–	0.05	1.92	3.60	5.48	8.53	11.93
359	–	0.18	1.07	1.94	4.43	7.92	12.93
458	–	0.14	2.04	4.21	6.13	9.97	16.73
469	–	0.01	0.71	1.57	4.86	6.95	13.77
654	–	0.07	0.79	2.23	3.92	7.78	8.66
655	–	0.23	1.55	3.75	6.25	4.85	7.04
659	–	0.09	1.62	2.94	4.20	5.31	8.83
831	–	0.07	0.82	1.77	3.04	5.97	8.18
833	–	0.09	0.90	1.66	4.38	5.86	12.28
837	–	0.10	1.05	1.73	6.08	5.41	10.31
Average[3]	–	0.18	1.41	2.62	5.01	6.94	11.12

[1, 2, 3] *Siehe Tabelle 5 – Voir tableau 5.*

Tabelle 6. Keimwachstum an Mustern der Ernte 1967, Sorte Record, während der Lagerung bei 10 C.
Tableau 6. Croissance des germes des lots cultivés en 1967, variété Record, durant le stockage à 10 C.

Table 7. Sprout growth during storage at 10 C on mature tubers of five cultivars, 1967–1968.

Date[1]	Sprout growth (% w/w)[2]				
	Bintje	Monona	Orion	Record	Woudster
22.11.67	–	–			
18.12.67	0.18	0.41	–	0.19	0.04
12.2.68	1.07	2.60	0.38	1.89	1.31
18.3.68	2.44	4.41	1.21	4.26	3.70
8.4.68	3.53	7.52	3.17	7.12	6.03
6.5.68	7.75	7.51	6.70	10.21	8.46
4.6.68	10.36	–	10.10	14.08	15.02

[1] *Datum – Date;* [2] *Keimwachstum (Gew. %) Croissance des germes (% en poids).*

Tabelle 7. Keimwachstum während der Lagerung bei 10 C an reifen Knollen von fünf Sorten, 1967–1968.
Tableau 7. Croissance des germes durant le stockage à 10 C de tubercules mûrs de cinq variétés, 1967–1968.

demonstrated during growth and at maturity by Burton & Wilson (1970), need no longer be operable a few weeks after harvest. In 1967/8 the effect, though not so marked at harvest as in 1966/7, was still noticeable 5-10 weeks later (Table 2). In 1966/7, the original highly significant effect was completely obliterated by the uncorrelated sweetening which occurred during storage. The six samples with more than 0.25% reducing sugar in January 1967 originated from 217, 345, 359, 458, 654 and 833 km N of 50° N, covering almost the whole range of latitude included in the experiment (Table 1). We can offer no explanation of the different behaviour in the two years.

Sugar content during prolonged storage at 10° C

The increase in sugar content, noted above as occurring at 10° C during the first few weeks after harvest, did not continue. In many cases the maximum value had been reached by the time of the first analysis of stored samples, although in a number of samples of the 1966 crop some further sugar accumulation occurred until February. During more prolonged storage there was a slow fall in the content of sugar, although that of reducing sugar never fell to the value found at harvest and often remained as a multiple of that amount (Tables 1 and 2). Late in the storage season, though sometimes as early as late March, this fall was replaced by a rise, particularly in non-reducing sugar, characteristic of the start of senescent sweetening. This will be discussed in more detail below.

If we consider the sugar changes during prolonged storage at 10° C in terms of their effect upon suitability for processing, then there was an improvement after the initial deterioration, though not to the quality at the time of harvest (Table 3). This improvement could well not occur under commercial conditions where sprouting is suppressed (see below).

Senescent sweetening and sprout growth at 10° C

It is a well-established fact that potato tubers sweeten after prolonged storage at temperatures higher than those at which low-temperature sweetening occurs (Barker, 1938; van Vliet & Schriemer, 1963; Burton, 1965; Isherwood & Burton, 1975). This senescent sweetening starts earlier and is more rapid the higher the storage temperature, and varies with the cultivar. It is rarely such as to be of practical importance in potatoes stored in simple farm stores at temperatures up to 10° C. There have been suggestions that senescent sweetening could be related to sprout growth (Huelin & Barker, 1939; van Vliet & Schriemer, 1963; Burton, 1965) but this was not certain in that the timing of the two phenomena is not obviously correlated - sweetening occurs at a variable time after the start of growth, sometimes considerably later, as illustrated by our results. Burton (1977) demonstrated, however, that in fact the mobilization of carbohydrate, which is responsible for the sweetening, always starts soon after the start of growth. It gives rise to sweetening only when the demands of sprout growth fall below the rate of mobilization. This occurs at a variable time after the start of growth because in different samples and cultivars the rates of both mobili-

zation and growth may vary. Although the start of carbohydrate mobilization is related to the start of growth, the continuation of mobilization does not depend upon the continuation of growth - it continues (though probably at a lower rate), and accelerates with time, even if growth is suppressed or the sprouts are removed manually (van Vliet & Schriemer, 1963; Isherwood & Burton, 1975). In such cases, because of the lack of demand from growing sprouts, there is an increase in the content of sugar above that present if sprouting were allowed to occur (van Vliet & Schriemer, 1963; Burton, 1965; Isherwood & Burton, 1975). The increase is mainly in the content of sucrose, but there may often be a sufficient rise in the content of reducing sugars to present a commercial problem.

In our experiments, the sprouts were allowed to grow, and our results do not therefore give a direct measure of differences, which might have occurred in commercial practice, in the senescent sweetening of samples of different origin.

There was no real evidence of any marked difference in the time of the start of sprout growth on samples grown in different localities (Tables 5 and 6). In both years the samples from 211 km N of 50°N may have started to grow a week or so earlier than most of the others, as may the samples from 217 km N in 1967. Apart from this the effect of locality of growth appeared to be slight. The dating of the start of growth on tubers from the 1967 crop was more precise, in that the first observations were made before detectable growth had occurred, and it is probable that in every case growth started during the first half of December. The amount of sprout growth which subsequently occurred showed some variation. In so far as this was related to the origin of the tubers, growth in the early stages may have been rather slow on the samples from the far north, but similar patterns of growth could be found on tubers from other localities - for example from 213 km N in both years; from 345 km N and 464 km N in 1966; from 359 km N and 469 km N in 1967. Of the cultivars grown at East Craigs, Orion started to sprout appreciably later the others (Table 7).

The dry matter content of the sprouts, derived to a very large extent from sugars translocated from the tubers to the sprouts, was not determined. As a rough approximation, based on determinations in other experiments, we can assume it to have been about 10%. Carbohydrate mobilized in the tubers, consisting of the sugars in the tubers plus the dry matter of the sprouts, can thus be roughly estimated from the data in Tables 1, 2 and 4 in conjunction with Tables 5, 6 and 7. Such estimates give a much better measure of the activity of the sweetening system than do the increases in sugar content alone. If we consider the values for 1967/8, averaged over all the centres (Tables 2 and 6) then we can estimate an average nett mobilization of carbohydrate, over and above the demands of respiration, rising from 0.08 mg per 100 g per day between 22/11/67 and 18/12/67, when sprouting was just starting, to 16.69 mg per 100 g per day between 6/5/68 and 4/6/68.

We must add to this accumulated and translocated carbohydrate the amount consumed in respiration, amounting perhaps to about 5-10 mg per 100 g per day between 22/11/67 and 18/12/67, and possibly rising to 25-50 mg per 100 per day between 6/5/68 and 4/6/68 (cf. Isherwood & Burton, 1975). The sugar actually accumulated in the

tubers, at a rate averaging 2.3 mg per 100 g per day between 6/5/68 and 4/6/68, when accumulation was most marked, thus probably represents only about 4-5% of the carbohydrate mobilized during this period.

As mentioned above, van Vliet & Schriemer (1963) showed that, if sprouting is suppressed, mobilization of carbohydrate nevertheless occurs; and, because of the lack of demand in the form of sprout growth and accompanying enhanced respiration, sugar accumulates to a greater extent than if growth is allowed. Our results unfortunately can give no guide to the extent of the accumulation which would have occurred with sprout suppression. The quantitative relationship between mobilization in the presence or absence of growth is unknown, though it is certainly less if growth is suppressed. For example, in the experiments of Isherwood & Burton (1975), the total sugar content early in June was about 1.6% in untreated tubers, cv. Home Guard, compared with about 3% in manually de-sprouted tubers and 2.1% in CIPC-treated tubers which had not had a strictly comparable temperature regime. The differences would have been equivalent to the dry matter in about 14% and 5% by weight of sprouts respectively - quite possible figures considering the timing and nature of treatment received. The rate of respiration of the sprouting tubers was much greater however, the greater carbon loss in this being itself equivalent to a multiple of the carbon in the greater sugar accumulation in the treated tubers. Starch mobilization, not necessarily appearing as sugars, must therefore have occurred to a much greater extent in the sprouting tubers.

The conclusions which can be drawn from our data as to senescent sweetening in tubers stored with sprout suppression can thus only be tentative and qualitative: that sugar accumulation would have been much earlier and greater than in our samples; that the start of accumulation, linked to the start of sprout growth, would probably not have differed markedly in samples from the different growing centres; and that the degree of senescent sweetening could well have differed in samples from different growing centres, corresponding to the different potential for growth, as expressed by actual growth in our samples.

'Conditioning' at 20° C

The purpose of 'conditioning' is to improve precessing quality by lowering the content of reducing sugar. Whether or not sucrose is also decreased, or even increased by turn-over of sugar, is of minor importance unless it is present in excessive quantities. In our experiments, transfer from 10 to 20° C in January 1967 led in every case to a decrease in the content of reducing sugars. Curves fitted to plots of sugar content against time at 20° C for the crops from different growing centres revealed no real differences and tended to the same minimum level, which averaged 73 mg/100 g fresh weight after 17 weeks at 20° C. As a result, storage at 20° C, of crops which had a high content of reducing sugars at harvest, could result in contents lower than the original; while the contrary could be true for crops with a low original content. As an example we can quote the average results for two groups of centres, in mg reducing sugar/100 g fresh weight:

Centres 4, 5, 6, 345–359 km N of 50 N; at harvest, 38; on transfer to 20 C, 272; after 4 weeks at 20 C, 135.

Centres 13, 14, 15, 831–837 km N of 50 N; at harvest 165; on transfer to 20 C, 242; after 4 weeks at 20 C, 141.

The minimum values reached after 17 weeks at 20 C were, respectively, 70 and 77 mg/100 g.

Because of the similarity in the behaviour of the different samples, the general effect of transfer can be illustrated by average values (Table 8). A plot of these shows that although the content of reducing sugar decreased from the time of transfer to 20 C, it would have taken 30–40 days to decrease it to below 0.1 % from the original barely acceptable 0.24 %. The content of non-reducing sugar was unaffected until the last analysis, by which time it had markedly increased, typical of senescent sweetening. This increase may partly have been achieved by drawing upon the reducing sugars, which had decreased still more. The senescent sweetening illustrated would thus have had no adverse effect, even a beneficial effect, upon processing quality.

Curves of sugar content in relation to time at 20 C, plotted for the crops from the

Table 8. Changes in the content of sugar after transfer from 10 to 20 C, average of results from all centres.

Date[1]	Days after transfer[2]	Content of reducing (RS) or non-reducing (NRS) sugars (mg/100 g fresh weight)[3]				Sprout growth (% w/w)[6]	
		tubers remaining at 10 C[4]		tubers transferred to 20 C[5]		10 C	20 C
		RS	NRS	RS	NRS		
25.1.67	0	244	73	244	73	0.67	0.67
8.2.67	14	269	92	199	88	1.41	1.11
21.2.67	27	208	84	115	84	1.79	1.43
7.3.67	41	186	56	113	75	2.23	2.50
21.3.67	55	204	84	104	95	3.22	4.74
24.5.67	119	181	124	73	273	11.21	12.32
24.5.67	0	-	-	181	124		
25.5.67	1	-	-	217	145		
5.6.67	12	-	-	155	256		

[1, 3] *Siehe Tabelle 1 - Voir tableau 1;* [2] *Tage nach Umlagerung - Jours après le transfert;* [4] *Bei 10 C verbleibende Knollen - Tubercules demeurés à 10 C;* [5] *Auf 20 C umgelagerte Knollen - Tubercules transférés à 20 C;* [6] *Keimwachstum (Gew. %) - Croissance des germes (% en poids).*

Tabelle 8. Aenderungen im Zuckergehalt nach Umlagerung von 10 C auf 20 C. Durchschnitt der Ergebnisse aller Zentren.

Tableau 8. Evolution de la teneur en sucres après transfert de 10 C à 20 C, moyenne des résultats de tous les centres.

individual growing centres, are of interest as showing the time which is necessary if unacceptable potatoes are to be rendered acceptable. These were as follows:

% Reducing sugar:	0.31	0.30	0.29	0.28	0.27	0.26	0.25	0.22	0.22	0.20	0.19	0.19	0.19
Days to reach 0.25%	8	10	5	6	5	2							
Days to reach 0.1%:	40	100	50	40	?	50	90	70	35	55	40	30	15

If will be seen that 1–2 weeks at 20 C sufficed to decrease a reducing sugar content of 0.27–0.31% to a marginally acceptable level of 0.25%. To reach a fully acceptable level of 0.1% needed at least 6 weeks and was not always possible during a total period of 17 weeks at 20 C. To reach such a level from an original value of about 0.2% could exceptionally be possible in about 2 weeks but more usually in 4–8 weeks. 'Conditioning' is thus only practicable if the desired changes are small.

Late in the storage season, when an unacceptable sugar content could be due in part to senescent sweetening, transfer from 10 to 20 C does not necessarily have a desirable effect upon the content of reducing sugar (Table 8). In our experiments the immediate effect, after 1 day at 20 C, was usually to cause some increase in the content. This was lost again during subsequent storage, but after 12 days at 20 C the content in a number of cases was little different to that at the time of transfer. Whether, as is possible, the initial transitory rise occurred also on transfer earlier in the storage season cannot be shown by our results because of the spacing of our earlier analyses. The rise in non-reducing sugar, already occurring in potatoes transferred to 20 C at the end of May, continued to a marked degree.

Sweetening at 2 C and subsequent de-sweetening at 20 C

The sweetening and de-sweetening of stored potato tubers have been studied extensively by many workers. Our results add little to previous knowledge and detailed discussion is unnecessary. All samples followed the usual sweetening pattern of a rapid increase in sugar content during the first 14 days followed by a slower increase thereafter as illustrated in Table 9. Maximum contents of reducing sugar were found 27 or 41 days after transfer to 2 C and varied from 0.94 to 1.64 g/100 g fresh weight (FW). The variation showed no correlation with the distance North of the growing centre. Accumulation of sucrose continued, together with some decrease in reducing sugars, until the last analysis at 2 C, 17 weeks after transfer. The mean daily rate of sugar accumulation in tubers from the different growing centres, calculated over the first 14 days, varied from 48 to 95 mg per 100 g FW per day and was positively correlated at the 1% level ($r = 0.712$) with the distance North of the growing centre. This could be fortuitous, being derived from only one experiment, and would need to be confirmed by more extensive work.

De-sweetening was equally effective, irrespective of whether it followed transfer to 20 C early in March or late in May (Table 10), the content of reducing sugar after 2 weeks' de-sweetening being little more than the original content at 10 C prior to transfer to 2 C (Tables 9 and 10). After 4 weeks at 20 C the de-sweetened tubers

Table 9. Sweetening of potatoes, cv. Record, from different growing centres, following transfer from 10 to 2 °C.

Growing centre[1], km N of 50 N	Content of reducing (RS) or non-reducing (NRS) sugar (mg/100 g fresh weight) after ... days at 2 °C[2]									
	0 (25.1.67)		14		27		41		119	
	RS	NRS	RS	NRS	RS	NRS	RS	NRS	RS	NRS
211	192	72	840	330	1360	450	1405	260	879	1285
213	187	67	704	407	1154	504	1110	235	535	861
217	287	35	–	–	1506	274	1120	265	755	1169
345	309	84	760	300	1060	310	1170	955	749	1296
356	220	65	710	413	1152	326	1130	315	580	1040
360	288	116	650	504	960	565	1165	550	708	1267
458	297	88	1036	395	1219	716	743	1114	747	1110
464	200	95	939	431	644	993	940	1351	1003	1454
654	268	64	930	305	1195	435	1335	420	1102	1706
655	194	77	725	304	895	325	1055	290	638	979
831	247	91	1125	400	1475	475	1640	445	1167	1579
833	259	55	1110	374	1585	510	772	1018	815	1145
837	221	34	1017	570	1190	480	1530	405	777	1121

[1] *Anbauzentrum – Centre de culture;* [2] *Gehalt an reduzierenden (RS) und nicht-reduzierenden (NRS) Zuckern (mg/100 g Frischgewicht) nach ... Tagen bei 2 °C – Teneur en sucres réducteurs (RS) et non-réducteurs (NRS) (mg/100 g de matière fraîche) après ... jours à 2 °C.*

Tabelle 9. Süsswerden von Kartoffeln, Sorte Record, aus verschiedenen Anbauzentren nach Umlagerung von 10 °C auf 2 °C.

Tableau 9. Sucrage des pommes de terre, variété Record, cultivée dans différents centres par transfert de 10 °C à 2 °C.

contained appreciably less than the original content of reducing sugar. The individual values after 4 weeks showed no correlation with the content of sugar at the time of transfer to 2 °C, but were positively correlated at the 1% level with the content at the time of harvest (r = 0.764) and with the distance North of the growing centre (r = 0.826). Again, as in the case of the other correlations noted previously, no reason can be advanced for the relationship, and the experimental basis for it is too slight for it to be regarded other than as a possible indication for further work. On the other hand, the highly significant positive correlations we found between the rate of de-sweetening and the total sugar content at the start of de-sweetening, would appear theoretically logical. Calculated over the first 7 days at 20 °C the rates of loss of sugar ranged from 70 mg per 100 g FW per day with an initial sugar content of 1.345% FW to 232 mg per 100 gW per day an initial content of 2.125%; correlation, r = 0.741. Calculated over the first 14 days at 20 °C, the daily rates ranged from 72 to 135 mg per 100 g FW per day, with initial sugar contents of, respectively, 1.345 and 2.291%; correlation, r = 0.947.

Table 10. De-sweetening of potatoes, cv. Record, after transfer from 2 to 20 °C, related to total sugar content at the time of transfer.

Days at 20 °C[1]		Content of reducing (RS) or non-reducing sugar (NRS) (mg/100 g fresh weight at a total sugar content (mg/100 g fresh weight) at the date of transfer of[2]												
		2291	2125	2085	1935	1857	1790	1755	1715	1665	1445	1385	1345	1345
A. Transferred[3] *7.3.67*														
0	RS:	940	1170	1640	1530	743	772	1335	1165	1405	1130	1120	1110	1055
	NRS:	1351	955	445	405	1114	1018	420	550	260	315	265	235	290
7	RS:	555	375	683	448	575	473	695	209	485	415	338	248	655
	NRS:	178	128	187	115	225	130	360	92	120	200	65	86	200
14	RS:	296	323	475	355	256	372	390	250	185	213	267	108	254
	NRS:	112	144	91	110	108	79	131	137	95	128	76	81	78
28	RS:	179	97	195	–	141	205	175	83	118	104	144	63	181
	NRS:	116	80	72	–	79	82	83	120	119	82	75	51	97
		2808	2746	2457	2164	2045	1975	1960	1924	1898	1857	1620	1617	1396
B. Transferred[3] *24.5.67*														
0	RS:	1102	1167	1003	879	749	708	815	755	777	747	580	638	535
	NRS:	1706	1579	1454	1285	1296	1267	1145	1169	1121	1110	1040	979	861
13	RS:	349	355	241	187	258	242	260	245	301	347	194	162	133
	NRS:	109	71	117	88	150	119	56	74	94	113	139	93	81
27	RS:	273	278	244	106	123	173	219	121	224	183	97	162	102
	NRS:	104	145	121	70	110	120	83	53	65	88	109	100	65

[1] *Tage bei 20 °C – Nombre de jours à 20 °C;* [2] *Gehalt an reduzierenden (RS) oder nicht-reduzierenden (NRS) Zuckern (mg/100 g Frischgewicht) bei einem Totalzuckergehalt (mg/100 g Frischgewicht) auf das Erntedatum von – Teneur en sucres réducteurs (RS) et non-réducteurs (NRS) (mg/100 g de matière fraîche) à un teneur en sucres totales (mg/100 g de matière fraîche) à la date de récolte de;* [3] *Umgelagert am – Transférés le.*

Tabelle 10. Rekonditionierung von Kartoffeln, Sorte Record, nach Umlagerung von 2 °C auf 20 °C in bezug auf den gesamten Zuckergehalt zur Zeit der Umlagerung.

Tableau 10. Réduction du sucrage des pommes de terre, variété Record, par transfert de 2 °C à 20 °C, en relation avec le taux de sucres total au moment du transfert.

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Zusammenfassung

Zuckergehalt und Keimwachstum von Knollen der Sorte Record von verschiedenen Anbauorten bei Lagerung bei 10, 2 und 20 C

Reife Knollen der Sorte Record, die in den Jahren 1966 und 1967 an 13 Zentren zwischen 211 und 837 km N des 50 N angebaut wurden, wurden bei 10 C gelagert. In jedem Fall erfolgte in den ersten paar Wochen der Lagerung ein Ansteigen des Gehaltes an reduzierenden Zukkern (Tabellen 1 und 2). 1966 überdeckte dieser Anstieg den Einfluss der Distanz nördlich des Anbauzentrums auf den Zuckergehalt, der während des Wachstums und bei der Reife augenscheinlich war. Bei der Ernte wiesen 20 Bestände einen für die Verarbeitung annehmbaren Zuckergehalt auf, aber nach dem Ansteigen zu Beginn der Lagerung waren nur noch zwei annehmbar (Tabelle 3). Später besserte sich dies etwas. Aber nur in einem Fall sank der Zuckergehalt auf den Stand zur Zeit der Ernte (Tabellen 1 und 2). Eine Anzahl anderer Sorten zeigten ein ähnliches Verhalten (Tabelle 4).

Nach verlängerter Lagerung (Mai–Juni) stieg der Zuckergehalt, besonders der Saccharose, was für das altersbedingte Süsswerden charakteristisch ist (Tabellen 1, 2 und 4). Die dafür verantwortliche Mobilisierung des Kohlehydrats beginnt sehr bald nach Beginn des Keimwachstums, aber sie verursacht das Süsswerden nur dann, wenn die Mobilisierung die Ansprüche des Wachstums übersteigt. Bei handelsüblicher Lagerung mit Keimverhinderung könnte das Süsswerden gefährlicher sein als hier verzeichnet. Der Beginn des Keimwachstums unterschied sich zwischen den Sorten (Tabelle 7), aber er zeigte keinen Einfluss des Anbauzentrums, obwohl sich die Wachstumsrate unterschied, indem sie oft, aber nicht ausschliesslich, bei den Mustern aus dem fernen Norden kleiner war (Tab. 5, 6).

Muster der Ernte 1966, die am Anfang der Lagerperiode von 10 C auf 20 C gebracht wurden, wiesen eine Abnahme im Gehalt an reduzierenden Zuckern auf, sie war aber nicht mehr von Bedeutung, wenn die Knollen später, nach Beginn des altersbedingten Süsswerdens, umgelagert wurden (Tabelle 8). Die Abnahme war in jedem Fall ähnlich. Es war kein Einfluss des Breitengrades des Anbauzentrums festzustellen.

Ein Einzelversuch über Zuckeranhäufung bei 2 C zeigte keinen Einfluss der Lage des Anbauzentrums auf die am Schluss angehäufte Menge, obwohl auch diese beträchtlich schwankte (Tabelle 9). Es gab einen deutlich positiven Einfluss des Ortes auf die Zuckerakkumulationsrate, der jedoch einer Bestätigung bedarf. Die nachfolgende Rekonditionierung durch Lagerung bei 20 C war im Mai gleich wirksam wie im März. Die Rate war mit der bei der Umlagerung auf 20 C vorhandenen Zuckermenge positiv korreliert (Tabelle 10).

Résumé

La teneur en sucres et la croissance des germes de la variété Record, cultivée dans différentes régions, quand elle est conservée à 10, 2 et 20 C

Des tubercules mûrs de la variété Record, cultivée dans 13 centres situés entre 211 et 837 km au nord du 50e degré de latitude nord, ont été conservés à 10 C. Dans chaque cas, il y a eu une augmentation de la teneur en sucres réducteurs durant les premières semaines de stockage (tableaux 1 et 2). En 1966, cette élévation a masqué l'effet de la localisation des centres de culture sur les sucres réducteurs; celle-ci étant apparente pendant les périodes de végétation et de stockage. A la récolte, 20 lots ont eu une teneur en sucres acceptable pour la transfor-

mation mais, après leur élévation pendent la période de stockage, 2 lots seulement convenaient (tableau 3). On observait une amélioration par la suite mais, dans un cas seulement, la concentration revenait au taux initial (tableaux 1 et 2). Un certain nombre de variétés se comportaient de façon identique (tableau 4).

Après une conservation prolongée (mai–juin), on notait une augmentation de la teneur en sucres, notamment en saccharose, caractéristique du 'sucrage' dû à la sénescence (tableaux 1, 2 et 4). La mobilisation des hydrates de carbone responsables de ce phénomène s'effectuait aussitôt après le démarrage de la germination et ne causait le 'sucrage' que lorsqu'elle excédait la quantité nécessaire à la croissance des germes. Dans le stockage pour la commercialisation avec utilisation d'inhibiteurs de germination, le 'sucrage' pourrait être plus important que celui mentionné ici. Le démarrage de la germination variait selon les variétés (tableau 7) mais la localisation des différents centres n'avait pas d'effet sur lui; toutefois, les taux de croissance étaient différents, étant souvent mais pas exclusivement moindre, pour les échantillons provenant des centres de culture les plus éloignés (tableaux 5 et 6).

Les échantillons récoltés en 1966 et stockés rapidement à 10 et 2 C ont montré une diminution de leur teneur en sucres réducteurs, qu'il n'était plus possible d'apprécier lorsque les tubercules avaient été stockés plus tardivement, au moment où le 'sucrage' dû à la sénescence était déclenché (tableau 8). La diminution de la teneur en sucres était identique dans tous les cas, démontrant l'absence d'effet de la latitude des centres de cultures.

Un seul essai sur l'accumulation des sucres dans les tubercules conservés à 20 C a montré cette absence d'effet de la latitude des centres de culture sur la concentration finale en sucres; cependant, des variations considérables ont été observées (tableau 9). Il y avait un effet positif apparent de la latitude qui demandait une confirmation. Par la suite, la diminution du taux de sucres par un temps de passage des lots à 20 C a été observée de la même manière en mai qu'en mars. Le taux était en corrélation positive avec la quantité de sucres présente au moment du transfert à 20 C (tableau 10).

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