Potato Research 39 (1996) 523 – 531

Effect of controlled atmosphere, temperature and cultivar on sprouting and processing quality of stored potatoes

O.S. KHANBARI[1] and A.K. THOMPSON

Silsoe College, Cranfield University, Silsoe, Bedford MK45 4DT, UK
[1]Present address: The Authority of Research and Extension, El-Kod Agricultural Research Centre, Yemen

Accepted for publication: 7 October 1996

Additional keywords: CO_2, O_2, Record, Saturna, Hermes, sprout length, fry colour, sugar, *Solanum tuberosum* L.

Summary

Three crisping potato cultivars, Record, Saturna and Hermes, were stored at 5 or 10 °C in gas mixtures of either 0.5% CO_2 and 21.0% O_2 (control) or 9.4, 6.4, 3.6 or 0.4% CO_2, all combined with 3.6% O_2. There was almost complete sprout inhibition, low weight loss and maintenance of a healthy skin for all cultivars stored in 9.4% CO_2 with 3.6% O_2 at 5 °C for 25 weeks. When tubers from this treatment were stored for a further 20 weeks in air at 5 °C the skin remained healthy and they did not sprout. The fry colour of crisps made from these potatoes was darker than the industry standard, but when they were reconditioned, tubers of cv. Saturna produced crisps of an acceptable fry colour while crisps from the other two cultivars remained too dark. Reducing sugar levels were related to fry colour both after storage and after reconditioning. The other gas combinations and the controls did not have the same effect on sprouting and none of the controlled atmosphere treatments controlled sprouting at 10 °C.

Introduction

Storing potatoes at low (2–5 °C) temperatures results in the accumulation of reducing sugars which, when the tubers are used for processing, give the crisps an unacceptable dark brown colour (Harris, 1992). Storage at a higher temperature (10 °C) reduces sugar accumulation, but tubers need to be treated with a disease-control chemical and a chemical sprout suppressant which is current standard practice for potatoes stored for processing (Burton, 1989; Khanbari & Thompson, 1994). Isherwood (1976) and Iritani & Weller (1978) showed that reconditioning at 20 °C for at least two weeks removed most of the sugars that had developed during low temperatures storage, but the sugar accumulation as a result of senescent sweetening, which can occur when tubers have been stored for long periods, was irreversible. Also tubers reconditioned after storage at 5 °C maintained higher sugar levels than tubers stored at 10 °C (Burton 1973; Schouten, 1992; Smith, 1987; Reust et al., 1984). Khanbari & Thompson (1994) showed that potato tubers stored in high CO_2 levels responded to a commercial reconditioning treatment better than those stored in air.

Controlled atmosphere storage to suppress sprouting was reported to be unsuitable for potatoes for table use (Ryall & Lipton, 1979), as oxygen levels of 2.5% and below increased decay (Lipton, 1967; Sherman & Ewing, 1983; Schouten, 1992). This effect could be aggravated by high carbon dioxide levels (Workman & Twomey, 1969). For

storage at 10 °C, Burton (1958) recommended 10% CO_2 and 10% O_2 but this combination of gases was found to be ineffective for long-term storage (Khanbari, 1995). At 8 °C storage of cv. Record for 6 months in 10% CO_2 and low O_2 (below 3%) was not suitable because of tissue breakdown (Khanbari, 1995). Hartmans et al. (1990) also showed partial detioration of tubers in 7% CO_2 during 300 days storage at 4 °C. Storage temperature of 2 to 4 °C may be used with controlled atmospheres to control sprouting, but results have been variable and inconclusive (Isenberg, 1979; Lougheed, 1969). However in later work Khanbari & Thompson (1994) showed that at 4 °C long-term storage was optimum in CO_2 levels of 9–12% and 3–4% O_2.

The present research was conducted to evaluate the effects of carbon dioxide in low oxygen atmospheres on long-term storage of potatoes and their behaviour when stored in air after the removal from controlled atmosphere storage.

Material and methods

Tubers of three crisping cultivars, Record, Saturna and Hermes, grown in Nottingham, UK, were harvested on 27 September 1993 and cured for two weeks at 15 °C and 90–95% relative humidity. Tubers from each cultivar were randomly selected and grouped into 80 lots. Each lot of 10 medium-size tubers (120 to 150 g each) was placed in a net bag. The initial weight of each bag of tubers was recorded. Eight bags from each cultivar were then placed randomly in each of ten air-tight 75 litre polyethylene containers (Model C217, Mailbox International Ltd, Cheshire, UK). The containers were divided into two groups of five, and the groups were placed in separate temperature-controlled rooms adjusted to 5 °C and 10 °C respectively. The containers were then connected to a computer-operated, gas flow-through

Table 1. Effect of different controlled atmospheres on sprout weight per tuber of three crisping cultivars stored at 5 °C or 10 °C for 25 weeks.

Storage temperature	Gas combinations		Mean sprout weight per tuber (g)		
	CO_2 %	O_2 %	*Record*	*Saturna*	*Hermes*
5 °C	9.4	3.6	0.0	0.0	0.0
	6.4	3.6	4.5	1.9	1.6
	3.6	3.6	12.7	9.9	10.0
	0.4	3.6	10.1	8.4	15.6
	0.5	21.0[a]	6.0	2.3	2.5
10 °C	9.4	3.6	5.1	5.8	5.8
	6.4	3.6	15.7	10.4	18.3
	3.6	3.6	17.3	13.3	16.1
	0.4	3.6	7.6	7.5	7.7
	0.5	21.0[a]	6.5	3.1	2.6

[a] Control
LSD (P = 0.05) 4.26 for comparing any pairs of results.

controlled atmosphere system which was programmed to produce 5 different gas combinations (Table 1). The gas mixtures were passed through each container separately in each storage room. Details of the controlled atmosphere system used in this experiment have been described by Khanbari & Thompson (1994). The system was automatically operated for a total of 10½ hours per day. This was spread into seven time intervals of 90 minutes each. During operation, the gases flowed through each storage container three times for 3 minutes each time. Gas levels were monitored by this operating procedure and the controlled atmosphere condition in each container was maintained within 0.1% of the set concentration for both CO_2 and O_2.

Assessment of tubers was made after 5, 15 and 25 weeks of storage when six bags from each controlled atmosphere combination (two bags of each cultivar) were removed and left at room temperature (~20 °C) for two hours before the measurement of weight loss. Tubers of one bag were assessed visually for rotting, using photographs and descriptions by Snowdon (1991). The tubers from the remaining six bags were stored at 5 °C in air for a further 20 weeks. The sprouting index was measured after 5, 15 and 25 weeks according to the method described by Cunnington & Gerrish (1992) and details are given by Khanbari & Thompson (1994). Sprouts were then cut off and weighed. The control (0.5% CO_2 and 21% O_2) and the samples stored in 9.4% CO_2 and 3.6% O_2 5 °C were all transfered to air and stored for a further 20 weeks also at 5 °C to evaluate any residual effect on sprouting and tuber quality. From each of 10 tubers, two of the middle slices were taken and split into two groups. Slices of one group were washed under tap water, surface dried with paper tissues and ten were directly fried at 180–183 °C for 3.5 minutes. From the other group, the middle sections were chopped and 10 g combined sample were frozen in dry ice, freeze dried using Edwards Serial No. 2165 freeze dryer (Edwards, Crawley, UK) and stored at -18 °C for sugar analysis. Tubers from the second bag were reconditioned for two weeks in a temperature-controlled room, adjusted to 20 °C and 90–95% relative humidity before the assessment. The method for crisp colour measurement was by the computer vision system, previously described by Khanbari & Thompson (1994).

To extract the sugars, 0.5 g of each of the combined freeze-dried samples of each potato cultivar were treated twice with 25 ml of 80% alcohol at 65 °C for 30 minutes each time. Each extract was vacuum evaporated and re-dissolved in 5 ml distilled water. 0.5 ml were freeze dried for analysis. The method for sugar analysis was that described by Davies (1988) and Miller et al. (1975) with some modifications. This procedure includes formation of volatile trimethylsilyl (TMS) esters of the sugars and separation by gas-liquid chromatography. TMS-sugar esters were prepared by dissolving the freeze-dried sugars in 100 µl BSTFA [bis (trimethylsilyl) trifluoroacetamide] containing 1% trimethylchlorosilane (Supelco, UK) and 400 µl of dimethylformamide (Fisons, UK). The content was agitated vigorously by an Autovortex Mixer SA2 (Stuart Scientific, UK.) for 30 seconds and was then allowed to stand at room temperature for 30 minutes before injection. 1 µl of the solution was split-less injected into a Carlo Erba gas chromatograph Fractovap 4160 Series (Carlo Erba Strumentazione, Milano, Italy), equipped with a flame ionisation detector and

an injector operating at 220 °C. Separation of the TMS-sugars was accomplished in a 30 m x 0.256 mm DB-1701 capillary column (J & W Scientific, USA) with film thickness of 0.15 μm. Hydrogen was used as the carrier gas at a flow rate of 40 cm^3 min^{-1}. Sugars were separated using a temperature programme of 140 °C for 2 min, rising to 250 °C at 20 °C min^{-1}. Identification of the sugars was made by means of a pre-calibrated data processor (DP 800, CE Instruments, UK).

Experiments were factorial randomised block designs and results were analysed statistically using Genstat 5 (Copyright 1990, Lawes Agricultural Trust).

Results and discussion

Sprouting was consistently greater for tubers held at 10 °C than at 5 °C which is in accordance with previous work (Burton, 1989; Harris, 1992). There was a significant difference ($P<0.05$) in sprouting among the three cultivars studied with cv. Saturna significantly lower than cvs Record and Hermes (Table 1).

Sprouting was suppressed for all three cultivars stored for 25 weeks at 5 °C in high CO_2. There was some indication that the combination of 3.6% O_2 with 0.4, 3.6 or 6.4% CO_2 increased sprouting during storage at 10 °C, with a similar effect for 0.4 and 3.6% CO_2 at 5 °C (Table 1). Burton (1958) and Reust et al. (1984) recorded an inhibitory effect of CO_2 on sprout growth but only at concentrations of 15 or 20% CO_2 at 10 and 8 °C respectively. Results of previous findings (Khanbari, 1995) at 8 °C show that there was a cultivar difference in response to CO_2 and confirm for cv. Record the results of Burton (1958) and Reust et al. (1984).

Throughout storage cv. Hermes generally showed the lowest sprouting, but the effect was more marked at 5 °C than at 10 °C. At 5 °C cvs Saturna and Record had similar levels of sprouting after 5 and 15 weeks (data not shown). The results were in agreement with those obtained for the cv. Record (Khanbari & Thompson, 1994) at a storage temperature of 4 °C, where some eyes failed to produce sprouts after 6 months of controlled atmosphere storage. The results are also in accordance with previous findings, reviewed by Burton (1989), which showed that there was a genetic variation in potato dormancy.

Weight loss of tubers during storage for 25 weeks was 2.3 to 3.7% at 5 °C, and 3.4 to 6.6% at 10 °C. Subsequent weight losses during reconditioning were 2.8 to 4.1% and 2.3 to 4.5% respectively. Full data are available in Khanbari (1995).

Rotting of tubers, identfied as gangrene (*Phoma foveata*) reached a maximum of 7% after 25 weeks storage in one controlled atmosphere storage treatment (Table 2). Rotting occurred at both temperatures on all three cultivars and at all controlled atmosphere combinations. There was little indication that any treatment was more prone to rotting although 4.2% of tubers stored at 10 °C had rots while only 2.9% of tubers stored at 5 °C showed signs of rotting, and the high CO_2 controlled atmosphere storage treatment at 10 °C had the highest number of rotting tubers. In previous work, observations on the effect of reduced O_2 (below 3%) at high CO_2 levels showed an increased decay of long-term stored potatoes (Isenberg, 1979; Burton, 1989; Schouten 1994).

Table 2. Effect of temperature and gas combinations on crisp lightness (fry colour) of potatoes stored for 25 weeks (data combined for 3 cultivars).

Storage temperature	Gas combination		Grey level directly after storage[a]	Grey level after reconditioning	Tubers showing rotting after storage[b]
	CO_2%	O_2%			
5 °C	9.4	3.6	132.4	155.8	3%
	6.4	3.6	130.5	155.2	3%
	3.6	3.6	134.3	153.6	3%
	0.4	3.6	144.1	155.6	2%
(Control)	0.5	21.0	135.8	149.8	2%
10 °C	9.4	3.6	144.6	157.2	7%
	6.4	3.6	141.7	153.5	4%
	3.6	3.6	146.6	154.8	1%
	0.4	3.6	149.9	157.6	4%
(Control)	0.5	21.0	149.7	153.0	4%
LSD ($P < 0.05$)			2.70	2.57	Not analysed
S.E.			0.98	0.93	

[a]Grey level of 148.7 or more was acceptable
[b]Mean of 90 tubers

After 25 weeks all the tubers stored in 9.4% CO_2 and 3.6% O_2 at 5 °C had almost no sprouts, while tubers from the other treatments had all developed sprouts and were shrivelled. Samples of potatoes from the three cultivars which had been stored at 5 °C in 9.4% CO_2 and 3.6% O_2 for 25 weeks were left at 5 °C, together with the controls, in air for a further 20 weeks. At the end of this period, tubers which had been stored throughout the 45 weeks in air had shrivelled and sprouted and exhibited weight losses of 19.3% for cv. Record, 24.3% for cv. Saturna and 30.1% for cv. Hermes. The tubers stored in 9.4% CO_2 and 3.6% O_2 followed by storage in air showed no sign of sprouts and tubers of all the cultivars maintained a healthy skin with weight losses of 6.2% for cv. Record 8.8% for cv. Saturna and 7.1% for cv. Hermes after 45 weeks storage. Some indication of this residual effect of high CO_2 had been reported by Schmitz (1991) for cv. Cara and early work (Hill, 1913) decribed experiments on peaches stored in increased levels of CO_2. These showed that their respiration rate was reduced, not only during exposure, but also that respiration rate returned to the normal level only after a few days in air. This residual effect of CO_2 has implications for the potato storage industry since it opens up a possible storage method of exposing the tubers to high CO_2 followed by air storage, which may suppress sprouting without the use of chemicals. Further work is needed to determine the minimum period of exposure to high CO_2 and or low O_2 before this effect is obtained. This residual inhibition of sprouting could be explained either as the directly inhibiting effect of the high CO_2 in the storage atmosphere (Schouten, 1992; Reust et al., 1984; Sherman & Ewing, 1983), or it could be that the high CO_2, to which the tubers had been exposed enhanced the accumulation of sprout-suppressing volatiles,

which carried through after the 25 week storage period. The changes in chemical composition of potato tubers exposed to increased concentrations of CO_2 in the storage atmosphere are not known in detail but include accumulation of sugars (Reust et al., 1984) and alcohols and aldehydes (Ulrich et al., 1952). Ulrich and his co-workers also reported reduced growth-substance activity and reduced activity of peroxidases and oxidases, including tyrosinase. Accumulation of alcohol may be one means by which a high concentration of CO_2 suppresses sprouting. The inhibitory effect of alcohol on sprouting has been demonstrated by Burton (1952) by exposing tubers of non-dormant cv. Majestic potatoes to amyl alcohol.

For crisps processed from potatoes directly after 5 weeks storage at 5 °C, all those from the controlled atmosphere-stored tubers produced either lighter or similar coloured crisps to the control, while at 10 °C there was no significant difference between the controlled atmosphere and control treatments (Table 2). After 15 weeks tubers stored in 5 °C in the two lower CO_2 levels had a lighter fry colour than the controls while those at the two higher CO_2 levels had similar fry colours. At 10 °C the two higher CO_2 levels had significantly darker fry colours than controls. After 25

Table 3. Sugars (g 100g-1 dry weight) in tubers of three cultivars stored for 25 weeks under different controlled atmospheres at 5 °C or 10 °C and then reconditioned in air for two weeks at 20 °C.

Cultivars	Gas combinations		5 °C		10 °C	
	CO_2%	O_2 %	RS[a]	TS[b]	RS	TS
Record	9.4	3.6	0.216	0.973	0.490	1.400
	6.4	3.6	0.348	1.109	1.138	2.523
	3.6	3.6	0.534	1.156	0.749	2.349
	0.4	3.6	0.510	1.299	0.523	1.175
(Control)	0.5	21.0	0.730	1.053	0.634	1.632
Mean			0.4883	1.138	0.707	1.816
Saturna	9.4	3.6	0.324	1.221	0.233	0.918
	6.4	3.6	0.612	0.993	0.240	0.883
	3.6	3.6	0.382	0.822	0.358	1.083
	0.4	3.6	0.220	0.511	0.117	0.920
(Control)	0.5	21.0	0.615	0.831	0.405	1.194
Mean			0.473	0.907	0.271	1.000
Hermes	9.4	3.6	0.480	0.851	0.219	0.475
	6.4	3.6	0.332	0.547	0.472	1.836
	3.6	3.6	0.735	1.229	0.267	1.149
	0.4	3.6	0.428	0.715	0.303	0.888
(Control)	0.5	21.0	0.932	1.627	0.510	1.127
Mean			0.682	1.094	0.354	1.095

[a] Reducing sugars
[b] Total sugars

weeks storage at 5 °C the three higher CO_2 levels all gave either darker crisps or had no effect. Those stored in 0.4% CO_2 with 3.6% O_2 produced significantly lighter crisps than the control. At 10 °C the three higher CO_2 levels also produced darker crisps than the control but 0.4% CO_2 with 3.6% O_2 produced significantly ($P<0.05$) lighter crisps. After reconditioning, tubers stored at 5 °C always had a significantly ($P<0.05$) lighter fry colour for those stored in controlled atmospheres compared to the control (Table 2). Tubers stored at 10 °C showed no significant differences ($P<0.05$) between the controls and the controlled atmosphere stored tubers except after 25 weeks storage when those in 0.4% CO_2 with 3.6% O_2 and 9.4% CO_2 and 3.6% O_2 produced significantly ($P<0.05$) lighter crisps.

Low O_2 atmospheres which affect crisp lightness (2.5–3.0%) were reported to minimise or retard the build-up of reducing sugars during short term storage of potato (Lipton, 1967; Sherman & Ewing, 1983; Parkin & Schwobe, 1990). However, high levels of CO_2 during short-term storage was also reported to produce dark crisps when processed directly after storage (Mazza & Siemens, 1990). Fry colour was closely related to the reducing sugar content (Table 3) as previously reported by Burton (1989).

All the tubers processed directly after 45 weeks storage produced unacceptably dark crisps (data not shown). Reconditioning of tubers at 20 °C for two weeks resulted in decreases in sugar content and consequent lightening of crisps produced from the tubers of cv. Saturna (Table 4). However, neither the tubers of cvs Record nor Hermes produced acceptably coloured crisps after reconditioning. Several workers reported cultivar differences in the response to reconditioning after long-term storage of potatoes in air (Iritani & Weller, 1978; Coffin et al., 1987). Tubers of cv. Record were reported to recondition to an acceptable sugar content after a period of 4 to 6 weeks at 20 °C (Williams & Cobb, 1992; Cunnington & Gerrish, 1992).

Table 4. Sugar content and fry colour (grey level) of tubers from three cultivars stored for 25 weeks in 9.4 % CO_2 and 3.6 % O_2 and a further 20 weeks in air all at 5 °C and then reconditioned for two weeks at 20 °C.

Tuber source	Cultivars	Type of sugar g 100g^{-1} dry wt			Grey level[a]
		Fructose	Glucose	Sucrose	
Processed directly after storage	*Record*	0.778	0.847	0.520	130.3
	Saturna	0.660	0.685	0.540	136.8
	Hermes	0.980	1.120	0.564	122.9
Processed after reconditioning	*Record*	0.628	0.563	0.897	132.7
	Saturna	0.381	0.343	0.489	151.8
	Hermes	1.030	1.127	1.133	123.6

[a] Grey level of crisps processed from the potatoes above.

Rotting levels remained low on tubers stored at 5 °C for 25 weeks in 9.4% CO_2 with 3.6% O_2 followed by 20 weeks in air. These tubers looked in good condition with a healthy skin and no internal rotting. The results indicate that there can be residual beneficial effects of controlled atmosphere storage of potatoes and demonstrate a way of overcoming the long term detrimental effects which could be applied to at least one cultivar. This raises the possibility of developing a long term storage system which would keep them in good quality without the use of chemical fungicides or sprout suppressants.

References

Burton, W.G., 1952. Studies on the dormancy and sprouting of potatoes. III. The effect upon sprouting of volatile metabolic products other than carbon dioxide. *New Phytologist* 51: 154–161.

Burton, W.G., 1958. The effect of the concentration of carbon dioxide and oxygen in the storage atmosphere upon the sprouting of potatoes at 10 °C. *European Potato Journal* 1: 47–57.

Burton, W.G., 1973. Physiological and biochemical changes an the tubers as affected by storage conditions. Proceeding of 5th Triennial Conference of the European Association of Potato Research, Norwich, England, pp. 63–81.

Burton, W.G., 1989. The Potato, 3rd edition. Longman Scientific & Technical, London.

Coffin, R.H., K.L. Yada, B.G. Parkin & D.W. Stanley, 1987. Effect of low temperature storage on sugar concentrations and chip colour of certain processing potato cultivars and selections, *Journal of Food Science* 52: 639–645.

Cunnington, A. & S. Gerrish, 1992. Potato Marketing Board, Annual Review, Sutton Bridge Experimental Station 1991, pp. 43–44.

Davies, H., 1988. Rapid determination of glucose, fructose and sucrose in potato tubers by capillary gas chromatography. *Potato Research* 31: 569–572.

Harris, P.M., 1992. The Potato Crop, 2nd edition. Chapman Hall, pp. 608–727.

Hartmans, K.J., A. van Es & S.P. Schouten, 1990. Influence of controlled atmosphere (CA) storage on respiration, sprout growth and sugar content of cv. Bintje during extended storage at 4 °C. Abstracts of Conference papers of the 11th Triennial Conference of the European Association for Potato Research, Edinburgh, UK, pp. 159–160.

Hill, G.R. Jr., 1913. Respiration of Fruits and Growing Plant Tissue in Certain Cases, with Reference to Ventilation and Fruit Storage. Cornell University, Agricultural Experiment Station, Bulletin 330, 26 pp.

Iritani, W.M. & L. Weller, 1978. Factors influencing reconditioning of Russet Burbank potatoes. *American Potato Journal* 55: 425–430.

Isenberg, F.M.R., 1979. Controlled atmosphere storage of vegetables. *Horticulture Review* 1: 337–394.

Isherwood, F.A., 1976. Mechanism of starch-sugar interconversion in *Solanum tuberosum*. *Phytochemistry* 15: 33–41.

Khanbari, O.S. & A.K. Thompson, 1994. Effect of controlled atmosphere storage at 4 °C on colour, sprout growth, rotting and weight loss of potato tubers. *Potato Research* 37: 273–282.

Khanbari, O.S., 1995. Effect and interaction of temperature, cultivar and storage gases in storage and processing quality of potatoes. PhD thesis, Silsoe College, Cranfield University, UK.

Lipton, W., 1967. Some effect of low oxygen atmospheres on potato tubers. *American Potato Journal* 44: 292–299.

Lougheed, E.C., 1969. Controlled atmosphere storage of Irish potatoes. *Proceedings National Controlled Atmosphere Research Conference, Michigan State University Horticultural Report* 9: 98.

Mazza, G. & A.J. Siemens, 1990. Carbon dioxide concentration in commercial potato storages and its effect on quality of tubers for processing. *American Potato Journal* 67: 121–132.
Miller, L.P., J.D. Harrington & G.D. Kuhn, 1975. Effect of variety and harvest date on tuber sugars and chip colour. *American Potato Journal* 52: 379–386.
Parkin, K.L. & M.A. Schwobe, 1990. Effect of low temperature and modified atmosphere on sugar accumulation and chip color in potatoes (*Solanum tuberosum*). *Journal of Food Science* 55: 1341–1344.
Reust, W., A. Schwarz & J. Aerny, 1984. Essai de conservation des pommes de terre en atmosphère contrôlée. *Potato Research* 27: 75–87.
Ryall, A.L. & W.J. Lipton, 1979. Handling, transportation and storage of fruits and vegetables. Vol. 1 (2nd edition): Vegetables and Melons, AVI, Westport, Connecticut.
Schmitz, S.A., 1991. Investigation on alternative methods of sprout suppression in temperate potato storage. MSc thesis, Cranfield University.
Schouten, S.P., 1992. Possibilities of controlled atmosphere storage of ware potatoes. *Aspects of Applied Biology* 33: 181–188.
Schouten, S.P., 1994. Increased CO_2 concentration in the store is disadvantageous for the quality of culinary potatoes. Gehalt im Lager nachteilig für die Qualität von Konsumkartoffeln. *Kartoffelbau* 45: 372–374.
Sherman, M. & E. Ewing, 1983. Effect of temperature and low oxygen atmospheres on respiration, chip color, sugars and malate of stored potatoes. *Journal of the American Society of Horticultural Science* 108: 129–133.
Smith, O., 1987. Potato chips. In: W.F. Talburt & O. Smith (Eds), Potato processing, 4th edition. AVI Publishing Co, Westport, Connecticut, USA, pp. 371–473.
Snowdon, A.L., 1991. A colour atlas of post-harvest diseases and disorders of fruits and vegetables. Volume 2, Vegetables. Wolf Scientific, London.
Ulrich, R., P. Marcellin & J. Mimault, 1952. Observations sur le développement des bourgeons des tubercules de pomme de terre. *Journal des Recherches du Centre National de la Recherche Scientifique*, Paris, 17.
Williams, R.O. & A.H. Cobb, 1992. The relationship between storage temperature, respiration, reducing sugar content and reconditioning regime in stored potato tubers. *Aspects of Applied Biology* 33: 212–220.
Workman, M. & J. Twomey, 1969. The influence of storage atmosphere and temperature on the physiology and performance of Russet Burbank seed potatoes. *Journal of the American Society of Horticultural Science* 94: 260–263.