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Fluctuations in sugars in cv. Record during extended storage at 10 °C

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Summary

Tubers of cv. Record (the major UK crisping cultivar) were stored at 10 °C for up to 320 days. Throughout storage, the levels of reducing sugar in the tissue surrounding the basal eye were considerably higher than those round the apical eye but the difference in sucrose between the two tissues was not as marked. During storage, there was an initial peak in total reducing sugar content, possibly associated with the break in dormancy, and a second peak associated with vigorous sprout growth. Regular removal of sprouts caused reducing sugar levels to continue to fall, after the initial rise, for much longer than in sprouting tubers and for the final sweetening to be considerably delayed, suggesting that the stage of sweetening subsequent to break of dormancy is possibly under the control of sprout growth. However, even in such material sugars may eventually rise, possibly due to ageing of the tuber.

Introduction

The colour of fried products, particularly crisps, is a major factor determining their acceptability by the consumer. The brown colour formed by frying is caused by the Maillard reaction between reducing sugars and amino acids (Burton, 1966). The level of reducing sugars in potatoes is used by the crisping industry to predict processing quality because their concentration is usually the major single compositional factor determining colour development (Burton, 1966). However, the correlations between reducing sugars and the brown colour of crisps may vary considerably (see Fuller & Hughes, 1984 for discussion).

Because potatoes for crisping are often stored from harvest until the following June or July, the pattern of sugar accumulation during storage has been extensively investigated. The results often conflict particularly in relation to the final irreversible rise in reducing sugars (senescent sweetening) and the influence of methods used to control sprout growth. These conflicts may be due to several factors, viz. the use of different varieties with different lengths of dormancy and different sprout vigour, control of sprout growth by different means (manual desprouting or use of one of a range of sprout suppressants), the use of different storage temperatures (7 °C to 20 °C), differences in the duration of storage and frequency of sampling, and also whether whole tubers or different tissues or regions of tubers have been analysed (Vliet & Schriemer, 1963; Isherwood & Burton, 1975; Burton, 1977; Dimalla & Staden, 1977; Bailey et al., 1978).

In recent years the UK crisping industry has been concerned about the apparent greater variation than previously experienced at lifting and subsequently during storage in sugars and crisp colour of cv. Record, which is the major crisping cultivar used in the UK for long term storage.

Because of the above uncertainities and the limited amount of information on the pattern of sugar accumulation during storage in different parts of tubers of cv. Record, an investigation was made on the effect of control of sprout growth on the distribution of sugars during extended storage at 10 °C. Sprouting was controlled by removing sprouts because sprout suppressants may have other biochemical affects. Because of its possible importance in relation to the sampling techniques used by crispers in estimating sugars, sugar was assessed in the different parts of the tuber (Fuller & Hughes, 1984) after storage at the temperature most frequently used by crispers.

Materials and methods

Record tubers were grown in 9.1 l polythene pots containing a compost of loam, peat and sand (3:2:1) and 9.1 g per pot of hoof and horn fertilizer (5.1 % N, 3.5 % P and 8.3 % K) in a glasshouse to reduce variation between plants and tubers and to ensure that the plants could be grown to full maturity without any danger of low night temperatures influencing sugar accumulation.

Harvested tubers of between 50 and 150 g were put randomly into sets of 20 and stored at 10 °C and at 90 % relative humidity. At harvest and subsequently at each sample date, cores of 8 mm diameter and 10 mm deep were taken from around the apical and basal eye (lowest eye) and the central pith tissue of 20 tubers. Cores from the 20 tubers were bulked to represent the three sites and used for sap extraction.

The tubers showed apical dominance and after they had all sprouted (i.e. when each tuber had a sprout longer than 3 mm) the sets of 20 tubers were put into two groups – a 'grown on' group where sprouts on all tubers in each set were allowed to continue to grow, and a 'desprouted' group where the sprouts on all tubers in each set were carefully removed at weekly intervals throughout storage. Samples were taken at more frequent intervals during the early stage of storage than the later stage so that the initial rise in reducing sugar would not be missed.

Analysis

A hand screw press was used to prepare samples for analysis because it has already been established (Fuller & Hughes, 1984) that 90 % of the variation in crisp colour could be explained by the concentration of total reducing sugars in expressed potato sap. Sap extraction and subsequent deproteinizing is a technique recommended by the EAPR working party on analytical methods (Anon.).

Deproteinization was achieved by using Carrez I (potassium ferrocyanide) and Carrez II (zinc sulphate) and centrifuging at room temperature for 15 min at 2000 rpm. Glucose and sucrose (after hydrolysis with invertase) were separately analysed with an automated method based on the manual glucose oxidase – peroxidase method. (Werner, Rey & Wielinger, 1970). Total reducing sugars (TRS) were estimated by using an automated method based on the manual hexokinase glucose-6-phosphate dehydrogenase method (Schmidt, 1961).

The data presented for sugars at each sample time are the means of triplicate analyses from a single sap extract of a 20 tuber bulk sample.

Results

All sugars were generally higher in the basal eye tissue than in the apical eye tissue (Figs 1, 2, 3 and 4). Sugars in the central pith tissue were generally intermediate between these two tissues and the data are not presented.

Sucrose levels at the basal eye increased after harvesting and reached a peak between the time the eyes opened (all tubers had one eye with the sprout tip visible) and 100 % sprouting, thereafter decreasing and eventually rising again at the time that sprout growth at the apical eyes accelerated (Fig. 5). However, in the desprouted tubers no marked increase in sucrose occurred at the end of the storage season.

In the apical eye tissue the pattern of sucrose accumulation is similar to that of the basal eye in both 'grown on' and 'desprouted' tubers. However, the level of sucrose, apart from the final sample of the 'grown on' tubers, is slightly lower in this tissue than in the basal tissue.

Only slightly higher TRS were found at the basal eye than at the apical eye at harvest. However by the time the apical eyes had opened, the TRS at the basal eye (Fig. 1) had increased by a factor of over 10 whereas the level at the apical eye had increased only by a factor of 4 (Fig. 2). Thereafter the level remained higher in the basal tissue than in the apical tissue throughout the storage period (cf. Figs 1, 2). The level of TRS dropped after the eyes had opened before leveling-off and rising again when apical sprout growth increased (Fig. 5). In desprouted tubers the TRS in the basal tissue continued to fall before levelling-off at between 250 and 300 days storage.

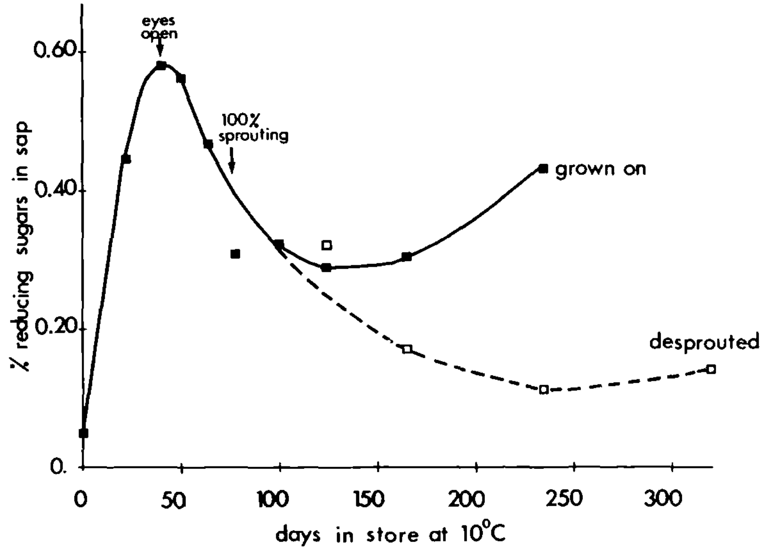
In the apical tissue similar patterns of TRS accumulation and differences between sprouted and desprouted tubers were found, except that the TRS were much lower and the changes far less marked than in tissue from the basal eye (Figs 1, 2).

Discussion and conclusions

The initial rise in sugars appears to reach its peak at the time at which the apical eyes open and it may be associated with the break in dormancy (Dimalla & Staden, 1977). Although the initial rise in TRS is considerable, the extent of the increase can vary between different samples of cv. Record (Burton & Wilson, 1978 and unpublished results). Although the highest levels of sugar have been found at the apical end of the tuber (Dimalla & Staden, 1977), the level of reducing sugars in this experiment and in other material of this cultivar (Fuller & Hughes, 1984) was generally found to be higher in the basal tissue. Cv. Russet Burbank also appears to behave in a similar way to Record (see Iritani et al., 1973). The relative size of the sugar pools in tubers will be a reflection of the interaction between mobilization, utilization and transport in the various tissues and may vary between cultivars due to physiological difference in sprout vigour and apical dominance. In this experiment no sprouting occurred in the basal eye tissue of any tuber.

Subsequent to the initial rise, the TRS and sucrose levels began to fall and to rise again in the sprouting tubers at about the time sprout growth accelerated (Figs 1, 2, 3, 4, 5). This agrees with the pattern of sugar accumulation previously shown for this variety

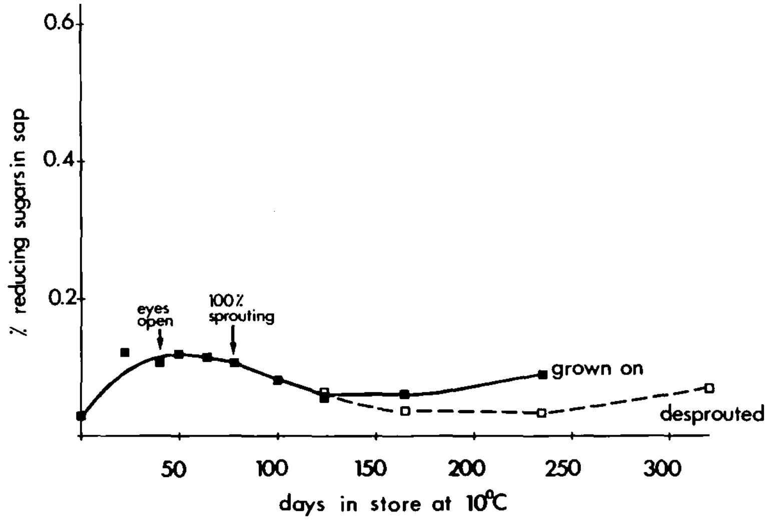
Fig. 1. Fluctuation in reducing sugars, cv. Record (basal eye).



% reducing sugars in sap - *% reduzierende Zucker im Saft - % de sucres réducteurs dans le jus;* Days in store at 10 ° C - *Tage im Lager bei 10 ° C - Jours de conservation à 10 ° C;* Eyes open - *'Keimbeginn' - Stade 'point blanc';* 100 % sprouting - *100 % keimend - 100 % germination;* Grown on - *Weiterwachsend - Non égermé;* Desprouted - *Abgekeimt - Egermé*

Abb. 1. Fluktuation bei reduzierenden Zuckern, Sorte Record (basales Auge).
Fig. 1. Evolution de la teneur en sucres réducteurs chez la variété Record (oeil basal).

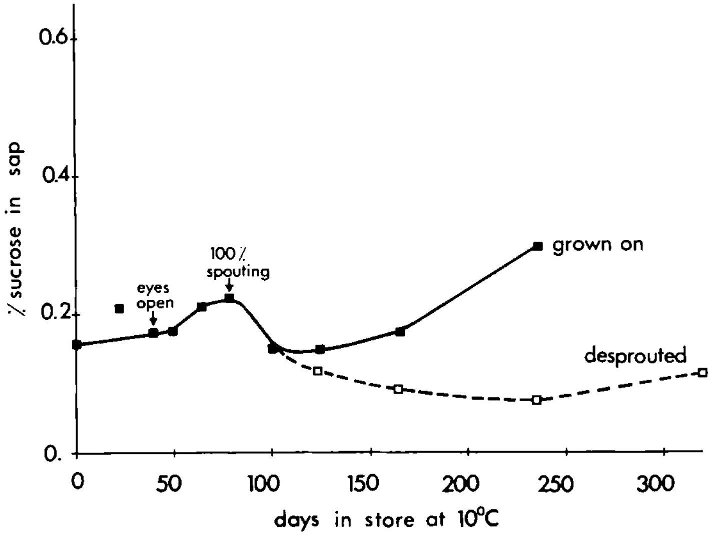
Fig. 2. Fluctuation in reducing sugars cv. Record (apical eye).



% reducing sugars in sap, days in store at 10 ° C, eyes open, 100 % sprouting, grown on, desprouted - *Siehe Abb. 1 - Voir Fig. 1*

Abb. 2. Fluktuation bei reduzierenden Zuckern, Sorte Record (apikales Auge).
Fig. 2. Evolution de la teneur en sucres réducteurs chez la variété Record (oeil apical).

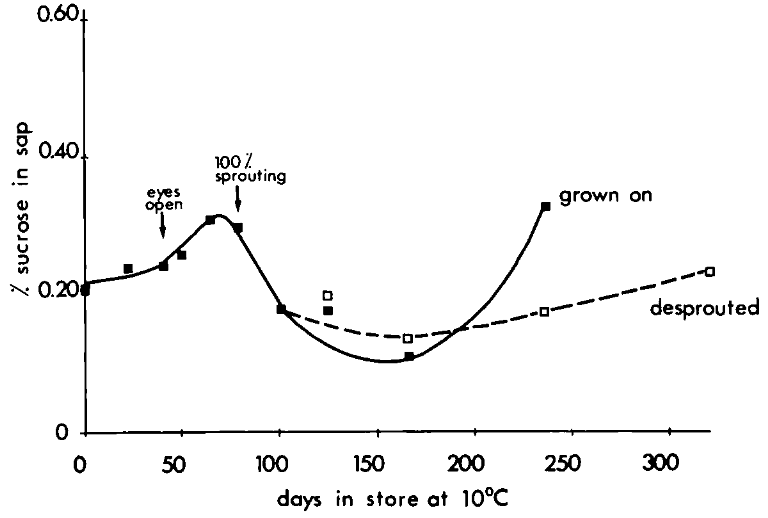
Fig. 3. Fluctuation in sucrose cv. Record (basal eye).



Days in store at 10 ° C, eyes open, 100 % sprouting, grown on, desprouted - *Siehe Abb. 1 - Voir Fig. 1;* % sucrose in sap - *% Saccharose im Saft - % de saccharose dans le jus*

Abb. 3. Fluktuation bei Saccharose, Sorte Record (basales Auge).
Fig. 3. Evolution de la teneur en saccharose chez la variété Record (oeil basal).

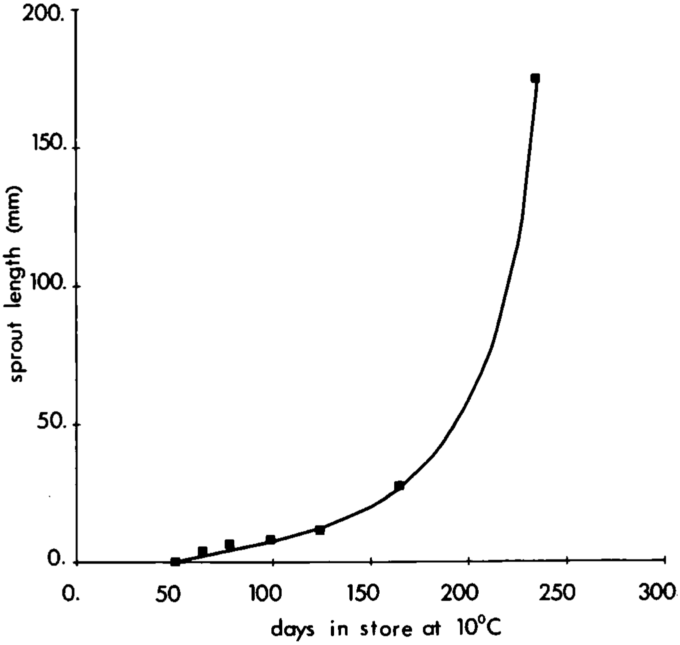
Fig. 4. Fluctuation in sucrose cv. Record (apical eye).



Days in store at 10 ° C, eyes open, 100 % sprouting, grown on, desprouted - *Siehe Abb. 1 - Voir Fig. 1;* % sucrose in sap - *Siehe Abb. 3 - Voir Fig. 3*

Abb. 4. Fluktuation bei Saccharose, Sorte Record (apikales Auge).
Fig. 4. Evolution de la teneur en saccharose chez la variété Record (oeil apical).

Fig. 5. Average sprout length per tuber (cv. Record).



Sprout length (mm) - *Keimlänge (mm)* - *Longueur des germes (mm)*; Days in store at 10 °C - *Siehe Abb. 1* - *Voir Fig. 1*

Abb. 5. Durchschnittliche Keimlänge pro Knolle (Sorte Record).
Fig. 5. Longueur moyenne des germes par tubercule (variété Record).

when stored at 10 °C (Burton & Wilson, 1978). Burton (1977) suggested that this final rise is associated with changes of membrane permeability initiated by biochemical changes preceeding or coincident with the start of sprout growth.

Furthermore it was suggested, primarily on the basis of experiments using the vigorous sprouting first early variety, Home Guard, stored at 20 °C (Isherwood & Burton, 1975), that these changes will proceed even if sprout growth is controlled by the use of sprout inhibitors or by manual desprouting and that without a sink - in the form of sprouts - sugars, particularly sucrose, will accumulate to a greater extent than in sprouting tubers.

In this present experiment it can be clearly seen that all sugars in all tissues are lower in desprouted potatoes than in sprouting potatoes. For example, the level of reducing sugars at the basal end even at 320 days is considerably lower in the desprouted tubers (where it reaches an acceptable level for processing) than in sprouting tubers at their lowest point (about 120 days storage). In fact, desprouting the tubers appears to have extended by 100 days the period during which the reducing sugar content continues to decrease, this effect being particularly marked at the basal end. A similar fall in reducing sugars was found by Bailey et al. (1978) by using disbudded tubers of the maincrop cv. Majestic stored in an unheated store from harvest until late May.

Both reducing sugars and sucrose in both tissues however may show a slight increase after about 230 days storage but this is 50–100 days later than in sprouting tubers.

The results of this experiment, unlike that of Isherwood & Burton (1975), suggest that the final rise in sugars towards the end of storage at 10 °C in cv. Record may be under the control of a feedback mechanism from the growing sprout. However, a rise in sugars after about 320 days, even in desprouted tubers, may occur due to the physiological ageing of tissue and breakdown of membranes as a result of very extended storage.

It is well established that accumulated day degrees can affect the physiological ageing of tubers (Wurr, 1978; O'Brien & Allen, 1981). Consequently, storage at 20 °C together with the use of a vigorous sprouting first early cultivar that is known to accumulate sugars rapidly during storage (and which may thus be physiologically very different to Record) may account for the very different result found by Isherwood & Burton using whole potatoes (1975). In their experiment, both desprouted and sprouted tubers may have aged considerably – possibly resulting in membrane breakdown – after storage at 20 °C from February until June.

Given that the conclusions of the present experiment apply generally, they have important implications for the storage of cv. Record. It should be possible – using sprout suppressants having no adverse side effects on sugar accumulation – to store Record at 10 °C and to lower slowly reducing sugars to an acceptable level over a few months and, where very late storage is required, to delay the onset of senescent sweetening by preventing ageing of the tissue by slightly lowering storage temperature.

Acknowledgements

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Zusammenfassung

Fluktuationen bei Zuckern in der Sorte Record während ausgedehnter Lagerung bei 10 °C

Änderungen bei Zuckern bei der Sorte Record (der bevorzugten Sorte für Crisps im Vereinigten Königreich) erfolgten während 320-tägiger Lagerung bei 10 °C (einer von Kartoffelverarbeitern bevorzugten Lagerungstemperatur zur Verhinderung von Süsswerden bei niedrigen Temperaturen) entsprechend dem Effekt des Keimwachstums. Beträchtlich höhere Gehalte reduzierender Zucker als im Bereich der apikalen Augen (Abb. 2) konnten während der Lagerung durchweg im Bereich der basalen Augen gefunden werden (Abb. 1). Der Unterschied im Gehalt an Saccharose zwischen beiden Gewebezonen war nicht so beträchtlich wie bei reduzierenden Zuckern (Abb. 3 u. 4). Zwei Maxima im Gesamtgehalt an reduzierenden Zuckern zeigten sich während der Lagerung (Abb. 1 u. 2), ein initiales Maximum, möglicherweise mit dem Abbruch der Dormanz assoziiert, und ein zweites in Verbindung mit kräftigem Keimwachstum (Abb. 5). Regelmässiges manuelles Abkeimen ergab nach anfänglichem Anstieg ein viel längeres kontinuierliches Absinken als in keimenden Knollen, ausserdem verzögerte sich das späte Süsswerden beträchtlich (Abb. 1 u. 2). Dies lässt vermuten, dass Süsswerden anschliessend an den Abbruch der Dormanz möglicherweise vom Keimwachstum bestimmt wird. Allerdings wird auch in derartigem Material, wahrscheinlich entsprechend dem Knollenalter, der Gehalt an Zuckern schliesslich ansteigen.

Résumé

Evolution des sucres chez cv. Record pendant la conservation de longue durée à 10 °C

Les modifications de la teneur en sucres survenant dans les différentes parties des tubercules au cours de la conservation ont été suivies pendant 320 jours à 10 °C (température utilisée par les transformateurs pour éviter le 'sucrage' dû aux basses températures) chez Record (principale variété du Royaume-Uni pour la fabrication des chips) en relation avec la croissance des germes. Un taux nettement plus important de sucres réducteurs a été trouvé dans les tissus avoisinant l'oeil de la base du tubercule (Fig. 1) que dans ceux entourant l'oeil apical (Fig. 2) tout au long de la période de conservation. La différence en saccharose entre les deux tissus n'était pas aussi marquée que pour celle des sucres réducteurs (Fig. 3 et 4). En ce qui concerne les sucres réducteurs totaux, deux pics ont été trouvés pendant la conservation (Fig. 1 et 2); le premier pic correspond vraisemblablement à la levée de dormance, le second à la croissance vigoureuse des germes (Fig. 5). Un égermage manuel continu conduisait à un abaissement des taux de sucres réducteurs après le premier pic plus long que pour les tubercules non égermés et le 'sucrage' final apparaissait beaucoup plus tardivement (Fig. 1 et 2), suggérant que le stade de 'sucrage' consécutif à la levée de dormance est vraisemblablement sous le contrôle de la croissance des germes. Cependant, dans un tel matériel, le taux des sucres peut éventuellement augmenter sous l'effet du vieillissement du tubercule.

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