Maintenance of Potato Processing Quality by Chemical Maturity Monitoring (CMM)

Joseph R. Sowokinos and Duane A. Preston

Station Bulletin 586-1988 (Item No. AD-SB-3441)
Minnesota Agricultural Experiment Station
University of Minnesota

MAINTENANCE OF POTATO PROCESSING QUALITY BY CHEMICAL MATURITY MONITORING (CMM)

Joseph R. Sowokinos and Duane A. Preston

Station Bulletin 586-1988
Item Number AD-SB-3441
Minnesota Agricultural Experiment Station
University of Minnesota

St. Paul, Minnesota

PRODUCT DISCLAIMER

AUTHORS

Author Joseph R. Sowokinos is a professor in the University of Minnesota's Department of Horticulture and Landscape Architecture. He is stationed at the Red River Valley Potato Research Laboratory, E. Grand Forks, MN 56721 (A laboratory cooperatively operated by the USDA-ARS; Minnesota Agricultural Experiment Station; The North Dakota Agricultural Experiment Station and the Red River Valley Potato Grower's Association).

Author Duane A. Preston is a professor and Area Extension Agent with the Minnesota Extension Service.

ABBREVIATIONS

[1]CIPC: isopropyl N-C_3-chlorophenyl carbamate

ACKNOWLEDGEMENTS

The authors would like to thank Eunice Paulson and Irene Shea for their excellent technical assistance.

CONTENTS

I. ABSTRACT

Monitoring the chemical maturity of potatoes during development, at harvest and in storage can help minimize losses from immaturity and/or stress effects that influence processed product color (i.e., chips and fries). Chemical maturity monitoring (CMM) is the first commercially feasible method to rapidly measure the chemical maturity of a potato field, on the basis of sugar content. CMM involves analysis of tuber sucrose and glucose content using the Yellow Springs Instrument (YSI), model 27, industrial analyzer in combination with a standard chip test.

Potatoes reach "chemical maturity" during a normal growth process when free sugars drop to a minimum level for processing. This bulletin provides a series of management suggestions for situations commonly experienced in the field, at harvest, or in storage. These suggestions have evolved from several years of consulting with the potato industry on minimizing the detrimental effects of reducing sugars on final product quality.

II. INTRODUCTION

It is well known that sucrose (Fig. 1) is the major free sugar found in immature potatoes. Sucrose is a 12-carbon non-reducing sugar that occupies a critical position in potato tuber development. Translocated to tubers from the leaves, sucrose is the major source of carbons and energy for starch synthesis and potato growth (Fig. 2) (7). The sucrose concentration is high in immature potatoes because its rate of translocation to the tuber exceeds its rate of metabolism in the tuber. Potato cultivars differ in the amount of sucrose they accumulate during growth. A range of from 4mg to 12mg sucrose/g fresh weight was reported in immature tubers of six different cultivars (4).

During potato development some of the carbon from sucrose is completely oxidized to $C0_2$, H_20 and energy (i.e., ATP) (Fig. 2) (3). A protein inhibitor prevents the enzyme invertase (Fig. 2, pathway C) from hydrolyzing sucrose to the two 6-carbon reducing sugars during growth (5). The invertase reaction (reaction 1) becomes active in storage, producing the undesirable reducing sugars from the available sucrose pool. Therefore, high

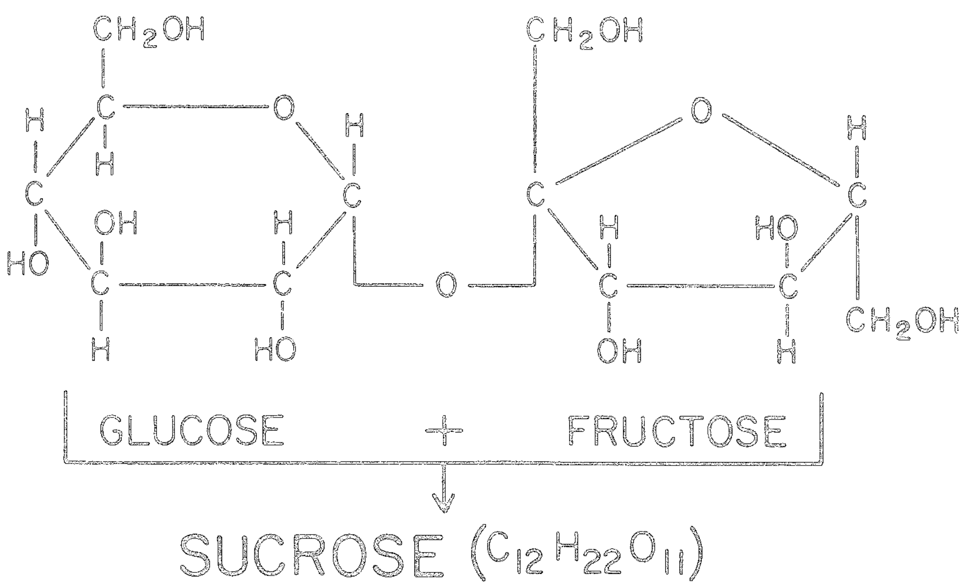


Figure 1. Sucrose (α-D-glucosyl-β-D-fructose)

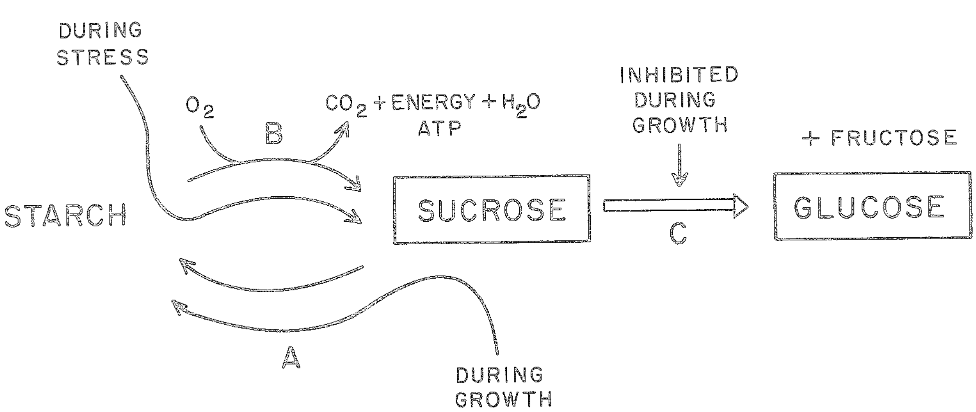


Figure 2. Carbohydrate pathways in potato tubers: (A) starch synthesis, (B) starch breakdown and (C) invertase hydrolysis of sucrose.

levels of sucrose present in potatoes at harvest, can be detrimental to chip color after a few days in storage.

(rx 1)

$$\text{Sucrose } (C_{12}) \xrightarrow[\text{invertase}]{} \text{Glucose } (C_6) + \text{Fructose } (C_6)$$

As raw potatoes are sliced and fried at high temperatures, excess reducing sugars react with the abundant free amino acids in the potato cell, forming brown to black pigmented chips in a non-enzymatic Maillard reaction (reaction 2) (6). Immature potatoes may directly process into acceptable colored chips at harvest, but can yield dark colored chips in a few days due to reactions 1 and 2.

(rx 2)

$$\text{Reducing } C_6 \text{ Sugars} + \text{Amino Acids} \xrightarrow{365^\circ F} \text{Browning}$$

As tubers mature in the field, sucrose content decreases to genetically determined values specific for each cultivar (4,7). The sucrose value or rating (SR=mg sucrose/g tuber) for potentially superior chip processing cultivars should be 1.5 or below. Cultivars vary in relation to their sucrose profile over the growing season (Fig. 3).

Certain cultivars, such as Lemhi and Crystal, maintain undesirably high sucrose levels as they approach physical maturity in September. Other cultivars, including Norchip, Dakchip, Kennebec and Russet Burbank, are genetically capable of reaching desirably low sucrose values prior to harvest.

Chemical maturity monitoring (CMM) of potatoes can be helpful in making management decisions with processing potatoes that are immature or under stress. This system utilizes information from sugar analysis conducted on a Yellow Springs Instrument (YSI) industrial analyzer, model #27 (Fig. 4) (10). The YSI allows rapid, simultaneous measurement of sucrose and glucose content. If the sucrose concentration rises above its SAFE value (i.e., as seen in Figure 5), this signals the storage manager to adjust the storage environment (i.e., temperature and/or ventilation), to remove excess sugar that affects processing quality.

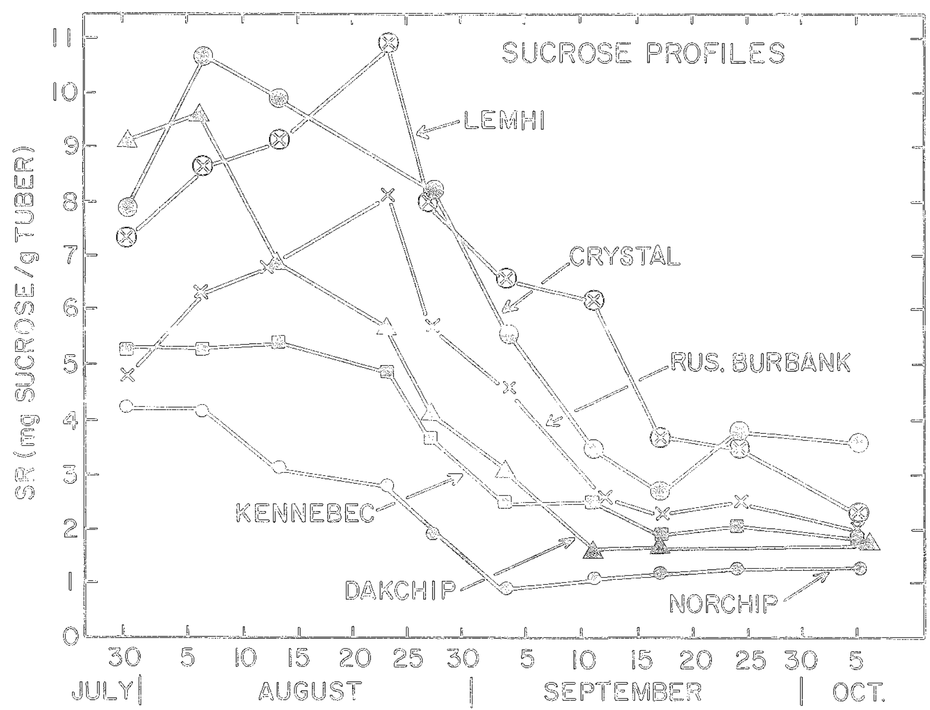
III. MATERIAL AND METHODS

A. Sampling from the field.

1. *If there is uniform topography and vegetation.*
   a. Walk into the field at least 50 feet.
   b. Select five to seven plants at random and collect all tubers.
   c. Place tubers in a mesh bag (30 tubers minimum).
   d. Mark each sample according to field and date sampled.

2. *If there is nonuniform topography or vegetation.*
   a. Select one sampling site from each distinct area type (i.e., upland and bottom land or wet and dry, etc.).
   b. Select five plants from a 10 foot square area at each sampling site.
   c. Collect and combine all tubers from each sampling site (30 tubers minimum).
   d. Identify each sampling site, date sampled and area condition (i.e., high, low, wet, dry).

Figure 3. Sucrose profiles of six potato cultivars during growth.



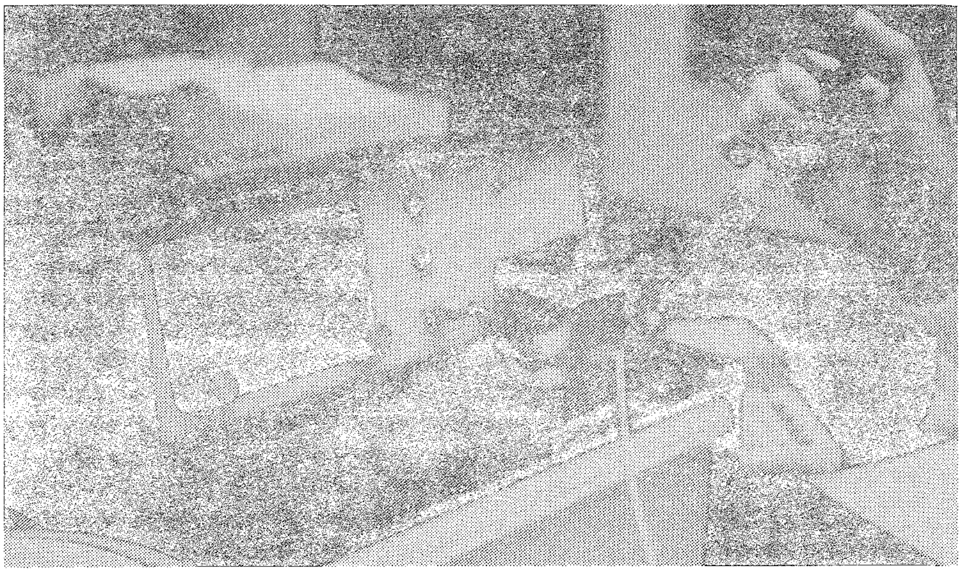


Figure 4. The YSI (Yellow Springs Instrument), model 27, industrial analyzer.

Samples should be protected from direct sunlight, heat, and cold. Store the samples in the dark, at room temperature, and provide good ventilation.

B. Sampling from storage.

1. It is desirable to select two samples per bin (i.e., top and bottom, front or back).

2. Remove surface tubers and collect 25 to 30 tubers. Do not select tubers in direct contact with the floor, side wall or any storage support.

3. Identify each bin, sampling site, date sampled and leave the bags of selected tubers in the bin environment until they are submitted for analysis.

C. Procedure for preparation of sugar extracts.

1. Select at random five or six healthy, average size tubers from each sample.

2. Use a cork bore to remove the center longitudinal core from each tuber, or use a knife to peel and cube the potato and then cut the cube in-half (stem end to bud end).

3. Select longitudinal pieces from cores or half cubes to equal 200g (0.441 lb).

4. Homogenize the sample (200g) in an Acme Juicer, model #6001 (Continental Distributing, Anaheim, CA). Collect the juice in a 600ml beaker and then pass three 100ml volumes of cold distilled water through the juicerator using a l00ml graduated cylinder. Wait one to two minutes between each wash.

5. Mix the juice and sediment, pour the slurry into a cold 500ml graduated cylinder and dilute to 430ml with cold distilled water. Pour the diluted juice back into the same 600ml beaker, mix, cover with plastic wrap and refrigerate the extract for approximately one hour.

6. Remove a 10ml portion of the juice into a small plastic vial and place the vial in an ice bucket at 4° C (39.2° F). The juice is now ready for injection into the YSI. If the sugar concentrations are not measured immediately, then the extracts should be quickly stabilized by freezing.

D. YSI reagents

1. High Phosphate Buffer (Na_2HPO_4-NaH_2PO_4)
   a. *0.32 M, pH 7.1* - Dissolve 30g Na_2HP0_4 (anhydrous MW = 142) and 10g NaH_2P0_4 into one liter of distilled water.
   b. *0.47 M, pH 8* - Add one vial of YSI #2714 buffer to 450ml of distilled water with 20g Na_2HP0_4.
   NOTE: Either buffer may be used with the YSI.

2. *Invertase* (β-fructosidase, Sigma Chemical Co., #I-4504). Add invertase powder so that there are approximately 6000 Units of activity per milliliter of distilled water. This usually involves adding approximately 10 to 20mg of invertase powder per milliliter of solution.

3. *Saline solution* - 0.01 M NaCl. Add 0.585g NaCl per liter of distilled water.

E. YSI sugar determination procedure.

1. Complete the daily operational check, glucose standardization and ferrocyanide test as indicated in the YSI operational manual.

2. Press the clear button to flush the calibration solution from the sample chamber.

3. When the ZERO/INJECT light appears, adjust the ZERO control for a reading of 0.

4. Rinse the syringepet twice with the $extract_1$ to be analyzed, fill with extract and inject it into the sample chamber.

5. When the READ light appears, the value displayed is the *free glucose* (glc_f) in mg/100 of juice. Record this value.

6. Press the CLEAR button, when the ZERO/INJECT light appears adjust the ZERO control for a reading of 0.

7. Rinse a different syringepet twice with invertase solution, then fill and inject invertase into the sample chamber. When the READ light appears, the value displayed is the *invertase value* (generally less than 5). Record the invertase value.

8. Rinse the first syringepet twice with $extract_1$, then fill and inject $extract_1$ into the sample chamber. Immediately press the CALIBRATE button and the DISPLAY will increase as glucose is liberated from sucrose.

9. When the DISPLAY stabilizes (i.e., all sucrose is hydrolyzed in three to four minutes), record the *total glucose value* (glc_t). If the reading is 450 or greater, the extract should be diluted one part to three parts with water and the steps 2 through 9 repeated. Remember to use a dilution factor of four in calculating the final sugar concentrations.

F. Calculation of SR (Sucrose Rating) and the percent glucose.

1. *SR (mg/g)* =
glc_t - invertase reading - glc_f $\div$ $0.526^a \times 0.0215^b$

[a]Each gram of sucrose liberated 0.526g glucose upon inversion.
[b]Dilution factor 0.0215 is the product of 430ml $\div$ 100ml $\div$ 200g.

2. *Percent glucose on a fresh weight basis* =
$glc_f \times 0.0215 \div 10$

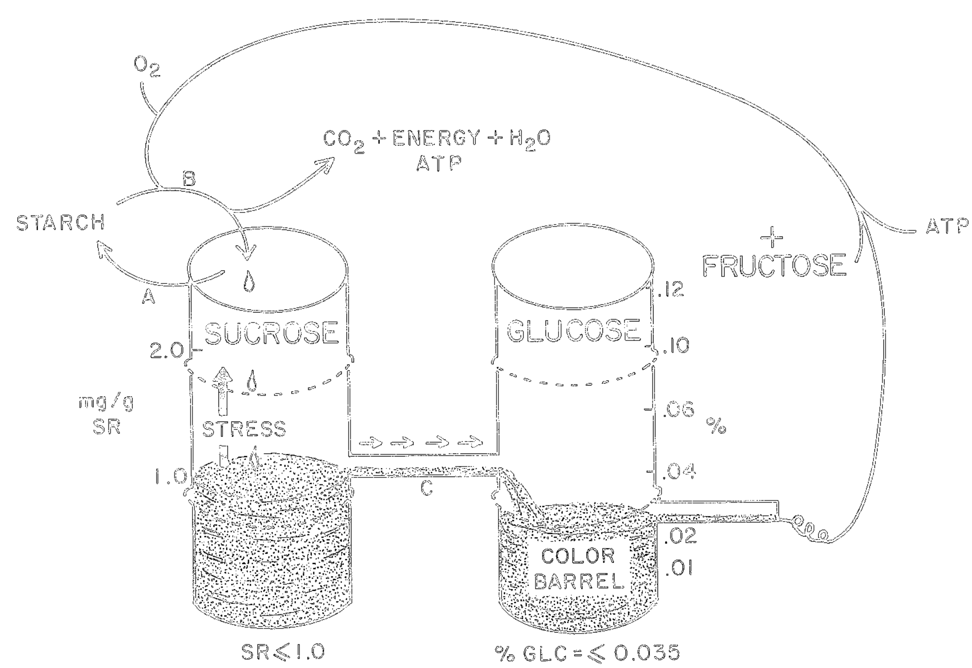
G. Determination of chip color.

A chip testing procedure used to produce potato chips on a small scale has been described previously (2). Grading of chip color is accomplished by comparing chip appearance to the five code chip color chart as developed by the Snack Food Association. The lightest color is 1 with the darkest being 5. Colors of 1 and 2 are acceptable, while colors 3 through 5 are not. Chip color charts can be purchased by writing to SFA, 1711 King Street, Suite One, Alexandria, Virginia 22314.

H. Calculation of sucrose content using a low-temperature anthrone procedure.

If a YSI industrial analyzer is not available, an alternate inexpensive anthrone procedure can be used to measure sucrose content (8,9). This method is just as sensitive and accurate as the YSI procedure. A disadvantage of the anthrone procedure is that glucose values are not

Figure 5. Representation of the desirable (SAFE) chemical maturity for Norchip potatoes in storage.



obtained, however, relative chip color analysis can be used to determine if reducing sugars are within an acceptable level.

IV. RESULTS AND APPLICATION OF CMM

The chemical maturity of potatoes can vary from year to year. Stresses occurring during maturation in the field (i.e.,moisture, heat, cold, etc.) can lead to higher than normal sugar levels in storage (1,10). Stresses also can be introduced during and after harvest from handling, cold, high CO_2, excessive heat, aging, etc. (11). Each of these stresses can accelerate pathway B (Fig. 2) yielding increased sucrose content and eventually darker chip color.

The chemical maturity typically reached by Norchip potatoes in stress-free storage is reflected by an SR < 1.0 and a glucose level < 0.035 percent on a fresh weight basis (Fig. 5). These concentrations represent the maximum tolerable levels of sucrose and glucose. They are referred to as their CONTROL or SAFE values.

Other processing cultivars should experience SAFE values close to those seen for Norchip in 10° C (50° F) stress-free storage. Non-processing cultivars may demonstrate a SAFE value for sucrose at this temperature, but glucose concentrations are generally several fold higher. If chemically mature potatoes are placed into stress-free intermediate temperature storage, they should maintain their SAFE sugar content until irreversible senescent sweetening occurs (i.e., within seven to nine months).

Management suggestions given in this bulletin are based on two major assumptions:

Assumption # 1.

The potatoes are healthy, sprout inhibited and stored at approximately 10° C (50° F) to ensure minimal sugar development induced by excessive heat or cold. If the potatoes are not healthy, suggestions on raising temperatures will need to be compromised.

Assumption #2.

The CMM technique is to be used with potato cultivars which have the general genetic potential to normally process both from the field and from stress-free storage. These cultivars reach acceptable sugar levels at or before the time of harvest and are able to maintain these values in intermediate temperature storage at 10° C (50° F). Genetically high sugar cultivars (e.g., Red Pontiac, Norgold Russet, Lemhi, Crystal, etc.) would respond to the management suggestions that follow, however, glucose concentrations reached would always be in excess of the SAFE values shown in Figure 5.

The following section lists situations that are commonly experienced in the field, at harvest, or in storage, where stresses can result in sugar concentrations higher than their SAFE values. For each situation, management suggestions are given to help minimize the detrimental effects of reducing sugars on the final color of the processed potato product.

V. FIELD SITUATIONS

Field Situation A

Potatoes reach acceptable chemical maturity by harvest time.

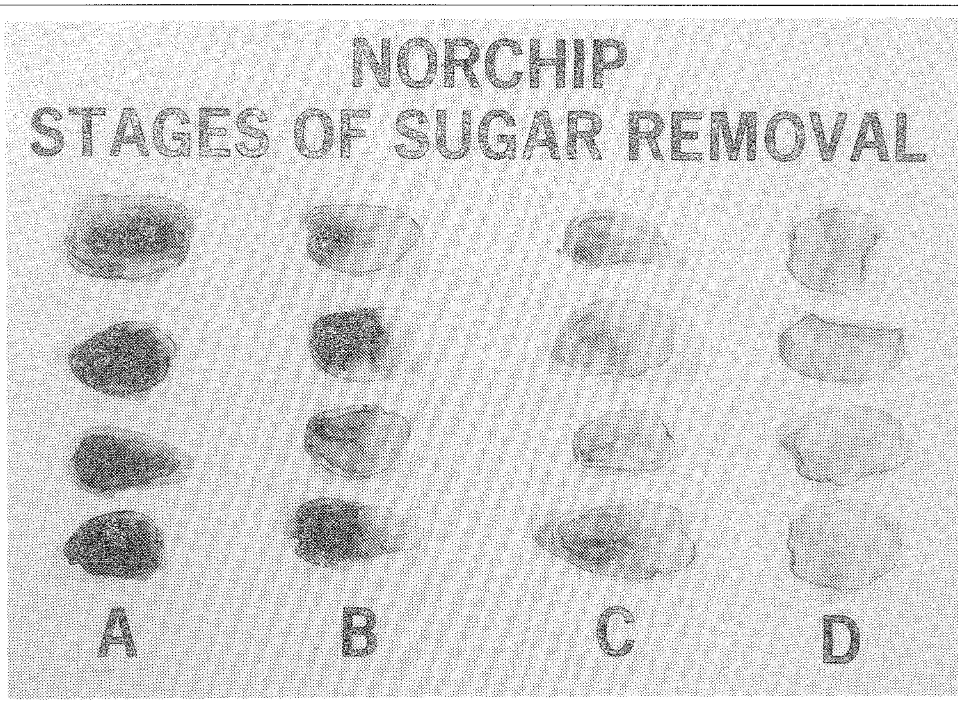


Figure 6. Sugar removal from potato chips: (A) chips are dark, (B) chips are half dark and half light, (C) chips are slightly dark near basal end and (D) chips are light.

e.g., SR < 1.5 and % glc < 0.035
(chip color = 1 or 2).

Management Suggestions A

1. These potatoes are chemically mature. Vine killing is not necessary to achieve chemical maturity. Normal harvesting and the application of Mertect may cause a slight rise in sugars. These sugars are rapidly removed during the wound healing, suberization period (i.e., two weeks at 15.6° C (60° F)). Chip color should remain acceptable throughout this early healing period.

2. After suberization is complete, gradually lower the temperature to 10° C (50° F) for long-term holding.

3. Sample bins monthly for chip color to ensure that a stress is not occuring during storage. After three to four months in storage, sample for sucrose to determine which bins are the most stable.

4. In a stress free environment at 10° C (50° F), chemically mature processing potatoes should yield good colored chips, over a several month period, until irreversible senescent sweetening begins.

Field Situation B

If Potatoes have acceptable sucrose but glucose is above 0.035 percent and chip color is dark.

e.g., SR < 1.5 and % glc > 0.035
(chip color = 3 or higher)

Management Suggestions B

1. Excess reducing sugars (i.e., glucose and fructose) should be rapidly removed during the early wound healing and suberization period of storage (two weeks at 15.6° C (60° F)).

2. After chip color is acceptable reduce the storage temperature to 10° C (50° F) for long-term holding. Then follow *Management Suggestion A, item 3.*

3. If the pulp temperature is 12.8° C (55° F) or less at harvest, it will be necessary to allow the pulp temperature to rise to 15.6° C (60° F) before significant sugar removal will occur. If considerable time is required to achieve acceptable color at this temperature (six weeks or more), it may be advisable to market these potatoes rather than reducing the temperature for long-term holding.

4. Chip color changes may be followed while potatoes are preconditioning at 15.6° C (60° F). Visible changes in chip color, indicating that sugars are being removed over a period of time, are listed below and in Figure 6.

(A) and (D). Within a sample some chips are dark and some are light, respectively.
(B). Some chips are half light and half dark.

The dark portion of some chips appears to be streaked with light areas or rays. Repeat testing after five days reveals that the percentages of dark chips (A) and half/half chips (B) are decreasing while the percentage of lighter chips (i.e., (C) and (D)) is increasing.

Field Situation C

Potatoes have high sucrose content and the percent glucose and chip color are acceptable.

e.g., SR > 1.5 and % glc < 0.035%
(chip color = 1 or 2)

Management Suggestion C

Chips from these potatoes could get darker after vine-kill or harvest. The degree of chip darkening depends on how much higher the sucrose content is above an SR of 1.0. As shown in Figure 5, excess sucrose is converted to reducing sugars, leading to darker chip color. Follow the suggestions given under *Management Suggestions B.*

Field Situation D

Potatoes have a high sucrose content and the chip color is unacceptable.

e.g., SR > 1.5 and % glc > 0.035
(chip color = 3 or higher)

Management Suggestions D

1. These potatoes are chemically immature. If the foliage is still green, vine-killing would prevent additional sucrose from moving into the tuber from the foliage and would also help initiate the removal of sucrose and reducing sugar pools. Chip color may remain dark or even get darker as sucrose is being hydrolyzed to additional reducing sugars (Fig. 5). If the soil temperature was cool so that the potato pulp temperature is 12.8° C (55° F) or less, sugars will not be removed at a significant rate until the tubers are placed in storage and the pulp temperature is allowed to increase to about 15.6° C (60° F). Now follow the suggestions given under *Management Suggestions B.*

2. If the foliage is already dead and/or if vine-killing is not conducted, tuber sugars will have to be removed during the wound healing, suberization period in early storage (15.6° C, 60° F). Proceed with *Management Suggestions B.* Depending upon the variety and the degree of immaturity, tubers may or may not precondition to an acceptable chip color. Improvement of chip color must be carefully followed as listed in *Management Suggestions B, item 4.* Additional testing every five days

will indicate if the sugars are still being removed even though the overall color is still unacceptable. If the chip color shows improvement, continue this conditioning temperature for additional five-day periods and retest. Stop preconditioning when chip color reaches an acceptable level and continue with *Management Suggestion B, item 2.* If the preconditioning period takes longer than one month, note the caution given in *Management Suggestion E, item 6.*

3. If suggestions listed under section D and B are followed and no color improvement is noted after three to four weeks of preconditioning, then these potatoes may have to be sold to fresh or flake markets.

VI. STORAGE SITUATIONS

The purpose of the CMM technique is to detect and help minimize the effect of stress(es) on processing quality. The technique is based on or regulated by the SAFE sugar values (Fig. 5). YSI sugar analysis, coupled with monthly checks on chip color are recommended to ensure that bins are stable, (i.e., that sugar values stay within the SAFE range).

CMM is designed to help identify storage environments that result in sugar accumulation. If management suggestions A, B, C or D listed above are followed, potatoes should yield acceptable color chips at a long-term storage temperature of near 10° C (50° F). If field testing has not been conducted, valuable time can be lost as the storage manager determines whether color problems are due to chemical immaturity or to a stressful storage environment. Both situations would lead to reducing sugar accumulation.

Indecision can hamper efforts to remedy a problem situation, resulting in increasing amounts of sugars being accumulated. Timeliness in responding to color loss in storage is critical to being successful in marketing bins of potatoes versus having them be rejected.

Consider the sucrose value in Figure 5 to be the CONTROL or SAFE value. *If sucrose increases above its SAFE value (1.0 mg/g), then the storage manager should be alerted to a potential problem situation.* Excluding disease loss and/or non-reversible tuber defects (i.e., bruises, vascular ring discoloration, etc.), sucrose and reducing sugars should not increase above their SAFE values in a chemically mature potato held at 10° C (50° F) unless a stress develops during storage. Sucrose normally remains low at this storage temperature until irreversible senescent sweetening occurs (Fig. 7).

Ventilation stress after harvest could cause sucrose values to increase to an SR of 2.0 or above. CMM could detect a stress effect prior to the occurrence of an appreciable change in chip color. If the stress is promptly removed through proper storage management, sucrose could return to its SAFE value without losing potato chip color quality.

Among the primary stresses in storage are those caused by poor ventilation and/or the use of propane internal combustion space heaters. These heaters are acceptable only if the combustion gases are properly vented.

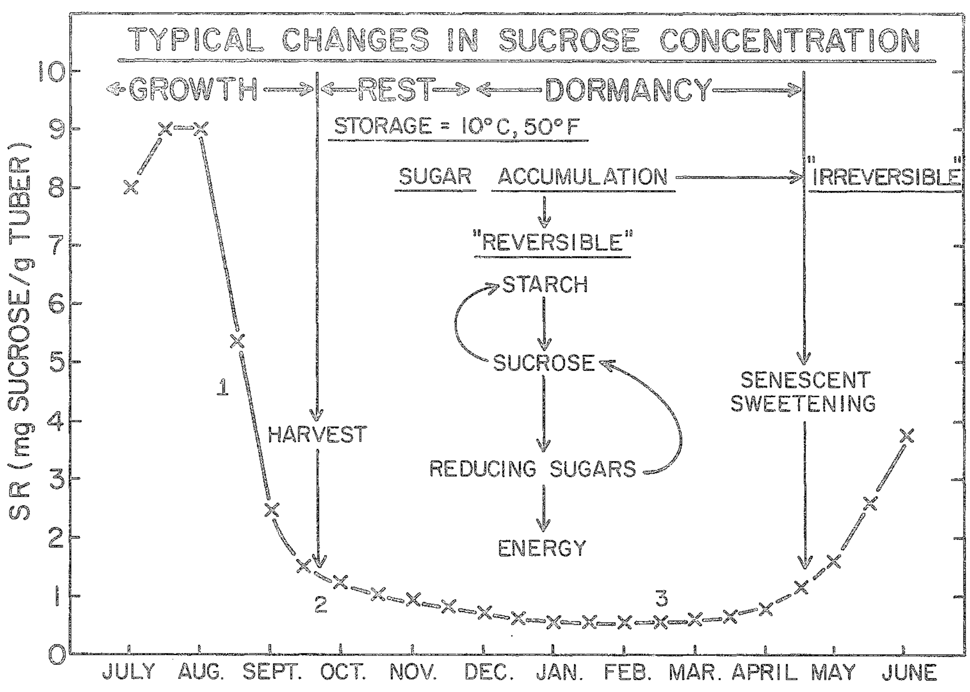


Figure 7. Typical changes in sucrose concentration during growth and storage of potato tubers.

Color Problems Occur in Early Storage (one to four months)

Storage Situation E

1. Potatoes attain SAFE values for sugars relatively easily and the temperature was lowered to 10° C (50° F).

2. Monthly examination of chip color indicated an even brown-shading occurring rather uniformly on most of the potato chips.

3. The chip color continues to darken with time, and dark centers may eventually appear.

Management Suggestions E

1. This situation is quite common when the oxygen concentration of a bin decreases (i.e., CO_2 increases), or air quality is decreased by volatiles from combustion heaters or other machinery in the bin area. Severe stresses can occur with open flame gas heaters if improperly vented. A mild stress situation may also occur with properly vented flame heaters if they have to be run extensively. Oxygen stress can also occur if principally inside air is recirculated with little mixing with fresh air. With ventilation stress, tuber sucrose and eventually glucose will increase above their SAFE values as illustrated in Figure 5.

2. The cause of the ventilation stress should be determined and corrected. Fresh air should be promptly circulated into the bin. If the outside temperature is cold (also a cause of stress) the air should be heated as it is introduced into the bin. If combustion or poorly vented gas heaters were creating the initial problem, use of electric space heaters may be considered.

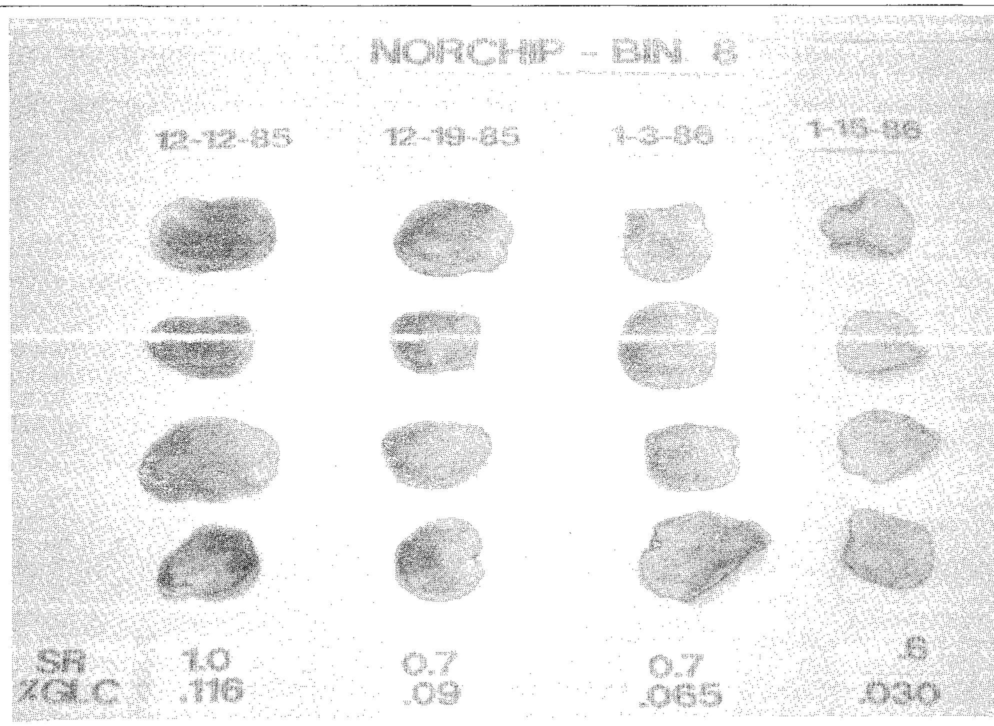
3. At 10° C (50° F) the removal of excess sugars from potatoes occurs extremely slowly. If the tubers are healthy, the temperature can be increased to 15.6° C (60° F).

4. If the stress is relieved early in the storage life of the potato, sugar levels will begin to decrease. Several weeks may be required for sugar to return to SAFE values. Past experience has shown that the sucrose barrel (Fig. 5) generally is reduced to a level close to its SAFE value (i.e., 1.0mg sucrose/g tuber) before the glucose barrel reaches its SAFE level (i.e., color barrel). Potatoes with glucose levels approximating 0.04 percent or below usually produce light colored chips.

Table I shows sugar values of several Norchip bins that experienced ventilation stress early in storage and then recovered. Bin 1 represents a non-stress environment where sugars were below their SAFE values and the potatoes are expected to yield good colored chips at most chipping intervals. Sugar values which are underlined are greater than their SAFE values and dark colored potato chips result. Tubers in bins 6 and 7 were under stress in October and early November from outside temperatures which were several degrees below zero. Propane heaters were started and mainly inside air was recirculated. Also, CIPC[1] was not applied and the tubers broke dormancy. On November 8, fresh air was introduced and sugar values began to decrease within one week (November 14).

The higher sucrose values on November 22 reflected a reuse of the propane gas heaters when the outside air

Figure 8. Color improvement in Norchip potatoes preconditioned at 15.6° C (60° F). Represents bin 8 from Table 1.



Bin		November 8	November 14	November 22	December 12	December 19	January 3	January 15	Febrary 2	Febrary 14	March 7	April 9
1	SR[1]				0.90	0.80		0.80	M[3]			
	%Glc[2]				0.03	0.03		0.04				
2	SR						1.30[4]	1.10	0.80		0.60	M
	%Glc						0.07	0.08	0.09		0.02	
3	SR				0.90	0.80	0.80	0.70	0.50	M		
	%Glc				0.09	0.08	0.06	0.06	0.02			
4	SR						1.40	0.90	0.60	M[5]		
	%Glc						0.10	0.07	0.04			
5	SR					2.10	1.40		0.70	M		
	%Glc					0.05	0.05		0.03			
6	SR	1.80	1.20	3.90[6]	1.70			1.00	M[5]			
	%Glc	0.14	0.12	0.09	0.09			0.04				
7	SR	2.30	1.70	4.50[6]	1.90				1.10	M[5]		
	%Glc	0.14	0.10	0.07	0.08				0.03			
8	SR				1.00	0.70	0.70	0.60	M			
	%Glc				0.12	0.09	0.07	0.03				
9	SR						1.40	0.70	0.70		0.50	M
	%Glc						0.10	0.11	0.04		0.05	

[1]SR = Sucrose rating = mg/g fresh weight of tuber. [2]%Glc = Percentage of glucose on a fresh weight basis. [3]M = Month marketed. [4]Underlined sugar values are above their **CONTROL or SAFE** level. [5]Sprouts hampered marketability. [6]Increase in SR due to extensive heating with gas heaters with little outside air being brought in.

Table 1. Changes in sucrose (SR)[1] and percentage of glucose (%Glc)[2] in ventilation stressed Norchip potatoes. Sugars are being removed at a storage temperature of 15.6° C (60° F).

temperature again decreased. Fresh air was again introduced, but this time the air was heated by electric space heaters. Sugars, over time, reached their acceptable SAFE sugar values and good colored chips resulted. The marketability of these potatoes was hampered, however, by excessive sprout growth. It is also noteworthy that SR levels dropped to1.0 or below prior to glucose reaching its SAFE value of between 0.03 and 0.04.

The other bins (i.e., 2,3,5,8,9), had CIPC application and were all successfully marketed. Bin 4 had an ineffective application of CIPC and sprouts hampered market quality by February. Chip color improvement, indicated for bin 8 in Table 1 is illustrated in Figure 8. SAFE sugar values were reached on January 15 and the potatoes were marketed in February.

5. YSI sugar testing should be repeated every 10 to 14 days to ensure that sugar removal is occurring. If the primary stress has not been removed, sugars will continue to accumulate. If the primary stress has been removed, one can follow the progress of sucrose approaching its SAFE value even though chip color remains dark. The operator may choose to use a sugar removal temperature near 12.8°-13.3° C (55°-56°F) if progress is satisfactory to meet marketing needs. Progress in improving chip color should be monitored as described in *Management Suggestion B, item 4.*

6. If acceptable chip color has returned within three weeks, the pulp temperature can be gradually decreased to 10° C (50° F). *Excess exposure to elevated temperatures is also a stress and can decrease the longevity of the potato.* If considerable time is required (i.e., six weeks or more) to obtain acceptably colored chips, it may be advisable to market these bins as soon as possible without trying to reduce the temperature on these physiologically aged tubers.

Color Problems That Occur in Late Storage (five to eight months)

Storage Situation F

As stated in *Management Suggestion B, item 3,* it is desirable to chip potatoes from bins monthly to ensure that stress is not occuring in storage. One stress always present is the process of aging (senescence) that will eventually lead to a loss of cellular integrity and irreversible sugar accumulation (Fig. 7). Raising the temperature or applying CIPC at this time will accelerate the rate of sugar production with resultant quality deterioration.

Monthly checks of sucrose content are extremely helpful in determining which bins are the most stable. *Those bins requiring little sugar adjustment in early storage and continue to maintain SAFE sugar values month after month would be excellent candidates for the late markets.* Bins showing a gradual increase in sucrose (even though slow) should be considered for early sale. Even a slight environmental stress over a long period of time would be detected by CMM.

Regardless of a potato bin's environment, CMM of sugar values helps to rapidly assess the combined effect of cumulative stresses acting on the internal composition of potato tubers.

Management Suggestion F

1. If the sucrose content approaches or exceeds its SAFE value after storage for several months, one may consider marketing these potatoes prior to bins that have continually maintained sucrose under 1.0 mg/g tuber.

VII. ONE EXAMPLE OF USING THE CMM TECHNIQUE WITH IMMATURE RUSSET BURBANK POTATOES

Russet Burbank french fries prepared from potatoes taken from the field early in October were extremely dark. The storer asked, "Would these condition to make acceptable fries?" It was decided to subject these high sugar potatoes to the same CMM strategy that would be used with chipping potatoes. Three samples were taken from the field on October 18 and their sugar values obtained were in the following range:

SR = 5.00 to 6.80,
%Glc = 0.20 to 0.27.

These results agreed with *Field Situation D,* which indicated that the potatoes were chemically immature with a high sucrose content and unacceptable color. The foliage was dead so vine-kill was not necessary. Harvesting (13,000 cwt) was completed by the end of October. As indicated in *Management Situation D, item 2,* these sugars would have to be metabolized during the wound healing, suberization period in early storage at 15.6° C (60° F).

The steps under *Management Suggestions B* were also implemented as recommended. *Management Suggestion B, item 3,* said if pulp temperatures of potatoes were 12.8° C (55° F) or less, it would be necessary to allow the pulp temperature to rise to at least 15.6° C (60° F). The actual pulp temperature was near 4° C (39.2° F).

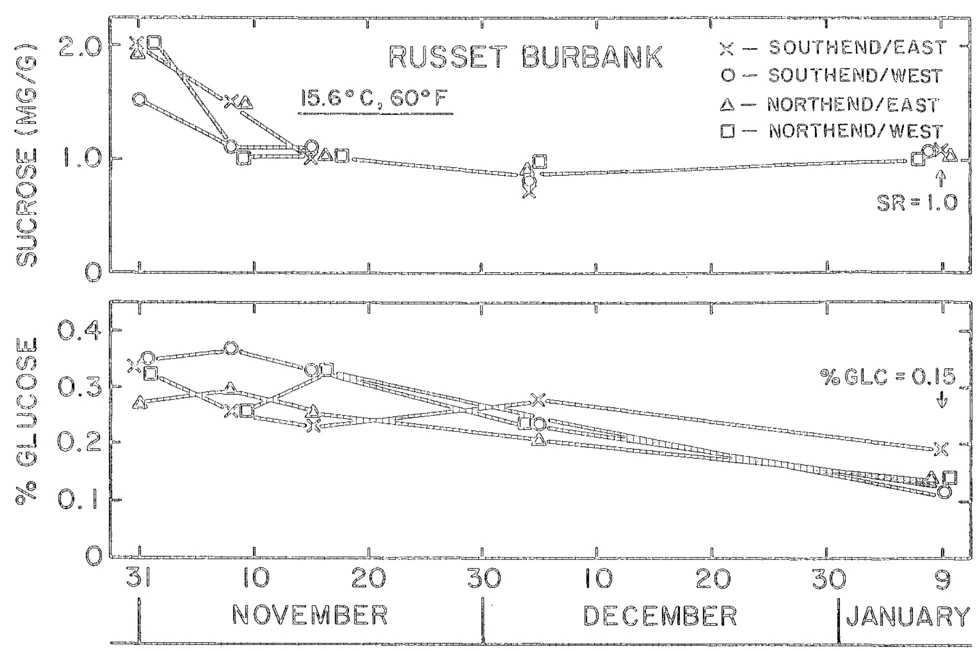
In storage the heat of respiration helped to raise the pulp temperature because fresh air was brought in only periodically. Electric heat was used in the storage facility. Between November 1 and November 15 (Fig. 9), the SR had decreased from near 2.0 to 1.0 where it stabilized for at least two months. This value for sucrose in Russet Burbank potatoes is apparently its SAFE value. After November 15 the percent glucose showed a slow decline from 0.23-0.33 percent, to near 0.15 percent on January 9. These potatoes then produced excellent colored fries and were marketed successfully. About a 4-fold higher glucose concentration is tolerated in tubers processed as french fries compared with potato chips (i.e., 0.15 versus 0.04 percent, respectively).

VIII. SUMMARY

Chemical maturity monitoring (CMM) has provided the first workable method to monitor the "chemical maturity" of potatoes from the field up to the time of processing. This method has been used commercially for approximately nine years. Growers, processors and storers are beginning to depend upon CMM defined sugar levels to guide their timing of vine-kill, harvesting sequence and market timing from storage.

The ever increasing demand for high quality processed products, combined with a very competitive industry, dictates that profits lost by immature and stressed potatoes can no longer be tolerated. CMM provides a method by which problem situations can be handled more efficiently than in the past. Monitoring of potatoes in the field can help detect potential maturity problems prior to

Figure 9. Changes in sucrose content (mg/g) and % glucose in Russet Burbank potatoes during preconditioning at 15.6° C (60° F).



storage. Early detection has led to adjustments in cultural practices (i.e., timing of vine-kill and/or harvesting sequences), adjustments in early storage conditions (i.e., temperature and/or ventilation practices), adjustments in marketing order of bins or a combination of the above.

If potato maturity is acceptable at harvest and storage facilities are adequately constructed and managed to maintain that quality, then CMM will simply indicate that sugar levels are within their SAFE range. This allows the storage manager to be concerned with other parameters which influence final chip acceptability (i.e., disease and bruise defects).

CMM will not prevent all immature or stressed potatoes from being lost for processing, but proper use of the CMM program will help the industry fine-tune their efforts to minimize the detrimental effects of reducing sugars on the final color quality of processed potato products.

REFERENCES

1. Iritani, W.M. and L.D. Weller. 1980. Sugar development in potatoes. Ext. Bull. No. 0717, Washington Agr. Exp. Stat., Pullman, WA.
2. Lulai, E.C. and P.H. Orr. 1980. Quality-testing facilities for grower use at the Potato Research Laboratory. Amer. Potato J. 57:662-628.
3. Mares, D.J., J.R. Sowokinos, and J.S. Hawker. 1985. Carbohydrate metabolism in developing potato tubers, In: P.H. Li (ed.). Potato Physiology. Academic Press, New York. pp. 279-327.
4. Nelson, D.C. and J.R. Sowokinos. 1983. Yield and relationships among tuber size, sucrose and chip-color is six potato cultivars on various harvest dates. Amer. Potato J. 60:949-958.
5. Pressey, R. 1966. Separation and properties of potato invertase and invertase inhibitor. Arch. Biochem. Biophys. 113:667-674.
6. Shallenberger, R.S., O. Smith, and R. H. Treadway. 1959. Role of the sugars in the browning reaction in potato chips. J. Agric. Food Chem. 7:274-277.
7. Sowokinos, J.R. 1973. Maturation of *Solanum tuberosum*. I. Comparative sucrose and sucrose synthetase levels between several good and poor processing varieties. Amer. Potato J. 50:234-247.
8. Sowokinos, J.R. 1978a. Relationship of harvest sucrose content to processing maturity and storage life of potatoes. Amer. Potato J. 55:333-344.
9. Sowokinos, J.R. and D.A. Preston. 1978b. A standardized sucrose rating (SR) procedure. Red River Valley Potato Fact Sheet. No. 101.
10. Sowokinos, J.R., E.C. Lulai, and J.A. Knoper. 1985. Translucent tissue defects in *Solanum tuberosum* L. I. Alterations in amyloplast membrane integrity, enzyme activities, sugars and starch content. Plant Physiol. 78:489-494.
11. Sowokinos, J.R., P.H. Orr, J.A. Knoper, and J.L. Varns. 1987. Influence of potato storage and handling stress on sugars, chip quality and integrity of the starch (amyloplast) membrane. Am. Potato J. 64:213-226.