RELATIONSHIP OF HARVEST SUCROSE CONTENT TO PROCESSING MATURITY AND STORAGE LIFE OF POTATOES[1]

J. R. Sowokinos[2-3]

Abstract

Potatoes capable of reaching low sucrose levels prior to harvest demonstrate superior processing maturity for chipping directly from intermediate temperature storage (11.7C, 53F). Forty-nine of fifty-three potato clones with a harvest sucrose rating (SR= mg sucrose/g tuber) between 1.0 and 2.8 chipped long term from storage (7.0 to 11.0 months). Eleven of twelve clones with an SR greater than 2.8 accumulated reducing sugars at a rapid rate and showed short term storage potential (0.5 to 5.3 months). A correlation coefficient of −0.845 was obtained by comparing the harvest SR value to the $\log_{10}$ of storage life with all clones sampled over two growing and storage seasons.

A standard sucrose rating (SR) procedure is described to rapidly detect annual variation in processing potato maturity to aid in determining proper post-harvest storage and utilization practices.

Resumen

Las papas capaces de alcanzar bajos niveles de sucrosa antes de la cosecha, demuestran inmadurez superior de procesamiento para producir papas fritas directamente de temperatura intermediaria de almacenamiento (11.7 C, 53 F). De 53 clones, 49 con una tasa de sucrosa de cosecha (SR = mg scrosa/g tuber) entre 1.0 y 2.8 produjeron papas fritas por períodos de tiempo largos de almacenamiento (7.0 to 11.0 meses). De 12 clones, 11 con un SR mayor a 2.8 acumularon azúcares reductores a una tasa rápida y mostraron potencial de almacenamiento corto (0.5 a 5.3 meses). Se obtuvo un coeficiente de correlación de 0.845, comparando el valor SR de cosecha

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con el $\log_{10}$ de la vida de almacenamiento de todos los clones muestreados durante dos estaciones de crecimiento y almacenamiento.

Se describe un procedimiento estandard de SR para detectar rápidamente variaciones anuales en procesamiento de maudrez de papas para ayudar en la determinación de almacenamiento después de la cosecha y las prácticas de utilización adecuada.

Introduction

It has generally been accepted that the storage quality of processing potatoes is influenced by tuber maturity at harvest. A scientific definition of processing maturity, however, remains vague and an accurate method for its detection is unavailable. Part of the difficulty stems from attempts to correlate properties associated purely with physical maturation, where vine or tuber growth ceases, to maturity for processing. Many potatoes can complete physical growth without being mature for processing purposes (23). Desirable tuber properties such as high yield, high specific gravity, skin set, etc., have not proven to be indicators of processing maturity (3,4,7,23). The major factor limiting the processing quality of potatoes is their rate of reducing sugar production in storage (5,7,8,21). Although the mechanism of sweetening has received considerable investigation at the membrane (10,13) and enzyme level (11,12,15,17,18,20,24), the physicochemical mechanism causing potato clones to accumulate reducing sugars at different rates in storage is still undefined. Until this variety dependent storage response is clarified on a chemical basis, and understanding of what constitutes the actual "mature state" for process storage will remain elusive.

It is well known that sucrose (12-carbon, non-reducing sugar) is the major free sugar found in immature potatoes (1,2,19,22). More recently, it was observed that poor processing potatoes consistently nonteined on an average 200 to 300% more sucrose per gram of tuber than good processors as physical growth ceased (23). Although sucrose does not participate in the unfavorable non-enzymatic browning of processed products directly, it serves as a substrate for reducing sugar production via the storage activated enzyme invertase (17,18). It was suggested that the level and availability of sucrose at harvest may be the critical factor determining a clone's initial rate of reducing sugar formation and thus affect its time-dependent processing quality from storage.

This study investigated the relationship between harvest sucrose content and the relative rate of reducing sugar accumulation in intermediate temperature storage with several potato clones. It was desired to define processing potato maturity based on its storage requirement, and to describe a sucrose rating (SR) system to rapidly predict maturity at harvest on field grown potatoes.

Materials and Methods

Potato Culture and Storage — Sixty-five potato clones were planted during the 1975 and 1976 growing seasons at the Research Farm of the Red River Valley Potato Growers' Association, Grand Forks, North Dakota. Fifty-one of these were advanced selections developed by Robert H. Johansen[4] and Florian I. Lauer[5]. Each year seven named cultivars served as commercial controls and included three whites (Norchip, Kennebec, Monona), three reds (Red Pontiac, Chieftan, Norland), and one russet (Norgold). Culture was identical with commercial methods in this area.

All samples were harvested mid-September and sucrose ratings (SRs) were determined immediately. Tubers were allowed to suberize at 25.6C (78F) for 12 days and then placed into storage at 11.7C (53F). An intermediate storage temperature was selected to prevent post-harvest sucrose accumulation that is normally observed at colder temperatures (9,24). The chip color of each clone was measured bimonthly with an Agtron Spectral Reflector to determine when excess reducing sugars had accumulated. A sample was considered lost for direct chipping when an Agtron Reading of less than 40 was obtained.

Reagents — A sucrose standard (0.1 ml = 0.1 mg) and 30% KOH were prepared by dissolving 0.025 g dried sucrose per 25 ml water and 35.29 g solid 85% KOH per 100 ml water, respectively. Anthrone was prepared by mixing 150 mg anthrone with 106 ml diluted sulfuric acid (76 ml concentrated sulfuric acid in 30 ml water). The solution was mixed until all anthrone was dissolved (2 hr) and stored in a brown bottle at 4C (39.2F). A 3 ml dispensing pipette or suction bulb should be used to pipette this reagent. New anthrone should be prepared after 2 weeks.

Sucrose Extraction — The standardized tuber extraction procedure is as follows. Select 4 to 5 average size healthy tubers, wash, peel, and cut pieces at random to equal 200 g. Juicerate and then pass 100 ml cold water through juicerator three times. Allow 2 to 3 min between washings. Take extract volume to 430 ml with cold water, mix, cover, and place in refrigerator (4C). Allow the extract to settle for approximately 1 hr and remove an aliquot of supernatant (5 ml) for sucrose determination. Samples should be analyzed immediately, but they are stable at 4C (39.2F) for at least 1 week or at −20C (−4F) for several months.

Clarification of tuber extracts by centrifugation or filtration was not necessary when samples were juicerated rather than homogenized with a blender. Therefore, for convenience use of an Acme Juicerator is recom-

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mended (Acme Juicer Mfg. Co. model #6001, 10th and Lowther Street, Lemoyne, PA 17403).

Sucrose Determination — The microdetermination of sucrose developed by Van Handel (25) was adapted for potato tubers. Removal of reducing sugars, protein, or other material from tuber extracts was not necessary when sucrose was quantitated according to this method. Reagent blanks (0.1 ml water) and sucrose standards (0.1 ml=0.1 mg) should be run to verify each group of determinations. Diluted tuber extracts (1 ml extract/4 ml water) should be run in triplicate (0.1 ml/tube). To each tube add 0.1 ml 30% KOH and heat at 100C (212F) for 15 min to destroy reducing sugars. Cool to room temperature, add 3 ml anthrone reagent, and incubate at low temperature (40C, 104F) for 40 min. Read the stable yellowish-green color at 620 nm.

Calculation of Sucrose Rating (SR) — Using the above procedure, the SR is calculated as follows:

$$OD_{extract} \times 0.1 \text{ mg sucrose} \div OD_{STD} \times 107.5_{\substack{\text{dilution}\\ \text{factor}}} = \text{mg sucrose/g tuber} = SR$$

The dilution factor was determined by the following calculation:

$$\frac{430 \text{ ml (total extract)}}{0.1 \text{ ml (assay volume)}} \times 5 \text{ (extract dilution)} \div 200 \text{ g tuber} = \underline{107.5}$$

If any of these values should vary during the standard sucrose extraction or assay procedure, an adjusted dilution factor can be obtained by appropriate substitution in the above relationship.

The standard SR values at harvest are based on a rating system from 1.0 to 10.0 mg sucrose per g of potato. All varieties or selections that we examined fell within this range. SR values can be converted to percent concentration on a fresh weight basis by dividing the SR by 10.

Sucrose Stability and Dilution of Tuber Extracts — Linear absorbance was observed at 620 nm when 5 to 200 μg sucrose were present per reaction mixture (Fig. 1). The dilution of tuber extracts required to reach this linear absorbance range depended upon the physiological stage of tuber development and cultivar. A dilution ranging from 1 to 1 (dilution factor = 43) to 1 to 4 with water was acceptable for calculation of harvest SRs in high or low sucrose potatoes. With immature or cold stored potatoes (elevated sucrose pools) up to a 10 fold dilution may be necessary. Linear absorbance was obtained with a tuber extract and sucrose standard diluted 0 to 10 fold (Fig. 2). In addition, an additive effect was observed when exogenous sucrose (50 μg/0.1 ml extract) was added to the tuber juice prior to dilution and assay. This indicated that sucrose was not removed enzymatically or destroyed non-enzymatically during this quantitative procedure.

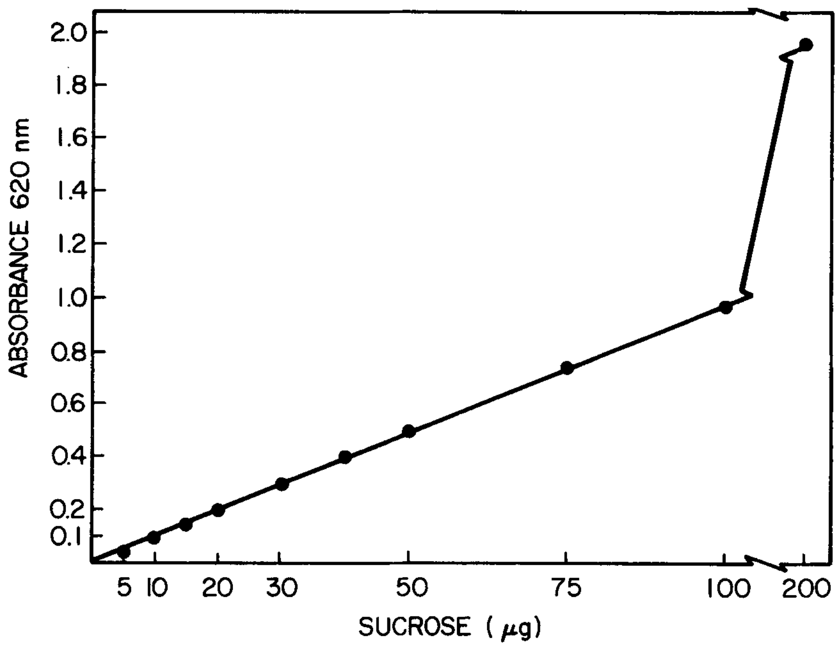

FIG. 1. Sucrose concentration (5 to 200μg) as a function of absorbance at 620 nm. See text for assay conditions.

Results and Discussion

Relationship Between Harvest Sucrose Content and Potato Storage Life — The correlation between SRs and months storage that quality chips (Agtron > 40) were obtained from 11.7C (53F) storage is seen in Figure 3. Sixty-five potato clones were sampled over the 1975 and 1976 growing and storage seasons. In regression analysis, best fit was obtained with a first order polynomial equation relating the $\log_{10}$ of storage life (y) to harvest SR value (x).

$$\log_{10} \text{Storage life} = a + b(SR)$$

A composite correlation coefficient for years 1975 and 1976 of −0.845 was obtained. This coefficient was markedly high even though only one variable of a biological complex system was considered and many diverse genotypes were tested. Utilizing 2nd or 3rd order regressions did not improve this relationship. By substituting calculated constant values for a and b, the following was obtained:

$$\log_{10} \text{Storage life (months)} = 1.4238 + (-0.2546)\ (SR).$$

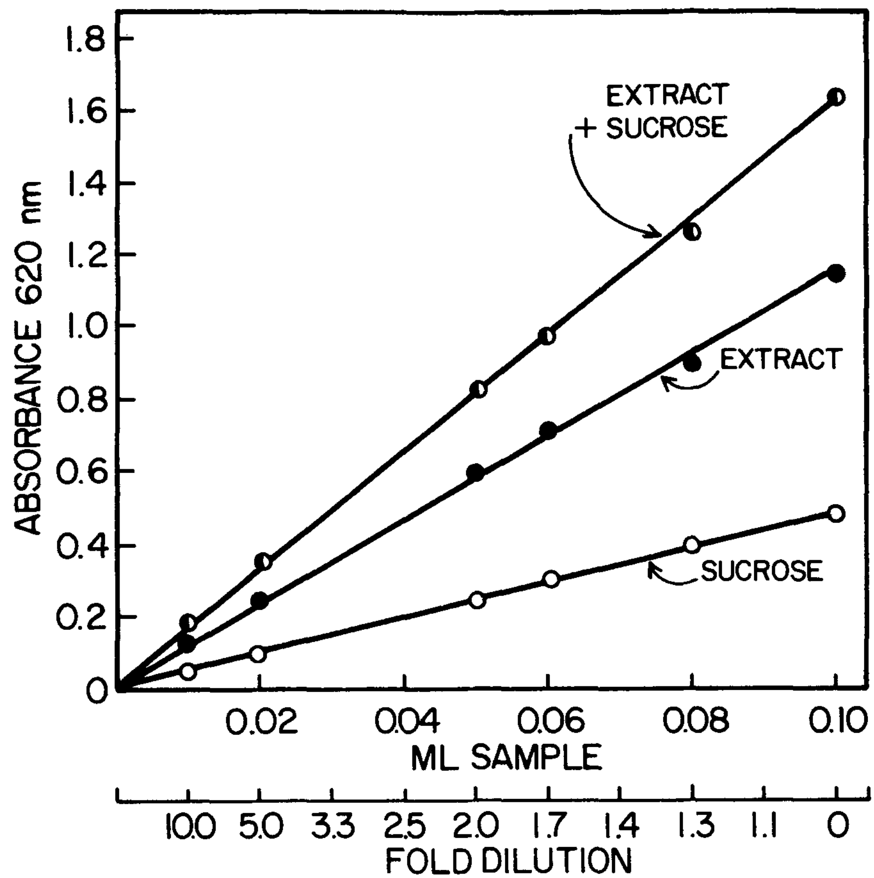

FIG. 2. Sucrose concentration versus absorbance at 620 nm with diluted tuber extracts (0 to 10-fold) (●—●), diluted sucrose standard (50μg/0.1 ml) (○—○), diluted tuber extracts plus added sucrose standard (◐—◐).

This equation was solved for y or storage life and the following relationship resulted:

$$\text{Storage life (months)} = \frac{26.5338}{10^{0.2546(SR)}}.$$

A shift from short to long-term storage potential occurred between an SR value of 2.5 and 3.0 (Fig. 3). Eleven of twelve samples with SRs greater than 2.8 demonstrated short-term chipability (0.5 to 5.3 months). Forty-nine of fifty-three samples with SRs equal to 2.8 or less demonstrated long-term chip quality from storage (7 to 10 months). It was evident that a

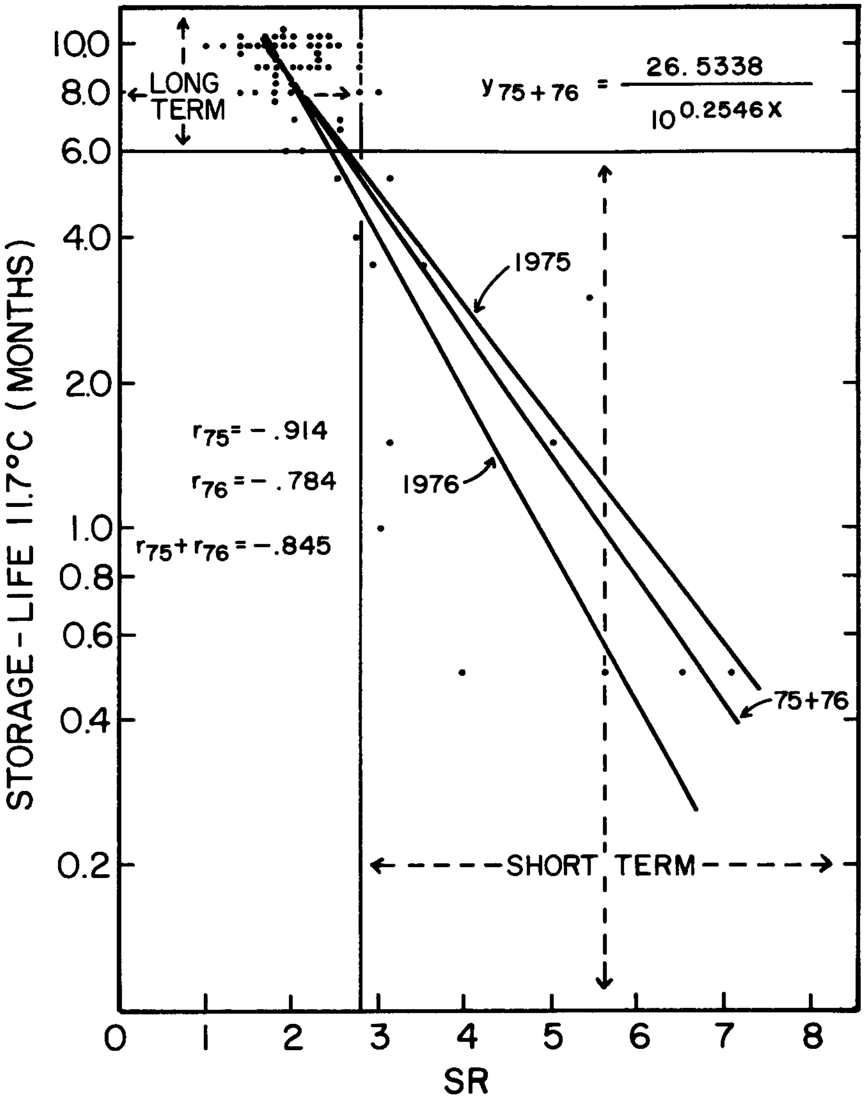

FIG. 3. Regression curve relating the $\log_{10}$ of storage-life (months) at 11.7C (53F) to the harvest sucrose-rating of sixty-five potato varieties and selections.

marked relationship existed between the SR value at harvest and the period when excess levels of reducing sugars accumulated.

Significance Between Harvest Sucrose Concentration and the Processing Maturity of Potatoes —Typical sucrose concentration changes in developing tubers of good and poor processing potatoes are seen in Figure

4. Varieties grown side by side, allowed to reach physical maturation (23), can differ as much as 600 to 700% in their harvest sucrose content. It is evident that the efficiency of endogenous sucrose removal is greater in Norchip compared to the poor processor Red Pontiac. At intermediate temperatures (8.9 to 12.8 C, 48 to 55 F), starch to sugar conversion is minimal (11,13,24) and harvest sucrose pools do not increase until normal sweetening occurs after prolonged storage (2,10,11). Under these particular storage conditions, the initial level and availability of sucrose at harvest may be the major factor limiting the rate of reducing sugar production. The velocity of reducing sugar production via invertase action is equal to a rate constant (k) times the substrate concentration (sucrose). Being a constant, k can be dropped leaving the relationship that velocity of reducing sugar production is equal to the concentration of sucrose. Theoretically, the initial rate of reducing sugar formation in Red Pontiac should be

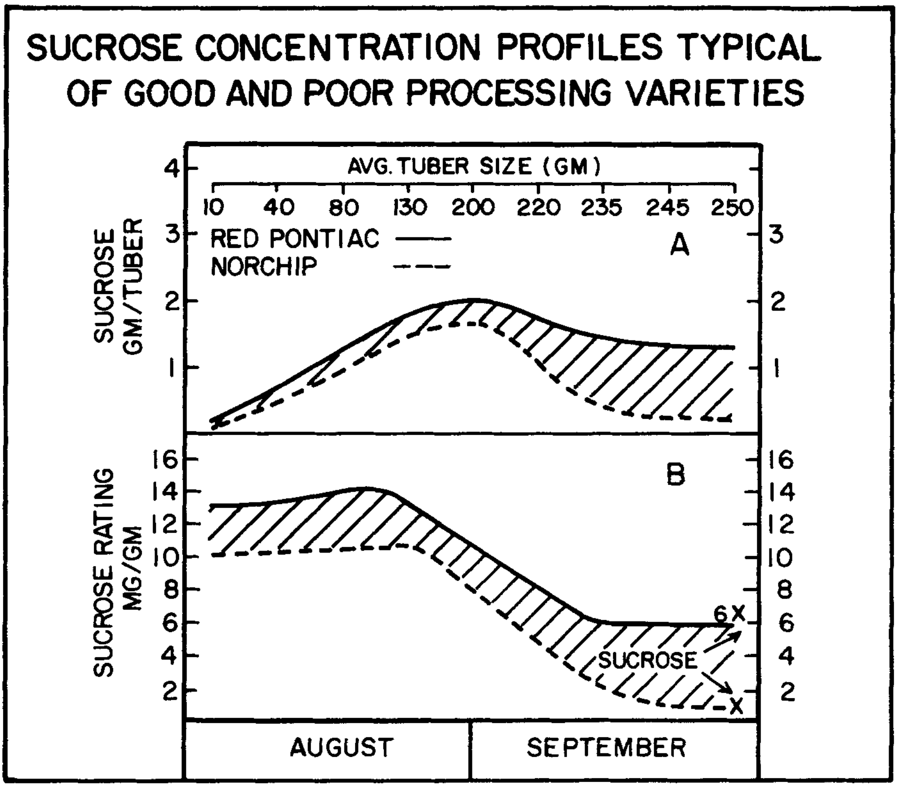

FIG. 4. Changes in sucrose concentration typical of good (Norchip) and poor (Red Pontiac) processing varieties during growth.

significantly greater than Norchip. This response is commonly observed in commercial storages. The substrate level in Red Pontiac at harvest is approximately 5 to 6 fold greater than the K_m of sucrose required to give 50% of the maxium reaction velocity (Fig. 5) (6,16). The rate of reducing sugar formation apparently exceeds its rate of removal for cellular energy requirements resulting in a rapid accumulation. With low-sucrose varieties the rate of reducing sugar formation is apparently close to its rate of utilization for energy purposes resulting in a slow accumulation with time. This substrate limiting effect could explain why Norchip or any variety harvested while immature (Fig. 4B) would behave as a poor processor in storage (SRs 6 to 14). A good storage potato for chip processing is one that contains the inherent ability to reach a low sucrose level (SR 1.0 to 2.8) prior to, or as physical growth is completed. Varieties such as Red Pontiac cease physical growth (physical maturity) without ever being mature for process storage (SR = 6). Norchip, on the other hand, reaches this "mature state" prior to obtaining physical maturity (SR < 2.8) (Fig. 4B).

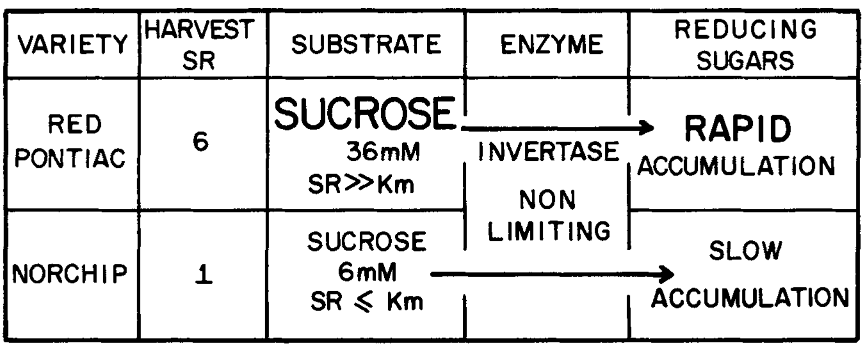

FIG. 5. Proposed effect of varying sucrose levels between good (Norchip) and poor (Red Pontiac) processing varieties on explaining differential rates of reducing sugar accumulation in intermediate temperature storage.

Utilization of SR Values to Predict Annual Variation of Processing Maturity and Storage Practices — Variations in processing maturity can be rapidly detected at harvest by utilizing the sucrose-rating system. The sum of atl field stresses (i.e. moisture, nutrient, temperature, disease, chemical application, etc.) which may effect the sucrose pool size as growth is completed would be reflected in the harvest SR value. Support for this was indicated by comparing the SR values from potato varieties grown both in 1975 and 1976 with storage performance. The 1975 growth period was typically short with adequate rainfall. In 1976, the season was unusually long due to extremely dry conditions. The samples tested appeared to fall into three general categories (Table I). Group A, apparently early maturers, had acceptable sucrose levels and demonstrated long-term chipability directly from storage both years. Group B was of particular interest since it differed markedly in individual SR values between 1975 and 1976. In 1975 Kennebec with an SR of 2.4 was marginal in chip quality for 9 months and was unacceptable early in storage (Agtron < 40). The three samples with SRs greater than 2.8 (0.28% sucrose on a fresh weight basis) showed short-term storage potential (1.5 to 3.5 months). The long, dry 1976 season apparently allowed these medium to medium-late potatoes extra time to more efficiently remove their sucrose pool as physical growth was completed (SRs 1.8 to 2.5). As a result, these samples demonstrated a shift from short to lono-term storage life for processing (Table , Group B). Kennebec was not lost early in 1976 and gave excellent Agtron readings (Agtron > 40) for 10 months. The normally non-processing variety Chieftan was also included in this group. The high-sucrose varieties Norgold Russet and Red Pontiac (Group C) gave unacceptable SR values both years and accumulated reducing sugars rapidly in storage.

TABLE 1. — *Storage quality as a function of annual fluctuations in sucrose-ratings (SR).*

Sample	1975 SR	Storage-life 11.7 C (Months)	1976 SR	Storage-life 11.7 C (Months)
Group A				
Norchip	1.0	10.0	1.4	10.0
8751-16	1.2	10.0	1.4	9.0
8742-2	1.5	10.0	1.8	11.0
8709	1.7	9.0	1.6	8.0
Bison	1.7	10.0	1.6	11.0
8224	1.8	8.0	1.8	8.0
8850-2	1.9	10.0	2.2	11.0
8888-2	1.9	10.0	2.0	9.0
Monona	1.9	10.0	2.3	11.0
Norland	2.1	8.0	2.0	7.0
8297-1	2.1	9.0	2.0	9.0
9086-1	2.3	10.0	2.3	10.0
8750-20	2.4	10.0	2.4	9.0
Group B				
Kennebec	2.4	9.0	1.8	10.0
8415	2.9	3.5	1.8	8.0
Chieftan	5.0	1.5	2.3	8.0
8891-3	5.4	3.5	2.5	8.0
Group C				
Norgold	6.5	0.5	5.6	0.5
Red Pontiac	7.1	0.5	3.8	0.5

If a variety obtains an acceptable sucrose level prior to harvest (SR < 2.8), this should ensure chip processing quality directly from long-term intermediate temperature storage. Pre-harvest sucrose analysis may also indicate a potential maturity problem 2 to 3 weeks in advance. Such early detection may eventually lead to adjusted cultural, storage, or utilization practices, with different lots of potatoes, to permit near normal post-harvest handling techniques. The use of SR as a vine kill indicator to aid control of processing potato maturity is presently under investigation.

The SR value is not anticipated to have as high a correlation to chip quality when stored at cold temperatures (3.3 to 7.2 C, 38 to 45 F). At low temperatures the endogenous sucrose pool is increased above harvest levels due to cold induced starch degradation (2,9,13,24). All varieties are lost from storage after sufficient cold stress, due to sucrose accumulation followed by excess reducing sugar production via invertase action (9,10,24). However, varieties also apparently differ in the rate of this cold-induced sugar accumulation with time. O'Keefe has independently indicated that low-sucrose potatoes have a greater success rate in surviving cold storage or cold storage followed by reconditioning than high sucrose potatoes (14). This result was obtained with over 100 varieties being tested for several years at 11 different growing locations.

Utilization of the SR System to Screen Potato Breeding Stocks —The SR system is presently being used to screen potato breeding stocks to rapidly identify those with low-sucrose potential. It is anticipated that this index will accelerate the selection and commercialization of superior storage and processing potatoes.

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