

#### July 1

#### This is to certify that the

#### dissertation entitled

Experiments on the Long-term Storage of Chipping Potatoes

presented by

Robert James Fick

has been accepted towards fulfillment of the requirements for

Ph.D. degree in Agricultural Engineering

Date 3/15/94

MSU is an Affirmative Action/Equal Opportunity Institution

0-12771



# LIBRARY Michigan State University

PLACE IN RETURN BOX to remove this checkout from your record. TO AVOID FINES return on or before date due.

DATE DUE	DATE DUE	DATE DUE
FEB LANGS		
ŞEP 2 0 2001		
082001		

MSU is An Affirmative Action/Equal Opportunity Institution

### EXPERIMENTS ON THE LONG-TERM STORAGE OF CHIPPING POTATOES

By

Robert James Fick

#### A DISSERTATION

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

DOCTOR OF PHILOSOPHY

Department of Agricultural Engineering

1994

#### **ABSTRACT**

### EXPERIMENTS ON THE LONG-TERM STORAGE OF CHIPPING POTATOES

By

#### Robert James Fick

Tuber sugar levels were used to anticipate late storage season sweetening. Based on biweekly sampling of stored Snowden tubers in 1992-1993, late season rises in sucrose and glucose were detected 8 weeks and 6 to 8 weeks, respectively, before glucose levels rose above 0.01%. Samples with 0.0075% glucose were found to have 90% probability of having a SFA color of  $\leq$  1.5; samples with 0.01% glucose were found to have a 90% probability of having a SFA color of  $\leq$  2. Snowden tubers stored at 10.0°C sweetened and yielded unacceptable chips at least 4 weeks before tubers stored at 7.2°C. Heat treatments at 26.7°C for up to 4 weeks following harvest had a minimal effect on the initiation date of late storage sweetening when subsequent storage was at like temperatures, but longer treatments increased the rate at which sugars rose.

Sampling from the top of the balanced airflow experimental storage bin provided a representative sample of sugars and chip color for the bin. The Snowden variety potatoes stored at 7.2°C responded to storage management in a manner similar to Atlantic variety potatoes stored at 10°C for extended storage seasons in 1990-91 and 1992-93. The Snowden variety can be cooled at

faster rates (0.3°C/day down to 9°C) than are normally recommended for processing potatoes in Michigan, without causing chip discoloration or rises in sugar levels. But pile to plenum temperature differences should not exceed 2.0°C. Smaller differences (1.5°C) may be better if an acceptable cooling rate can be maintained. Faster cooling rates and lower storage temperatures (7-8°C for Snowden) can reduce the need for sprout inhibitors. Snowden potatoes stored below 4.4°C with low temperature induced sweetening were successfully reconditioned in the laboratory 1 of the 2 years. Reconditioning can be successful if temperatures above 10°C are used, but storage at temperatures below the lower limit for the variety are not recommended.

#### **ACKNOWLEDGEMENTS**

I would like to thank Dr. Roger Brook who I value as both a colleague and a friend. I am also grateful to the members of my guidance committee, Drs. Randy Beaudry, Jerry Cash, Philip FitzSimons and Daniel Guyer for their suggestions and contributions.

The research was funded by a Special Grant (USDA 88-34141-3372) and aided by the cooperation and support of the Michigan Potato Industry Commission and Techmark Inc. Thanks also to Dennis Iott and Iott Farms, and to Tom Bishop and Bishop Farms.

I'd like to thank my family for their encouragement and, lastly, I'd like to thank my wife Catherine for all her support and for making the last three years so enjoyable.

#### TABLE OF CONTENTS

			F	Page
Lis	t of Tables			viii
Lis	t of Figures			. x
1.	INTRODI	ICTION		1
2.	LITERATU	JRE REVIEV	N	. 3
			POTATOES	
	2.1.1		riod	
	2.1.2		tioning	
	2.1.3			
	2.1.3		• • • • • • • • • • • • • • • • • • • •	
	2.1.4		n rate	
			ATOES	-
	2.2.1		nent of sugars	
	2.2.2		e Sugar Levels for Chipping Potatoes	
	2.2.3		gar transformation	
	2.2.4		perature and Senescent Stress	
	2.2	-	nzymes	
		2.2.4.1.1	ATP linked Phosphofructokinase (PFK) and PPi	
			linked Phosphofructokinase (PPi-PFK)	11
		2.2.4.1.2	Invertase, Sucrose 6-P synthase (SPSase),	
			UDPglucose pyrophosphorylase (UPPLase)	11
		2.2.4.1.3	Inorganic Phosphorus (Pi)	13
		2.2.4.1.4	Amyloplast Membrane	14
			yp	
3.	MATERIA	LS AND M	ETHODS	15
			SEASON SWEETENING EXPERIMENT	15
	3.1.1	VARIETIE	S	15
	3.1		Production	15
	3.1		tion of Potatoes	16
			ng and Sprout Inhibitor Treatment	16
	3.1.2		STORAGES	17
			Freatments and Storage Temperatures	17
			dity Control	17
		.2.3 Tempe	erature Pattern for 7.2°C storage	17

		3.1.3	SAMPLING PROCEDURES	18
		3.1.	3.1 Chip Samples	
		3.1.		18
	3.2	EXPERI		19
		3. <b>2.</b> 1 .		19
		3.2.2	Control System	20
		3.2.3		20
		3.2.4		22
		3.2.5		22
		3.2.6		22
		3.2.7		26
		3.2.8		26
	,	3.2.9		26
4	DEC		AND DISCUSCIONS	~=
4.			AND DISCUSSIONS	27
		199 <b>2-</b> 19		27
		1992-19 4.1.1		
		4.1.1 4.1.2	Results of Field Storage Experiments	27 31
		4.1.2 4.1.3	0 1	31
	•	4.1.3	Discussion of Chip Color and Sugars in Field Storage Experiments	36
		4.1.4	Discussion of Chip Color and Sugars in Late Storage	50
	•	1.1.1		36
	42	VARIA	BILITY IN SAMPLE SUGAR LEVELS FROM THE FIELD	50
			GE BINS	37
		4.2.1		39
		4.2.2		42
		4.2.3	Discussion of Variability in Tuber Sugar Levels in	
		1.2.0		42
	4.3	LATE S	- 1 - 1 - 0	 44
		4.3.1		45
				45
			1.2 Results of Snowden stored at 10.°C	
			1.3 Discussion Temperature Transfer	
		4.3.	1.4 Discussion of Snowden at 7.2°C	55
			1.5 Discussion of Snowden at 10.0°C	
		4.3.	1.6 Comparison of Late Storage Season Snowden	
			Sweetening at 7.2°C and 10.0°C	57
		4.3.2	Atlantic Variety Late Storage Sweetening	58
			2.1 Results of Atlantic Stored at 10.0°C	58
		4.3.	2.2 Results of Atlantic stored at 12.5°C	59
		4.3.	2.3 Discussion of Atlantic at 10.0°C and 12.5°C	
	4.4	FIELD 9	STORAGE BINS	67
		4.4.1	Atlantic vs Snowden in 1990-1991 Storage Season	67
		4.4.	1.1 Results 1990-1991	67

	4.4.1.2	Discussion 1990-1991	67
	4.4.2 Sno	owden Storage For 1991-1992	67
	4.4.2.1	Results of Cooling Rate Comparison	67
	4.4.2.2	Discussion of Cooling Rates	68
	4.4.2.3	Results of Sprout Control	68
	4.4.2.4	Discussion of Sprout Control	68
	4.4.2.5	Results of Reconditioning	69
	4.4.2.6	Discussion of Reconditioning	69
	4.4.2.7	Discussion of Bin Exhaust Problems	69
	4.4.3 Sno	owden Storage for 1992-1993	72
	4.4.3.1	Results of Cooling Rates and Storage Temperatures	72
	4.4.3.2	Discussion of 1992-1993 Cooling Rates and Storage	
		Temperatures	74
	4.4.3.3	Results for Reconditioning	74
	4.4.3.4	Discussion of Reconditioning	<i>7</i> 5
	4.4.3.5	Results of Weight Loss in Storage	<i>7</i> 5
	4.4.3.6	Discussion of Weight Loss in Storage	<i>7</i> 5
	4.4.3.7	Result for Sprout Growth	75
	4.4.3.8	Discussion of Sprout Growth	<i>7</i> 5
5.	CONCLUSION	S	76
6.	RECOMMEND	ATIONS FOR THE STORAGE OF SNOWDEN	78
7.	SUGGESTIONS	S FOR FUTURE WORK	79
8.	REFERENCES		80
AP	PENDICES		
	APPENDIX A	Sugar and temperature for research bins for 1990-1991	
		season	84
	APPENDIX B	Sugar, temperature and agtron color for research bins,	
	THI LIVED C	1991-1992	88
	APPENDIX C	Equations for Figure 4.2 (acceptable samples versus	
		glucose level)	92
		,	
	APPENDIX D	T test for the difference between means of samples at	
		0.6, 1.7, 3.0 and 4.3 m above the floor in the three	
		research bins for the 1992-1993 storage season, Snowden	
		variety	95
		-	
	D.1 Pai	red t test for all data	96

D.2	Paired t test for trimmed data	.08
APPENDIX	E Curves of late storage season sweetening, 1992-1993 1	.20

#### LIST OF TABLES

	Pa	age
TABLE 1.1	Utilization of potatoes consumed in the USA in 1992	. 1
TABLE 3.1	Storage Dates and Parameters, 1990-1991	23
TABLE 3.2	Storage Dates and Parameters, 1991-1992	24
TABLE 3.3	Storage Dates and Parameters, 1992-1993	25
TABLE 4.1	Glucose (%)*, Sucrose (%)* and Color (SFA)** for Snowden in Field Storage Bins. 1992-1993	28
TABLE 4.2a	Glucose (%)*, Sucrose (%)* and Color (SFA)** for Snowden variety in Late Storage Season Sweetening Experiment. 1992-1993	29
TABLE 4.2b	Glucose (%)*, Sucrose (%)* and Color (SFA)** for Atlantic variety in Late Storage Season Sweetening Experiment. 1992-1993	30
TABLE 4.3	Snowden sugar levels (%)* for all samples from field storage bins grouped by color (SFA)**, 1992-1993	32
TABLE 4.4	Sugar levels (%)* for all samples from the late storage season sweetening experiment grouped by color (SFA)**, 1992-1993	35
TABLE 4.5a	Summary of paired t test for differences between means. ALL DATA	41
TABLE 4.5b	Summary of paired t test for differences between means. TRIMMED DATA	41
TABLE A.1	Potato sugar and temperature data for 1990-1991	84

TABLE B.1a	Potato sugar and temperature data for bin 1, 1991-1992 89
TABLE B.1b	Potato sugar and temperature data for bin 2, 1991-1992 90
TABLE B.1c	Potato sugar and temperature data for bin 3, 1991-1992 91
TABLE C.1	Acceptable chips and glucose levels for intervals, 1992-93
TABLE E.1	Coefficients for sweetening curves, 1993

#### LIST OF FIGURES

		Page
Fig. 2.1	A theoretical scheme for the partitioning of carbons in potatoe Enzymes represented are: (1)UDPglucose pyrophosphorylase, (2) sucrose 6-P synthase, (3) sucrose 6-P phosphatase, (4) alkaline invertase, (5) acid invertase, (6) phosphoglucomutase, (7) phosphohexose isomerase, (8) fructose 6-P,2-kinase, (9) fructose 2,6-bisphosphatase, (10) PPi linked phosphofructokina (11) ATP linked phosphofructokinase, (12) fructose 1,6-bisphosphatase, (13) triose-P, Pi translocator protein, (14) ADPglucose pyrophosphorylase, (15) starch synthase, (16) α-glucose phosphorylase, (17) pyruvate kinase and (18) hexose-Pi translocator protein. From Sowokinos (1990)	ase,
Fig. 3.1	Ventilation system and sensor placement within the potato bir	ı. 21
Fig. 4.1	Color (SFA") versus glucose and average glucose for samples 1992-1993. '% fresh weight basis. "Snackfood Association.	
Fig. 4.2	Probability of SFA color for levels of glucose in chip samples the 1992-1993 storage season (research bins)	
Fig. 4.3	Bin temperature and glucose levels at 0.6, 1.7, 3.0 and 4.3 m (top) above bin floor. Note: Glucose scale is different for bin 3	. 38
Fig. 4.4	Bin temperature and sucrose levels at 0.6, 1.7, 3.0 and 4.3 m (top) above bin floor.	. 40
Fig. 4.5a	Sugar levels for Snowden variety with no heat treatment and 7.2°C holding temperature	. 46
Fig. 4.5b	Sugar levels for Snowden variety with 1 week heat treatment 26.7°C and 7.2°C holding temperature.	

Fig. 4.5c	Sugar levels for Snowden variety with 2 week heat treatment at 26.7°C and 7.2°C holding temperature	47
Fig. 4.5d	Sugar levels for Snowden variety with 4 week heat treatment at 26.7°C and 7.2°C holding temperature	47
Fig. 4.6a	Glucose late storage season sweetening for Snowden variety stored at 7.2°C. (18.3°C after 3/16/93)	50
Fig. 4.6b	Sucrose late storage season sweetening for Snowden variety stored at 7.2°C. (18.3°C after 3/16/93)	50
Fig. 4.7a	Sugar levels for Snowden variety with no heat treatment and 10.0°C holding temperature	51
Fig. 4.7b	Sugar levels for Snowden variety with 1 week heat treatment at 26.7°C and 10.0°C holding temperature	51
Fig. 4.7c	Sugar levels for Snowden variety with 2 week heat treatment at 26.7°C and 10.0°C holding temperature	52
Fig. 4.7d	Sugar levels for Snowden variety with 4 week heat treatment at 26.7°C and 10.0°C holding temperature	52
Fig. 4.8a	Glucose late storage season sweetening for Snowden variety stored at 10.0°C	54
Fig. 4.8b	Sucrose late storage season sweetening for Snowden variety stored at 10.0°C	54
Fig. 4.9a	Sugar levels for Atlantic variety with no heat treatment and 10.0°C holding temperature	60
Fig. 4.9b	Sugar levels for Atlantic variety with 1 week heat treatment at 26.7°C and 10.0°C holding temperature	60
Fig. 4.9c	Sugar levels for Atlantic variety with 2 week heat treatment at 26.7°C and 10.0°C holding temperature	61
Fig. 4.9d	Sugar levels for Atlantic variety with 4 week heat treatment at 26.7°C and 10.0°C holding temperature	61
Fig. 4.10a	Glucose late storage season sweetening for Atlantic variety stored at 10.0°C.	62

Fig. 4.10b	Sucrose late storage season sweetening for Atlantic variety stored at 10.0°C.	62
Fig. 4.11a	Sugar levels for Atlantic variety with no heat treatment and 12.5°C holding temperature	63
Fig. 4.11b	Sugar levels for Atlantic variety with 1 week heat treatment at 26.7°C and 12.5°C holding temperature	63
Fig. 4.11c	Sugar levels for Atlantic variety with 2 week heat treatment at 26.7°C and 12.5°C holding temperature	64
Fig. 4.11d	Sugar levels for Atlantic variety with 4 week heat treatment at 26.7°C and 12.5°C holding temperature	64
Fig. 4.12a	Glucose late storage season sweetening for Atlantic variety stored at 12.5°C	66
Fig. 4.12b	Sucrose late storage season sweetening for Atlantic variety stored at 12.5°C	66
Fig. 4.13	Sprout control for samples of 60 tubers, 15 at each level, 1991-1992. Bin 1 was treated with sprout inhibitor on 11/20/91	<b>7</b> 0
Fig. 4.14	Color (SFA) of reconditioned potatoes. 1992. Reconditioned at 8.3, 11.7, 15.5°C and at 1 week steps of 8.3, 11.7 and 15.5°C	70
Fig. 4.15a	Bin temperature and sugars for bin 1, 1991-1992	71
Fig. 4.15b	Bin temperature and sugars for bin 2, 1991-1992	71
Fig. 4.16	Temperatures and sugar levels for field research bins. Note: change in scale and sucrose units for bin 3. 1992-1993	73

#### 1. INTRODUCTION

Potatoes are harvested throughout the year in the United States. Of the potatoes grown in 1992, about 89% were harvested in the fall (National Potato Council, 1993). Storage is required to maintain a uniform supply of potatoes throughout the year.

The environment required in the storage will depend on the manner in which the potatoes are to be utilized. Potato utilization in the United States is outlined in Table 1.1.

TABLE 1.1 Utilization of potatoes consumed in the USA in 1992.\*

rkesh	30.0%
PROCESSED	
Frozen	37.8%
Chips (and shoestrings)	12.7%
Dehydrated	10.1%
Canned	1.4%

From National Potato Council's 1993 Potato Statistical Yearbook.

When potatoes are to be used for chipping their suitability for processing into chips is dependent on sugar content in addition to internal and external defects. The susceptibility of potatoes to low temperature sweetening and stress related sweetening necessitate a more complete understanding of potato physiology.

Physiological aging of tubers, which will vary by growing conditions as well as by storage conditions, may affect the suitability of tubers for long term

storage. A study was conducted on the response of tubers of differing physiological ages could be determined during long-term storage.

In 1992 a Bin Monitoring Program was initiated by the Michigan Potato Industry Commission to aid growers in the evaluation of the storage potential and in the marketing of their potatoes. Much of the background information for this program was obtained in the Michigan State field research bins. The monitoring and control provided by these bins can provide an important tool in determining the variability that can be expected within a bin and also provide a scientific method to test changes in storage procedures.

#### **OBJECTIVES**

- To develop guidelines for the critical sugar levels and the significance of changes in sugars levels of physiologically aged potatoes
- To monitor the effects of cooling rate and low temperature storage limits on the long term storability of chipping potatoes.
- To develop guidelines for the long term storage of Snowden potatoes

#### 2. LITERATURE REVIEW

#### 2.1 STORAGE OF POTATOES

In the storage of potatoes, it is critical to recognize that the potato is a living organism and the proper environment is needed to protect this perishable product. Improper storage has been estimated to cause a loss of nearly one-third of the potato crop harvested in many countries (Niederhauser, 1993).

Storage losses are normally designated as losses of either weight or quality. The three elements controlled in a potato storage are the temperature, humidity, and oxygen availability. If any of these elements are neglected, product quality can suffer. A good storage can limit storage losses in a good product, but nothing can be done to improve a poor product. It is therefore necessary to assure the quality and maturity of potatoes going into storage.

The market for the stored potatoes will also affect the choice of storage conditions. The principal markets for potatoes in Michigan are seed, table stock, and processing. Storage conditions are most restrictive for processing potatoes where a very low and uniform content of reducing sugars is required (Burton et al., 1992). Prolonged exposure to low temperatures and stress (e.g. handling, rapid temperature change, oxygen depletion) can cause starch conversion to sugars and will cause dark colored processed products (a result of a Maillard reaction between the reducing sugars and amino acids in the potatoes).

The following storage procedures are used for mature chipping potatoes

grown without excessive stress, and harvested under conditions that will not alter the normal biological processes in the potato tuber.

#### 2.1.1 Curing period

Following harvest, a period of time is required for temperature equilibration and wound healing. The optimal harvest conditions for potatoes are temperatures of 10-18°C and soil moisture availability of 60-65% (Plissey, 1993). When the tubers are placed in the storage, temperatures of different tubers may vary 5°C or more. Up to a week may be required for equalization of the temperatures and drying of the tubers.

After harvest, a suberization or wound healing phase starts. This phase allows recovery from the shock of harvesting and handling and formation of new skin on damaged areas.

Ventilation is essential during the curing period. Air movement and exchange are necessary in controlling temperature, moisture, and the exchange of oxygen and carbon dioxide. Recommendations on fan operation have suggested minimum levels of eight hours a day in two intervals (Cargill et al., 1989), and evening only operation (Schaper and Preston, 1989). Mazza and Siemens (1990) measured the CO<sub>2</sub>, sugars, and chip color in commercial storages and found the highest CO<sub>2</sub> levels during suberization. Increases in sugar levels generally occurred immediately after rises in carbon dioxide levels.

From conversations with growers across Michigan, it is apparent that during curing, most managers of chip storages in Michigan run fans

continuously with pile air temperatures held between 12.5°C and 16°C depending on variety and tuber temperature at harvest. A tuber which is in thermal equilibrium with its surroundings will have a slightly elevated temperature due to metabolic heat production. Burton et al. (1992) estimated a temperature gradient of 0.2°C from the center of a tuber to the periphery. This was calculated using an approximate specific heat of the tissue of 3.6 J°C<sup>-1</sup>·g<sup>-1</sup> and a typical heat production of 50 mJ·g<sup>-1</sup>·h<sup>-1</sup>.

Ventilation rates of at least 56 m<sup>3</sup> t<sup>-1</sup>·hr<sup>-1</sup> are recommended for chip potato stores in Michigan (Forbush and Brook, 1993). Some fresh air should be provided regularly to prevent the build up of carbon dioxide and the depletion of oxygen which can be detrimental to potatoes (ASAE EP475 4.3, 1993). A level of 1.0% carbon dioxide should be considered the upper limit with a common level in ventilated bins of 0.2 to 0.3%.

#### 2.1.2 Pre-conditioning

Pre-conditioning is an extension of suberization where the reducing and non-reducing sugars are respired or "burned off". The storage environment is maintained similar to suberization with temperatures around 16°C. The preconditioning treatment has been adapted due to unpredictability in the reconditioning of potatoes (Schaper and Preston, 1989). Reconditioning is the practice of warming the potatoes from the holding temperature to obtain desirable processing color.

The duration of the pre-conditioning treatment is dependent on the chip color and sugar content. Some potatoes may not need pre-conditioning while

others may never attain desired levels. This treatment is completed when chips from the potatoes have reached an acceptable sugar level, usually judged by chip color.

#### 2.1.3 Cooling

After the potatoes have reached acceptable sugar levels and chip color, cooling should be initiated. Potato storage ventilation systems in Michigan are designed to mix fresh air with recirculated air to cool the storage. Ambient conditions determine how rapidly cooling can take place. Advances in control systems allow precise metering of fresh air with recirculated air, eliminating much of the guesswork in ventilation cooling systems.

For processing potatoes, Cargill et al. (1989) recommended a maximum rate of 3°C per week. Another common practice recommended by Thornton (1989) is cooling as quickly as possible to a holding temperature of 10°C.

#### 2.1.3 Holding

Once the potatoes have reached the desired holding temperature, the ventilation rate can be reduced if desired. Temperature uniformity is very important to maintain the required process color for long term storage of potatoes, especially as the pile approaches the lower limit for the variety.

#### 2.1.4 Ventilation rate

The influence of airflow rate on chip potato storage management was investigated by Forbush and Brook (1993). All rates achieved the required temperature and humidity control. Although lower ventilation rates are used in other parts of the country, a ventilation rate of 56 m<sup>3</sup> t<sup>-1</sup>·hr<sup>-1</sup> is still

recommended for chip potato storage in Michigan, particularly to be able to deal with potatoes harvested during a wet fall.

#### 2.2 SUGARS IN POTATOES

The balance between starch and sugar is maintained in the potato as it grows. As the tuber matures, the sucrose levels decrease (Iritani and Weller, 1977) and reducing sugars drop to levels that are acceptable for processing and storage. Sowokinos (1978) modeled the relationship of harvest sucrose content to processing maturity and storage life of potatoes. He found that a low sucrose rating at harvest was a good indicator of storability for chipping.

#### 2.2.1 Measurement of sugars

The levels of reducing sugars, and more specifically glucose, are often used as a quantitative indicator of acceptability of potatoes for chipping.

Leszkowiat et al. (1990) suggested that only part of the chip color could be accounted for by the reducing sugars and that part of the variation in color was due to the sucrose. But under usual storage conditions the glucose levels correlate very well with the chip color.

#### 2.2.2 Acceptable Sugar Levels for Chipping Potatoes

Mazza et al. (1983) demonstrated that reducing sugars, tuber temperature, and sucrose were important in determining chip color of stored tubers. The relative importance of each parameter varied with the age of the tubers, year in which the potatoes were grown and stored, and cultivar. He concluded that the quantitative relationship between the factors assayed was not sufficiently stable to serve as a general measure of prediction.

Santerre et.al. (1986) determined that sucrose levels were useful in the determination of tuber maturity. A sucrose rating (mg sucrose/g fresh tuber) of 1 was used to determine maturity of varieties for processing. Sowokinos and Preston (1988) developed procedures for monitoring chemical maturity of potatoes on the basis of sugar content. For the cultivar Norchip, they recommended harvest sugar levels of less that 0.1% (fresh weight basis) for sucrose and less than 0.035% for glucose. They suggested that other processing cultivars should experience safe levels close to those observed for Norchip.

Though chip color is the true test of the marketability of potatoes, comparisons of chip color are much more difficult to quantify than sugars. Even when differentiation can be made using an Agtron colorimeter, repeatability of a given sample of chips is dependent on chip placement and variation in the sample. Orr (1990) compared two Agtrons, using crushed and whole chips and discussed their application. He concluded that whenever color comparisons of processed potato products are being made, any change in instrumentation or analysis procedures requires a correlation check if data are to be interchanged.

#### 2.2.3 Starch-sugar transformation

The transformation of starches to sugars in storage is variety-dependent and is also influenced by stress during growth, maturity at harvest, and storage environment. The pathways leading to stress-induced sweetening are still unexplained at the molecular level as many factors act in regulating sugar

synthesis and degradation in potatoes. The temperature and intactness of the cell structure are both important in the formation of sugars, along with the key enzymes discussed below.

#### 2.2.4 Low Temperature and Senescent Stress

Lowering the temperature slows most biological reactions including respiration and this is the basis for low temperature storage. Shekhar and Iritani (1978) found evidence of physical changes in the membranes of potato tubers that had accumulated sugars at low temperatures. Potatoes are not considered chill sensitive in the classical sense as the process is reversible. The sensitivity of potato tubers to low temperatures is mainly concerned with the transformation of starch to sugars.

Burton (1974) found a temperature coefficient (Q<sub>10</sub>) for potato respiration of 1.2-1.3 in the temperature range of 10-20°C. The minimum respiration rate for Russet Burbanks was found to occur around 7°C (Boe, 1974). Hunter (1986) determined that a respiration rate of 4 mg·kg<sup>-1</sup>·hr<sup>-1</sup> of carbon dioxide at time of harvest indicates relatively mature tubers. He also found a minimum respiration rate at 7.2°C.

Barichello et al. (1990a) demonstrated that the cold sweetening resistant ND 860-2 showed a higher respiration rate than the cold-sensitive Norchip. Similar results were found by Ehlenfeld et al. (1990). Both agreed that the trend of higher respiration in 'cold-chippers' may contribute to their low sugar accumulation primarily through variations in the enzyme activity of phosphofructokinase (discussed in section 2.2.4.1.1).

Senescence in potato tubers has most often been studied when the tubers are intended for seed. Reust and Aerny (1985) used the physiological age of tubers as determined by sucrose, citric acid and malic acid as indicators of senescence. Sucrose rose quickly as sprouting occurred. van Ittersum et al. (1990) developed a method to assess cultivar differences in rate of physiological aging of seed tubers using measurements of sprout weight, number of sprouts and growth vigor.

Isherwood and Burton (1975) found sugar accumulation occurred in senescent tubers at 20°C even in the absence of wilting (of the tubers) and particularly if sprout growth was prevented chemically or the spouts removed. Hughes (1984) measured sugars in the cultivar Record, stored at 10°C and attributed rises in sugars at 320 days to senescence.

The concept of measuring the physiological age for seed tubers as the number of day-degrees above a base temperature from the onset of sprouting to planting is quantitative and practical (Allen et al., 1992). The base temperature is 4°C and lower depending on the variety. How this could be applied to chipping tubers is unknown.

#### 2.2.4.1 Key Enzymes

To better understand how stresses affect sweetening in potatoes, Sowokinos (1990) developed a *theoretical scheme* for the partitioning of carbon in potatoes (Figure 2.1). The ability of stress to cause sugar accumulation is likely due to a shift or variation in the balance between starch synthesis and degradation, respiration, sucrose formation and sucrose hydrolysis.

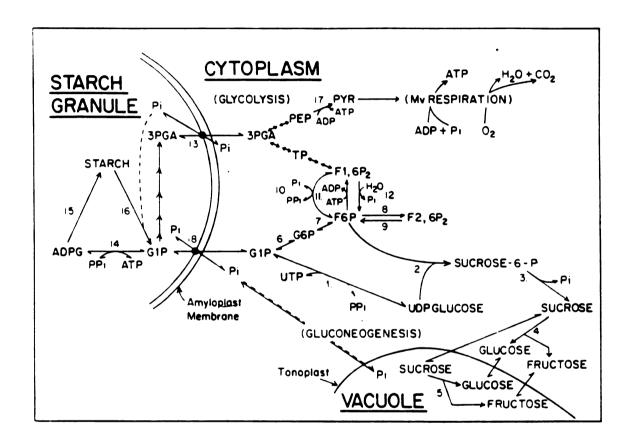


Fig. 2.1 A theoretical scheme for the partitioning of carbons in potatoes. Enzymes represented are: (1)UDPglucose pyrophosphorylase, (2) sucrose 6-P synthase, (3) sucrose 6-P phosphatase, (4) alkaline invertase, (5) acid invertase, (6) phosphoglucomutase, (7) phosphohexose isomerase, (8) fructose 6-P,2-kinase, (9) fructose 2,6-bisphosphatase, (10) PPi linked phosphofructokinase, (11) ATP linked phosphofructokinase, (12) fructose 1,6-bisphosphatase, (13) triose-P, Pi translocator protein, (14) ADPglucose pyrophosphorylase, (15) starch synthase, (16) α-glucose phosphorylase, (17) pyruvate kinase and (18) hexose-P, Pi translocator protein. From Sowokinos (1990).

## 2.2.4.1.1 ATP-linked Phosphofructokinase (PFK) and PPi-linked Phosphofructokinase (PFP)

Glycolysis may be restricted at low temperatures by the activity of PPi-PFK and ATP-PFK (Figure 2.1, rx 10 and 11). Sinha et al.(1990) found a negative correlation between PFP and sugar accumulation in stored tubers, i.e. a high PPi-PFK activity is associated with low glucose content and vice-versa. Claassen et al. (1991) suggested that PFP activity contributes to the cold induced accumulation of sugars by controlling PPi concentration, thus facilitating UDP-Glu and sucrose synthesis.

### 2.2.4.1.2 Invertase, Sucrose 6-P synthase (SPSase), UDPglucose pyrophosphorylase (UPPLase)

The enzymes invertase, Sucrose 6-P synthase and UDPglucose pyrophosphorylase are believed to be critical in influencing sugar formation in gluconeogenesis (Figure 2.1, rx 1, 2, and 4).

The presence of invertase and an invertase inhibitor has been reported in potato tubers (Schwimmer et al., 1961) and confirmed by others. When tubers are held at low temperatures, invertase activity is increased and there is a reduction in inhibitor activity (Pressey, 1969). Ross et al. (1992) concluded that acid invertase in the vacuole or at the tonoplast was more likely than SPSase to regulate sugar accumulation in stored tubers.

SPSase has been cited as demonstrating several characteristics of a regulator enzyme (Dwelle, 1990). The activity of SPSase has been shown to track the increases in sugars at low temperatures (Pressey, 1970; Pollock and

ap Rees, 1975). Sowokinos (1990) reported a greater increase in the specific activity of SPSase in varieties sensitive to low temperature sweetening than varieties less sensitive to low temperatures.

Murata (1972) found that for SPSase to reach 50% of its catalytic activity, high concentrations of UDPglucose (Km =2.5 mM) are required. The level found in potato tubers is 10-20 times lower (Morrell and ap Rees, 1986). This would indicate that the UDPglucose supplied by reaction 1 in Figure 2.1 would be rate limiting. Sowokinos (1990) found the UPPLase activity versus glucose to be highly correlated over long term storage at 3°C and with the varietal activity being the highest in the highest sugar clones.

#### 2.2.4.1.3 Inorganic Phosphorus (Pi)

The location of inorganic phosphorus or compartmentation of the cell is also believed to play a role in starch to sugar conversion (Isherwood, 1976). Shehkar and Iritani (1978) found a positive correlation between the Pi and reducing sugar concentration. The largest concentration of Pi is in the vacuole and leakiness of the tonoplast during cold stress could be responsible for elevating the level of Pi in the cytoplasm.

Excess Pi would aid the mobilization of carbon from the amyloplast to the cytoplasm and would also serve as an inhibitor of ADPglucose pyrophosphorylase (Sowokinos and Preiss, 1982). Senescence stress has also been suggested in increased permeability of the tonoplast by Sowokinos (1990).

#### 2.2.4.1.4 Amyloplast Membrane

Sowokinos et.al. (1987) found that senescence in Norchip potatoes

occurred after 8 to 10 months of storage at 10°C. Once senescence initiated gross physical changes in the integrity of the amyloplast membrane, handling stress was accented. Lulai et al. (1986) looked at a physiological defect that involved translucent-like tissue which occurred randomly in Kennebec potato tubers after 8 months storage. The defect appeared to be an exaggerated form of senescence in the amyloplast membrane.

Barichello et al. (1990b) used chill sensitive Norchip and chill sweetening resistant ND 860-2 varieties to compare the starch granule composition over storage time. ND 860-2 had higher amylose and lower amylopectin as well as a higher crystallinity as compared to starch isolated from Norchip potatoes. Data suggest that starch granule composition is a factor differentiating the low-temperature sweetening sensitive cultivar from the resistant potato cultivar.

#### 3. MATERIALS AND METHODS

#### 3.1 LATE STORAGE SEASON SWEETENING EXPERIMENT

Late in the 1991-1992 storage season, potatoes from many storages in Michigan produced dark chips when exposed to small temperature changes or for no apparent reason at all. Reconditioning (warming the potatoes) was often unsuccessful in removing sugars and the physiological age of the tubers (resulting from a warm growing season) was cited as a probable contributing factor (personal contacts with growers and potato researchers at Michigan State University). A laboratory experiment was performed during the 1992-1993 storage season to:

- 1. To determine the rate of aging when potato tubers are held at a high temperature, 26.7°C, as determined by increases in sugar content and changes in chip color.
- 2. To estimate the rates of sugar accumulation in physiologically aged tubers and develop guidelines to address the sequence of sugar changes.

#### 3.1.1 VARIETIES

The two potato varieties used in this experiment were the Snowden and the Atlantic. Both varieties are high yielding, round whites that are commonly stored in Michigan. The Snowden is a more recently developed variety that has become the most common long-term storage chipping potato in Michigan.

#### 3.1.1.1 Potato Production

The potatoes used in this experiment were grown on irrigated clay soil at Bishop Farms in Bay County, Michigan. The fields were sprayed with

maleic hydrazide (MH30), a sprout suppressant, in mid-August. Diquat was used for vine kill 10 to 20 days before harvest.

#### 3.1.1.2 Collection of Potatoes

The Snowden potatoes were harvested the morning of October 6 at a pulp temperature of approximately 15°C. The Atlantic potatoes were harvested the morning of October 7 at a pulp temperature of about 14°C. Both varieties were dug with a conventional harvester and were handled the same as potatoes entering commercial storage. Tubers for the experiment were collected from the sorting line and placed in mesh sacks at a point where they were leaving a fluidized sand bed sorter to be conveyed into the storage. The Snowden tubers were stored overnight in the MSU Agricultural Engineering Building at about 15.5°C.

#### 3.1.1.3 Washing and Sprout Inhibitor Treatment

On October 7 the potatoes were transported to the MSU Montcalm research station, run through an automatic washer and dipped in a solution of Sprout Nip, which contains the sprout inhibitor isopropyl N-chlorphenylcarbamate (CIPC). The solution was mixed at the concentration recommended for spray treatment of tubers. This is standard procedure for research potatoes at MSU<sup>1</sup>. The tubers were then air dried and transported back to the Michigan State campus and held in a cooler at 15.5°C (59.9°C) until October 8.

<sup>&</sup>lt;sup>1</sup>Personal communication with Dick Chase, MSU Extension Potato Agronomist.

#### 3.1.2 POTATO STORAGES

On October 8 the tubers were randomly divided into treatment groups. The tubers were placed in perforated stackable boxes of dimensions  $41 \times 51 \times 15 \text{ cm}$  (16 x 20 x 6 in.).

#### 3.1.2.1 Heat Treatments and Storage Temperatures

Tubers of different physiological ages were created by placing the harvested tubers in storage at 26.7°C (80°F) for periods of 0, 1, 2 and 4 weeks. During heat treatments, tubers were inspected every other day. Rotted tubers were removed to prevent the rotting of other tubers. After the heat treatment, the tubers were transferred to coolers at 15.5°C for two weeks (suberization), and then to the final storage temperatures.

The Snowden potatoes had final storage temperatures of 7.2 and 10.0°C (45.0 and 50.0°F), and the Atlantic potatoes had final storage temperatures of 10.0 and 12.5°C (50.0 and 54.5°F).

#### 3.1.2.2 Humidity Control

The relative humidity of the heat treatment room, the suberization room, and the 7.2°C storage were held above 90%. The 10.0 and 12.5°C storages were held above 80% but could not be held higher due to limitations of the temperature control systems.

#### 3.1.2.3 Temperature Pattern for 7.2°C Storage

The storage holding the Snowden tubers at 7.2°C was gradually and inadvertently warmed from 7.2°C on March 1 to 18.3°C (65.0°F) on March 21. The temperature remained at 18.3°C until the end of the experiment.

#### 3.1.3 SAMPLING PROCEDURES

#### 3.1.3.1 Chip Samples

Samples of eight tubers were taken for chipping and sugar analysis biweekly or when a temperature transfer occurred. The eight unpeeled tubers were sliced lengthwise through the stem. Three slices of thickness 1.5 mm (0.060 inches) were taken from each tuber and were placed in cold tap water while the remainder of the potato was prepared for the sugar sample. The slices were left in the cold water for at least 0.5 minutes and up to 5 minutes with the norm being about 1.5 minutes. The soaking in water rinsed the slices and also allowed easier separation in the fryer.

The slices were drained and fried in soybean oil at 182°C (360°F). The fry time was approximately 115 seconds as recommended by Gould (1989), or until all the water had been cooked out (ie, only a few bubbles rising).<sup>2</sup>

The chip samples were then visually scored using the Snackfood Association's 1 to 5 color chart using 0.5 steps (Snackfood Association, undated).

#### 3.1.3.2 Sugar Samples

The sugar analysis followed closely the procedure of Sowokinos and Preston (1988). 200 grams of the potato centers were juiced into pint plastic fruit jars. Three portions of cold (4°C) distilled water were used to wash the sample to a total volume of 430 ml. The juice in the plastic jar was then

<sup>&</sup>lt;sup>2</sup>The fry time is dependent on the specific gravity of the potato, the oil temperature, the slice thickness, and the degree of separation of the slices as they enter the oil.

refrigerated for one hour and a 10 ml sample placed in a 30 ml plastic blood sample vial and frozen on dry ice for later analysis.

Every 2 or 4 weeks the frozen samples were thawed to room temperature and a Yellow Springs Instruments (YSI) model 2700 sugar analyzer was used to determine the glucose and sucrose concentrations.

#### 3.2 EXPERIMENTAL STORAGES

The MSU research bins are operated in conjunction with the Storage and Handling Committee of the Michigan Potato Industry Commission. The objectives of the research bins for the years 1990-1993 were:

- 1. To compare the storage recommendations for Atlantic and Snowden potatoes.
- 2. To determine the variability in tuber sugar levels that can be expected in a potato storage.
- 3. To determine the critical sugar levels in the storage of Snowden potatoes.
- 4. To monitor the effects of varying cooling rates and lower temperature storage limits.

#### 3.2.1 Storage and Ventilation System

The MSU storage is a set of three bins, each measuring 2.44 x 2.44 x 5.50 m (8' x 8' x 18') high. Two of the bins were located in a commercial potato facility at Bishop Potato Farm (Pinconning, MI) and the third in a commercial potato facility at Iott Farm (Kalkaska, MI).

Each potato storage research bin had an independent air handling

system capable of maintaining a desired storage environment for that bin.

#### 3.2.2 Control System

Each ventilation system was controlled using a 656 Fancom<sup>3</sup> environmental control computer. The computer controls fresh air and recirculation air volume and humidifying and heating devices. Control changes are made based on feedback from the sensors that are placed in the ventilation system and in the pile as illustrated in Figure 3.1:

- · temperature sensors at one meter increments within the pile
- · temperature and relative humidity of ventilation air
- · temperature and relative humidity of recirculation air
- · temperature of fresh air

#### 3.2.3 Environmental Control

The controller was set to maintain the difference between any two pile temperature sensors at less that 0.2°C (0.36°F) and the difference between the plenum and the pile average at no more that 2°C (3.8°F).

<sup>&</sup>lt;sup>3</sup>Trade names are used solely to provide specific information. Mention of a trade name does not constitute a warranty of the product by the authors or by Michigan State University or an endorsement of the product to the exclusion of other products not mentioned.

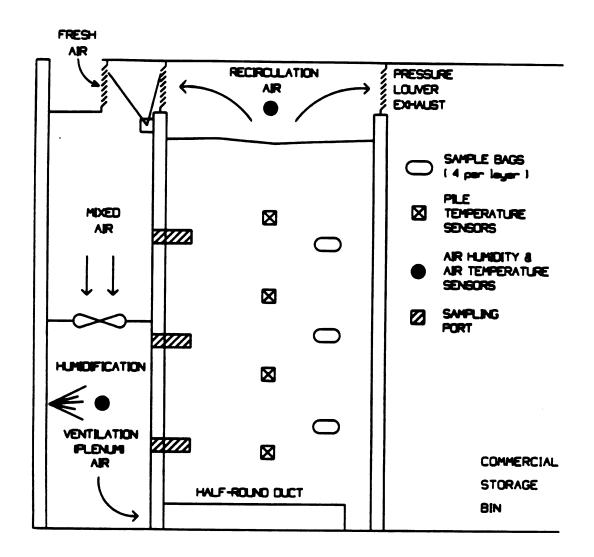


Figure 3.1. Ventilation system and sensor placement within the potato bin.

Dates, temperatures and ventilation information are presented in Table 3.1 for the 1990-1991 season, Table 3.2 for the 1991-1992 season, and Table 3.3 for the 1992-1993 season.

3.2.4 1990-1991 Storage Management - Snowden and Atlantic potatoes were stored for an extended season and their response monitored for the storage strategies used in previous research on Atlantic potatoes. The Atlantic potatoes were held at 10°C (50°F) and the Snowden potatoes were held at 7.2°C (45°F). Other storage procedures are listed in Table 3.1.

## 3.2.5 1991-1992 Storage Management

After the storages were filled and the tubers suberized, the bins were cooled at the rates listed in Table 3.2. Bin 1 was cooled at a rate commonly used in commercial storages and was treated with sprout inhibitor on November 20, 1991. Bins 2 and 3 were cooled at faster rates and were not treated with sprout inhibitor.

On approximately January 18, 1991 the exhaust louver for the building enclosing Bins 1 and 2 malfunctioned and the experiment was terminated.

### 3.2.6 1992-1993 Storage Management

The bins were cooled to the temperatures and at the rates listed in Table 3.3. Bin 1 was stored at 7.2°C and bin 3 was stored at 4.4°C. Bin 2 was cooled until color developed in chips and then the temperature was increased to hold at 7.0°C. Some warming of bins 1 and 2 was done in March for reconditioning of the potatoes.

TABLE 3.1a Storage Dates and Parameters (Metric Units)

4000 4004	DD 7.4 (4.1	77.0 (2)
1990-1991	BIN 1 (Atlantic)	BIN 2 (Snowden)
Harvest date	Sep. 26, 1990	Sep. 26, 1990
Harvest temperature	19. <b>4</b> °C	13.9°C
Suberization run time	24 hours	24 hours
Cooling run times	6/12 hours	6/12 hours
Ventilation rate	$82.1 \text{ m}^3/\text{t}$	$104.5 \text{ m}^3/\text{t}$
Slot velocity	360 m/min	427 m/min
Desired R. H.	90%	90%
Start Cooling/End Precond.	Oct. 31, 1990	Oct. 31, 1990
CIPC Application	Nov. 12, 1990	Nov. 12, 1990
Set cooling rate (actual)	$0.1^{\circ}$ C/day(0.08)	0.1°C/day(0.10)
Start holding	Jan. 8, 1991	Jan. 22, 1991
Holding run times	3/12 hours	3/12 hours
Holding temperature	10°C	7.2℃
Market date	Apr. 9, 1991	Apr. 9, 1991

TABLE 3.1b Storage Dates and Parameters (English Units)

aria raramicicio (2	
BIN 1 (Atlantic)	BIN 2 (Snowden)
Sep. 26, 1990	Sep. 26, 1990
67°F	57°F
24 hours	24 hours
6/12 hours	6/12 hours
2.2 cfm/cwt	2.8 cfm/cwt
1180 ft/min	1400 ft/min
90%	90%
Oct 31 1000	Oct. 31, 1990
	Nov. 12, 1990
·	•
• • • • • • • • • • • • • • • • • • • •	0.18°F/day(0.18)
Jan. 8, 1991	Jan. 22, 1991
3/12 hours	3/12 hours
50°F	45°F
Apr. 9, 1991	Apr. 9, 1991
	BIN 1 (Atlantic) Sep. 26, 1990 67°F 24 hours 6/12 hours 2.2 cfm/cwt 1180 ft/min 90% Oct. 31, 1990 Nov. 12, 1990 0.18°F/day(0.15) Jan. 8, 1991 3/12 hours 50°F

TABLE 3.2a Storage Dates and Parameters (Metric Units)

1991-1992 (All Snowden)	BIN 1	BIN 2	BIN 3
Harvest date	Sep. 18, 1991	Sep. 18, 1991	Sep. 13, 1991
Harvest temperature	25.6°C	25.6°C	23.9°C
Suberization run times	24 hours	24 hours	24 hours
Cooling run times	24 hours	24 hours	24 hours
Ventilation rate	$56 \text{ m}^3/\text{t}$	$56 \text{ m}^3/\text{t}$	$56 \text{ m}^3/\text{t}$
Slot velocity	232 m/min	232 m/min	232 m/min
Desired R. H.	95%	95%	95%
Start Cooling/End Precond.	Oct. 16, 1991	Oct. 16, 1991	Oct. 4, 1991
CIPC Application	Nov. 20, 1991	None	None
Set cooling rate (actual)	$0.1^{\circ}$ C/day(0.09)	$0.3^{\circ}$ C/day(0.16)	$0.05^{\circ}$ C/day(0.27)
Start holding	Jan 15, 1992	Jan 10, 1992	Nov. 15, 1991
Holding run times	3/12 hours	3/12 hours	3/12 hours
Holding temperature	7.2°C	5.6°C	3.9℃
Market date (exp. ended*)	Jan. 18, 1992*	Jan 18, 1991*	May 7, 1992

TABLE 3.2b Storage Dates and Parameters (English Units)

TABLE 3.20 Storage Dates	<u>and Parameters (E</u>	inglish Units)	
1991-1992 (All Snowden)	BIN 1	BIN 2	BIN 3
Harvest date	Sep. 18, 1991	Sep. 18, 1991	Sep. 13, 1991
Harvest temperature	78°F	78°F	<i>7</i> 5°F
Suberization run times	24 hours	24 hours	24 hours
Cooling run times	24 hours	24 hours	24 hours
Ventilation rate	1.5 cfm/cwt	1.5 cfm/cwt	1.5 cfm/cwt
Slot velocity	760 ft/min	760 ft/min	760 ft/min
Desired R. H.	95%	95%	95%
Start Cooling/End Precond.	Oct. 16, 1991	Oct. 16, 1991	Oct. 4, 1991
CIPC Application	Nov. 20, 1991	None	None
Set cooling rate (actual)	$0.2^{\circ}F/day(0.16)$	$0.6^{\circ}F/day(0.29)$	1.0°F/day(0.48)
Start holding	Jan 15, 1992	Jan 10, 1992	Nov. 15, 1991
Holding run times	3/12 hours	3/12 hours	3/12 hours
Holding temperature	45°F	42°F	39°F
Market date (exp. ended*)	Jan. 18, 1992*	Ian 18, 1991*	May 7, 1992

TABLE 3.3a Storage Dates and Parameters (Metric Units)

1992-1993 (All Snowden)	BIN 1	BIN 2	BIN 3
Harvest date	Oct. 5, 1992	Oct. 5, 1992	Sep. 16, 1992
Harvest temperature	15°C	15°C	21.7°F
Suberization run times	24 hours	24 hours	24 hours
Cooling run times	24 hours	24 hours	24 hours
Ventilation rate	$56 \text{ m}^3/\text{t}$	$56 \text{ m}^3/\text{t}$	$56 \text{ m}^3/\text{t}$
Slot velocity	232 m/min	232 m/min	232 m/min
Desired R. H.	97%	97%	97%
Start Cooling/End Precond.	Oct. 25, 1992	Oct. 25, 1992	Oct. 15, 1992
CIPC Application	None	None	None
Set cooling rate (actual)	0.3°C/day(0.17)	$0.3^{\circ}$ C/day(0.19)	0.5°C/day(0.26)
Start holding	Dec. 9, 1992	Dec. 17, 1992	Nov. 25, 1992
Holding run times	3/12 hours	3/12 hours	3/12 hours
Holding temperature	7.2°C	Approx. 5.5°C	3.9°C
Market date	March 31, 1993	March 30, 1993	April 21, 1993

TABLE 3.3b Storage Dates and Parameters (English Units) 1992-1993 (All Snowden) BIN 3 BIN 1 BIN 2 Harvest date Oct. 5, 1992 Oct. 5, 1992 Sep. 16, 1992 59°F 59°F 71°F Harvest temperature Suberization run times 24 hours 24 hours 24 hours Cooling run times 24 hours 24 hours 24 hours Ventilation rate 1.5 cfm/cwt 1.5 cfm/cwt 1.5 cfm/cwt Slot velocity 760 ft/min 760 ft/min 760 ft/min Desired R. H. 97% 97% 97% Start Cooling/End Precond. Oct. 25, 1992 Oct. 25, 1992 Oct. 15, 1992 CIPC Application None None None Set cooling rate (actual)  $0.54^{\circ}F/day(0.31)$  $0.54^{\circ}F/day(0.34)$  $0.9^{\circ}F/day(0.47)$ Dec. 17, 1992 Start holding Dec. 9, 1992 Nov. 25, 1992 Holding run times 3/12 hours 3/12 hours 3/12 hours 39°F Holding temperature 45°F Approx. 42°F Market date March 31, 1993 March 30, 1993 April 21, 1993

## 3.2.7 Weight Loss

Four sample bags of about 9 kg (20 lbs) each were placed at three levels in each bin to determine the weight loss during storage. The bags were placed on the floor of the storage, at 1.5 m (5 ft) and at 3 m (10 ft).

## 3.2.8 Sampling

Bins 1 and 2 were sampled weekly during the 1990-1991 and 1991-1992 seasons, and biweekly during the 1992-1993 season. For the 1991-1992 season, bin 3 was sampled weekly until December 1, 1991 and thereafter was sampled biweekly. For the 1992-1993 season, bin 3 was sampled biweekly until January 19, 1993 and monthly thereafter.

15 tuber samples were taken from the top of the pile and from three levels within the pile. The samples were chipped and analyzed for sugars in the manner described in section 3.3, using all 15 tubers for chips and 8 tubers for sugar samples.

## 3.2.9 Reconditioning

On April 7 1992, samples from bin 3 were transferred to warmer storages for reconditioning. Three treatments were placed in storages at 8.3°C (47°F), 11.7 (53) and 15.5 (60). A forth treatment was held at 8.3°C for one week, 11.7°C for one week and then at 15.5°C for the remaining time. Ten tubers from each treatment were sampled weekly for fry color and sugar levels.

On April 21 1993, samples from bin 3 were transferred to storages at 12.5°C (54.5°F) and sampled biweekly for 6 weeks.

### 4. RESULTS AND DISCUSSIONS

The sugar samples collected during the 1990-1991 and 1991-1992 seasons were analyzed using a YSI Model 27 sugar analyzer. The lower limit of the Model 27 analyzer under good operating conditions is approximately 0.1 g/l which corresponds to a glucose level of 0.022%. The sucrose levels were calculated from the glucose readings before and after reduction of the sample with invertase. Since the critical glucose level for darkening of processed chips as determined in this study falls below the level of accuracy for the YSI Model 27, the data collected during the 1990-1991 and 1991-1992 storage seasons is limited in its application.

A YSI Model 2700 sugar analyzer was purchased by the Michigan Potato Industry Commission during the summer of 1992 and was used for analysis of samples from the 1992-1993 season.

Data from 1990-1991 and 1991-1992 field research bins are listed in Appendices A and B. Table 4.1 lists the sugar levels and chip color (1992-1993 season) for the four levels in the three field research bins. Tables 4.2a and 4.2b display the sugar levels and chip color Snowden and Atlantic potatoes in the laboratory experiments. Plots and discussion are included later in this chapter.

### 4.1. CORRELATION BETWEEN CHIP COLOR AND SUGARS, 1992-1993

## 4.1.1 Results of Field Storage Experiments

The sugar data of Snowden samples from the three research bins in 1992-1993 were sorted by chip color using the Snackfood Association's 1 to 5 color chart using 0.5 steps (Snackfood Association, undated). The average,

TABLE 4.1. Glucose (%), Sucrose (%) and Color (SFA) for Snowden in Field Storage Bins. 1992-1993.

150	Sampling lo	cation	Glucose & height fr	from floor 4.3 m	1 1	Sampling 0.6 m	cation	Sucrose & height for 3.0 mm	from floor 4.3 m	1 1	SFA Color
0		47		5		0.103	0.123			0.113	1 5
9 0		3 2	0.0037	0900.0	0.0044	0.089	: 0.	0.073	0.114	0.094	1.0
0			•	.003	•	0.082	۰.		•	0.089	1.0
-				100	•	0.049		•		ود0.0 170	
0030 0.				.003	0.0032	0.070	. 0			0.078	1.0
0			0.0030	.003	•	.04	٥.			0.054	
٥.			•	. 007	•	•	7	•	•	0.093	
			•	.012	0.0083			0.078	•	0.099	
75 0.			•	. 009		٠	٥.	•	٠	0.074	
95 0.004	00.		0.0138	.010	•	٠	٥.	•		0.078	
73 0.005	.005		•	.012	•	.04	٥.	0.035	•	0.052	
38 0.0	010		•	•	•	. 05	٥.	. 05	•	90.	
52 0.010	010		0.0067	. 01	0.0084	0.073	0.077	0.064	0.084	.07	
0					0.0053		•			Ξ.	
~	.003		•		.002				. 08		
0.005	.005		0.0028	0.0071		0.089	0.106	•	0.		
0.001	.001		•	.002	•			•			
4 0.003	. 003		•	. 003	•		•	•	. 07	•	
0.	.004			. 003	0.0031	0.067	0.072		0.074	0.071	
<b>3</b> 0.003	. 003		•	. 002	•	•	•	•	.07	•	
0.003	.003		•	•	•	0.073	•	•	0	•	
0.00	3 :		٠	. 014	•	•	•	•	2	•	
2.0	7.0		•	470.	•	٠	•	•		٠	
0.02	0.0		•		•			•	) (		
0.01	. 6		0.0114	. 047	0.0230	160.0	0.100	•	80.		
0.020	0.20		•	000	•			•		0	
0073 0.0151	.015		0.0077	0.0095	0.0099	0.073	80.	0.049	0.038	0.061	1.5
54 0.										0.	
39 0.			•	.007	•				•	٦.	
30 0.				.005	•	٥.	٥.	•	. 09	0.	•
17 0.			•	. 003	•		•	•	90.	٥.	
84 0.	•		•	900.	•	٥.	•	٠	Ξ.	Γ.	
15 0.			•	•	•	7	٦.		. 16	Ξ.	•
82 0.			•	.078		Ξ.	7	•	.27	7	•
20 0.	•		•	.108	•	۲,	7	•	. 23	7	•
70 0.	•		•	Τ.	•	~	?		. 23	7.	•
0959 0.1008	•		0.1159	0.1621	0.1187	0.180	0.191	0.186	0.260	0.204	5.0
64 0.	•		•	<b>-</b> .	٠	∹ .	?	٠	. 55	?	
7			•		•	-		•		<b>-</b> .	

'% weight on a fresh weight basis. "SFA, Snackfood Association color rating. Blank spaces - no measurements were taken.

TABLE 4.2a. Glucose (%)', Sucrose (%)' and Color (SFA)'' for Snowden variety in Late Storage Season Sweetening Experiment. 1992-1993. SNOWDEN HOLDING TEMPERATURE 7.2°C

		Glucose	se &	Weeks	weeks of near c	Sucrose	rreatment at 26.7°C preceding Sucrose &	preceding		Color (	(SFA)	
DATE	0 week	1 week	2 week	4 week	0 week	1 week	2 week	4 week	0 week	1 week	2 week	4 week
10/08/92	0.0054	0.0054	0.0054	0.0054	0.114	0.114	0.114	0.114	1.0	1.0	1.0	1.0
10/16/92	0.0037	0.0034	0.0034	0.0034	0.073	0.088	0.088	0.088	1.5	1.5	1.5	1.5
10/23/92	0.0037		0.0039	0.0039	0.087		0.130	0.130	1.0	1.0	1.0	1.0
10/30/92		0.0039		0.0030		0.097		0.095	1.0	1.5	1.0	1.0
11/06/92	0.0125	0900.0	0.0024	0.0026	0.132	0.123	0.064	0.095	1.5	1.5	1.0	1.5
11/19/92	0.0118	0.0054	0.0017	0.0224	0.079	0.075	0.032	0.084	1.5	1.5	1.5	1.5
12/04/92	0.0148	0.0073	0.0077	0.0037	0.101	0.112	0.117	0.087	2.5	2.0	1.5	1.5
12/21/92	0.0151	0.0138	0.0118	0.0067	0.086	0.109	0.091	060.0	2.5	2.5	2.0	1.5
01/04/93	0.0157	0.0144	0.0170	_	0.117	0.104	0.113	0.163	1.5	1.5	1.5	1.0
01/18/93	0.0183	0.0116	0.0280	_	0.105	0.099	0.097	0.237	1.5	1.5	1.5	2.0
02/01/93	0.0058	0.0065	0.0138	_	060.0	0.075	0.085	0.109	1.5	1.5	1.0	2.0
02/15/93	0.0065	0.0045	0.0069	0.0133	0.038	0.040	0.035	0.119	1.5	1.5	2.0	1.5
03/01/93	0.0039	0.0047	0900.0	0.0101	0.061	0.063	0.044	0.100	1.0	1.5	1.5	1.5
03/16/93	0.0022	0.0043	0.0045	0.0067	0.043	0.041	0.051	0.098	1.0	1.0	1.5	1.5
03/28/93	0.0024	0.0017	0.0015	0.0178	0.039	0.027	0.031	0.208	1.0	1.0	1.0	2.0
04/12/93	0.0019	0.0019	0.0002	0 000 0	0.061	0.067	0.077	0.215	1.0	1.5	1.5	1.5
04/26/93	0.0037	0.0052	0.0054	0.0110	0.129	0.151	0.147	0.221	1.5	1.5	1.5	2.0
05/10/93	0.0067	0.0099	0.0155	0.0110	0.134	0.224	0.165	0.221	1.5	1.5	2.0	2.0
05/24/93	0.0075	0.0086	0.0151	0.0103	0.212	0.288	0.221	0.307	1.5	1.5	2.0	2.0
06/01/93	0.0155	0.0103	0.0088	0.0196	0.292	0.277	0.186	0.383	2.5	2.5	2.5	2.5
06/22/93	0.0133	0.0142	0.0114	0.0101	0.152	0.194	0.239	0.192	2.5	2.5	3.0	3.0
SNOWDEN HOLDING TEMPERATU	DING TEM	PERATURE	JRE 10.0°C	1 1 1 1 1 1								

		week	1.0	1.5	1.0	1.0	1.5	1.5	1.0	1.0	1.0	1.0	1.0	1.0	1.5	2.5	2.0	2.5	4.0	3.0	3.5		0
		week 4		٠,	_	0	0		0	_	_	_	_	_	_	_	_	_	_	_	_	<u>.</u>	_
	(SFA)	7 7	-	-	-	7	-	-	7	7	7.0	7.0	-	7	1.0	1.0	1.0	2.0	٥. ٥.	ω.	σ.	J. 5	4
	Color	1 week	1.0	1.5	1.0	1.5	1.0	1.5	1.0	1.0	1.0	1.0	1.5	1.0	1.0	1.0	1.0	1.5	2.0	2.5	2.5		3.0
storage		0 week	1.0	1.5	1.0	1.0	1.5	1.5	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.5	1.5	2.5	2.5	2.5	3.0
preceding		4 week	0.114	0.088	0.130	0.095	0.095	0.084	0.079	0.078	980.0	0.071	0.094	990.0	0.137	0.164	0.211	0.239	0.277	0.224	0.273		0.327
t 26.7°C	se &	2 week	0.114	0.088	0.130		0.064	0.062	0.082	0.059	0.060	0.035	0.090	0.035	0.022	0.043	0.047	0.138	0.201	0.154	0.152	0.249	0.226
eatment a	Sucrose	1 week	0.114	0.088		0.097	0.071	0.032	0.088	0.088	0.136	0.067	0.106	0.034	0.034	0.046	0.136	0.081	0.158	0.132	0.197		0.228
Weeks of heat treatment at 26.7°C preceding storage		0 week	0.114	0.073	0.087		0.062	0.078	990.0	0.067	0.068	0.040	0.051	0.026	0.042	0.032	0.072	0.080	0.092	0.111	0.135	0.148	0.134
Weeks		4 week	0.0054	0.0034	0.0039	0.0030	0.0026	0.0224	0.0026	0.0034	0.0032	0.0032	0.0034	0.0028	0.0065	0.0028	0.0232	0.0363	0.0849	0.0441	0.0613		0.1636
	se &	2 week	0.0054	0.0034	0.0039		0.0024	0.0024	0.0039	0.0030	0.0024	9000.0	0.0045	0.0013	0.0019	0.0028	0.0043	0.0172	0.0540	0.0862	0.0729	0.0512	0.1213
	Glucose	1 week	0.0054	0.0034		0.0039	0.0034	0.0017	0.0041	0.0034	0.0041	0.0039	0.0271	0.0026	0.0015	0.0024	0.0062	0.0049	0.0209	0.0241	0.0224		0.0275
		0 week	0.0054	0.0037	0.0037		0.0030	0.0026	0.0037	0.0049	0.0022	0.0013	0.0024	0.0011	0.0028	0.0024	0.0045	0.0071	0.0056	0.0155	0.0331	0.0183	0.0258
		DATE	10/08/92	10/16/92	10/23/92	10/30/92	11/06/92	11/19/92	12/04/92	12/21/92	01/04/93	01/18/93	02/01/93	02/15/93	03/01/93	03/16/93	03/28/93	04/12/93	04/26/93	05/10/93	05/24/93	06/01/93	06/25/93

'% weight on a fresh weight basis. ''SFA, Snackfood Association color rating. Blank spaces - no measurements were taken.

TABLE 4.2b. Glucose (%)', Sucrose (%)' and Color (SFA)'' for Atlantic variety in Late Storage Season Sweetening Experiment. 1992-1993.
ATLANTIC HOLDING TEMPERATURE 10.0°C

				Weeks	Weeks of heat treatment at 26.7°C preceding storage	reatment	at 26.7°C	preceding	storage			
		Glucc	ucose 🐮			Sucrose	ose 🕻			Color (	(SFA)	
DATE	0 week	1 week	2 week	4 week	0 week	1 week	2 week	4 week	0 week	1 week	2 week	4 week
10/08/92	0.0062	0.0062	0.0062	0.0062	0.110	0.110	0.110	0.110	1.5	1.5	1.5	1.5
10/16/92	0.0041	0.0054	0.0054	0.0054	0.097	0.105	0.105	0.105	1.5	1.5	1.5	1.5
10/23/92	0.0153		0.0206	0.0206	0.094		0.264	0.264	2.0	2.5	2.5	2.5
10/30/92		0.0155		0.0290		0.103		0.301	2.0	2.5	3.0	3.0
11/06/92	0.0129	0.0196	0.0159	0.0075	0.046	0.085	0.095	0.108	2.5	3.0	3.0	3.0
11/19/92	0.0196	0.0071	0.0067	0.0039	0.292	0.041	0.038	0.042	2.0	2.0	2.5	2.0
12/04/92	0.0133	0.0280	0.0219	0.0118	0.073	060.0	990.0	0.087	2.5	2.5	2.5	2.5
12/21/92	0.0288	0.0288	0.0198	0.0221	0.092	0.142	0.111	0.129	2.5	3.0	2.5	2.0
01/04/93	0.0198	0.0037	0.0198	0.0219	0.140	0.071	0.097	0.093	2.0	1.5	2.0	1.5
01/18/93	0.0284	0.0034	0.0112	0.0024	0.088	0.074	0.052	0.053	2.0	1.5	2.0	1.5
02/01/93	0.0232	0.0047	0.0146	0.0273	0.078	0.075	0.080	0.138	2.0	1.5	2.0	2.0
02/15/93	0.0110	0.0080	0.0125	0.0129	0.047	0.044	950.0	0.068	2.0	2.0	2.5	2.5
03/01/93	0.0140	0.0114	0.0062	0.0000	0.044	0.083	0.046	0.070	2.0	2.0	2.0	2.0
03/16/93	0.0148	0.0103	0.0303	0.0082	0.051	0.089	0.118	0.062	2.0	2.0	2.0	2.0
03/28/93	0.0129	0.0114	0.0052	0.0516	0.091	0.063	0.033	0.100	2.0	2.0	2.0	3.0
04/12/93	0.0092	0.0196	0.0514	0.0310	0.079	0.142	0.254	0.104	2.0	2.0	3.0	3.0
04/26/93	0.0181	9800.0	0.0237	0.0690	0.152	0.092	0.191	0.280	2.0	2.0	3.0	3.5
05/10/93	0.0142	0.0101	0.0359	0.1075	0.116	0.116	0.105	0.167	2.5	2.5	3.0	3.0
05/24/93	0.0277	0.0995	0.0359	0.1090	0.208	0.206	0.117	0.184	2.5	3.0	3.0	<b>4</b> .0
06/01/93	0.0144	0.0142	0.0335	0.1264	0.109	0.132	0.117	0.299	2.0	3.0	3.0	3.5
06/25/93	0.0529	0.1324	0.1176	0.1791	0.201	0.359	0.154	0.404	<b>4</b> . 0	4.5	4.5	
THE HOLDING TEMPERATION	THE STATE		RP 12 5°C									

ALLANITIC HOLDING LEAFERA	CULTUM IE	ar Ervat One	ONE 14:3	Weeks	Weeks of heat treatment at 26.7°C preceding storage	reatment	at 26.7°C	preceding	storade			
		Glucose	se &			Sucrose	se &			Color (	(SFA)	
DATE	0 week	1 week	2 week	4 week	0 week	1 week	2 week	4 week	0 week	1 week	2 week	4 week
10/08/92	0.0062	0.0062	0.0062	0.0062	0.110	0.110	0.110	0.110	1.5	1.5	1.5	1.5
10/16/92	0.0041	0.0054	0.0054	0.0054	0.097	0.105	0.105	0.105	1.5	1.5	1.5	1.5
10/23/92	0.0153		0.0206	0.0206	0.094		0.264	0.264	2.0	2.5	2.5	2.5
10/30/92		0.0155		0.0290		0.103		0.301	2.0	2.5	3.0	3.0
11/06/92	0.0185	0.0097	0.0159	0.0075	0.054	0.044	0.095	0.108	3.0	2.5	3.0	3.0
11/19/92	0.0058	0600.0	0.0092	0.0039	960.0	0.028	0.073	0.042	2.5	2.5	3.0	3.0
12/04/92	0.0217	0.0200	0.0202	0.0215	0.114	0.091	0.139	0.146	2.0	2.5	2.0	1.5
12/21/92	0.0146	0.0144	0.0088	0.0131	990.0	0.061	0.051	0.084	2.0	2.0	2.5	2.0
01/04/93	0.0176	0.0123	0.0071	0.0153	0.073	0.076	0.056	0.095	2.0	2.0	2.5	2.0
01/18/93	0.0092	0.0230	0.0097	0.0073	0.048	0.052	0.025	0.049	2.0	2.0	2.0	2.0
02/01/93	0.0129	0.0077	0.0058	0.0144	0.026	0.00	0.038	0.081	2.0	2.0	2.0	1.5
02/15/93	0.0024	0.0028	0.0071	0.0030	0.019	0.030	0.036	0.041	1.5	1.5	2.0	1.5
03/01/93	0.0047	0.0071	0.0054	0.0084	0.051	0.043	0.051	0.137	1.5	1.5	2.0	2.0
03/16/93	0.0062	0.0123	0.0062	0.0108	0.089	0.112	0.081	0.103	2.0	2.0	2.0	2.0
03/28/93	0.0062	0800.0	0.0058	0.0086	0.133	0.158	0.108	0.117	2.0	1.5	2.0	2.5
04/12/93	0.0133	0.0176	0.0056	0.0133	0.098	0.303	0.111	0.221	2.0	2.5	2.5	2.0
04/26/93	0.0069				0.131				1.5			
05/10/93	0.0230	0.0166	0.0131	0.0415	0.290	0.196	0.125	0.185	2.5	2.5	3.0	3.5
05/24/93	0.0071	0.0027	0.0099		0.154	0.260	0.273		2.5	2.5	3.0	
06/01/93	0.0196				0.185							
06/25/93	0.0350	0.0363	0.0572		0.342	0.626	0.565		0.4	<b>4</b> .0	4.5	

'% weight on a fresh weight basis. "SFA, Snackfood Association color rating. Blank spaces - no measurements were taken.

standard deviation and range of the glucose and sucrose levels for each chip color are displayed in Table 4.3.

The linear correlation between chip color and glucose levels had an  $R^2$  = 0.80 (p-value < 0.001). A poorer correlation was found between the chip color and sucrose levels ( $R^2$  = 0.58 with a p-value < 0.001).

Figure 4.1 is a plot of chip color versus % glucose for all samples from the three bins. The portion of the curve that is of primary interest is for chip colors below 2.5 or 3.

All the samples were sorted by glucose in ascending order and divided into intervals. The percent of acceptable samples/interval were calculated for each interval using an acceptable color of 1.5 and 2.0 (SFA). The interval width started at 0.001% for low sugar levels (0.004-0.005%) and was increased as the sugar level rose above 0.01%. This was necessary to incorporate a number of samples in each interval. Each interval had a least 5 samples. The percent of acceptable samples per interval versus glucose level are plotted in Figure 4.2. Curves were fit to the data and are listed in Appendix C.

## 4.1.2 Results of Late Storage Season Sweetening Experiments

Chip color and the corresponding sugar levels for the Snowden and Atlantic potatoes in the late storage sweetening experiments are displayed in Table 4.4. The linear correlation coefficients for the Snowden chip color with glucose and sucrose levels were 0.63 and 0.51, respectively. The correlation coefficients for Atlantic chip color with glucose and sucrose levels were 0.50 and 0.38 (all p-values < 0.001).

TABLE 4.3. Snowden sugar levels (%) for all samples from field storage bins grouped by color (SFA) , 1992-1993.

		% Gluco	se		
Color(SFA)	Average	Standard Dev.	Low	High	#Samples
1.0	0.003	0.001	0.001	0.007	44
1.5	0.006	0.003	0.002	0.015	52
2.0	0.011	0.005	0.005	0.025	16
2.5	0.020	0.007	0.007	0.030	12
3.0	0.031	0.020	0.011	0.078	12
3.5					0
4.0	0.093	0.025	0.071	0.120	4
4.5	0.120	0.042	0.097	0.183	4
5.0	0.146	0.034	0.096	0.200	10
		% Sucro			
Color(SFA)				High	#Samples
Color(SFA) 1.0	Average 0.076	% Sucro	se		#Samples
Color(SFA) 1.0 1.5	Average	% Sucros	se Low	High	#Samples 44 52
Color(SFA) 1.0 1.5 2.0	Average 0.076 0.078 0.078	% Sucros Standard Dev. 0.016 0.022 0.031	Low 0.044	High 0.114	#Samples 44 52 16
Color(SFA) 1.0 1.5	Average 0.076 0.078	% Sucros Standard Dev. 0.016 0.022	Low 0.044 0.035	High 0.114 0.120	#Samples 44 52 16 12
Color(SFA) 1.0 1.5 2.0	Average 0.076 0.078 0.078	% Sucros Standard Dev. 0.016 0.022 0.031	Low 0.044 0.035 0.035	High 0.114 0.120 0.137	#Samples 44 52 16
Color(SFA) 1.0 1.5 2.0 2.5	Average 0.076 0.078 0.078 0.098	% Sucros Standard Dev. 0.016 0.022 0.031 0.039	Low 0.044 0.035 0.035 0.058	High 0.114 0.120 0.137 0.164	#Samples 44 52 16 12 12 0
Color(SFA) 1.0 1.5 2.0 2.5 3.0	Average 0.076 0.078 0.078 0.098	% Sucros Standard Dev. 0.016 0.022 0.031 0.039	Low 0.044 0.035 0.035 0.058	High 0.114 0.120 0.137 0.164 0.275	#Samples 44 52 16 12 12 0 4
Color(SFA) 1.0 1.5 2.0 2.5 3.0 3.5	Average 0.076 0.078 0.078 0.098 0.137	% Sucros Standard Dev. 0.016 0.022 0.031 0.039 0.002	Low 0.044 0.035 0.035 0.058 0.046	High 0.114 0.120 0.137 0.164 0.275	#Samples 44 52 16 12 12 0

<sup>&#</sup>x27;% weight on a fresh weight basis.
"SFA, Snackfood Association color rating.

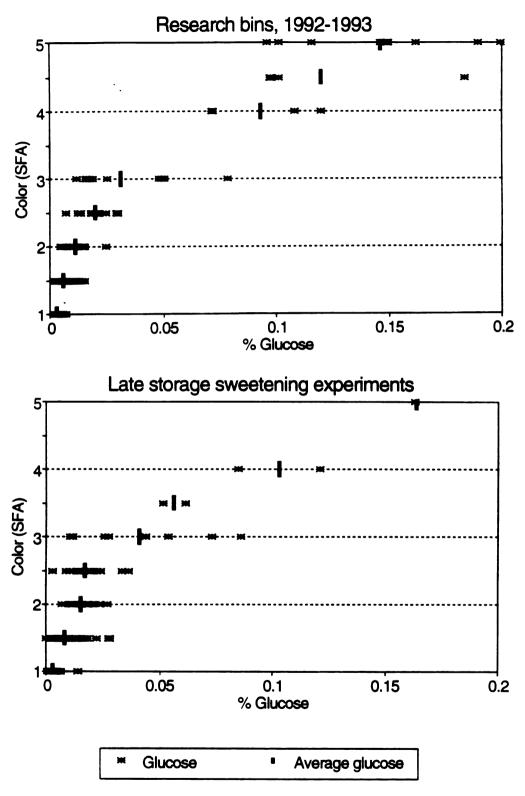


Fig. 4.1 Color (SFA") versus glucose and average glucose for samples in 1992-1993. '% fresh weight basis. "Snackfood Association.

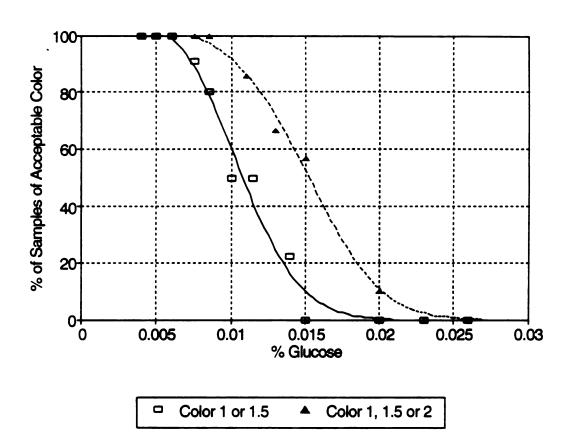


Fig. 4.2 Probability of SFA color for levels of glucose in chip samples for the 1992-1993 storage season (research bins).

TABLE 4.4. Sugar levels (%) for all samples from the late storage season sweetening experiment grouped by color (SFA), 1992-1993.

### SNOWDEN

		% Gluco	se		
Color(SFA)	Average	Standard Dev.	Low	High	#Samples
1.0	0.003	0.002	0.001	0.014	47
1.5	0.008	0.007	0.000	0.028	48
2.0	0.015	0.006	0.007	0.027	14
2.5	0.017	0.008	0.003	0.036	16
3.0	0.041	0.028	0.010	0.086	8
3.5	0.056	0.007	0.051	0.085	2
4.0	0.103	0.026	0.085	0.121	2
4.5					
5.0	0.164		0.164	0.164	1
		% Sucro	se		
Color(SFA)		Standard Dev.	Low	High	#Samples
1.0	Average 0.067	Standard Dev. 0.032	Low 0.022	0.163	47
1.0		Standard Dev. 0.032 0.049	Low 0.022 0.032	0.163 0.288	
1.0 1.5 2.0	0.067 0.103 0.174	Standard Dev. 0.032 0.049 0.072	Low 0.022 0.032 0.035	0.163 0.288 0.307	47
1.0	0.067 0.103 0.174 0.182	0.032 0.049 0.072 0.081	Low 0.022 0.032	0.163 0.288	47 48 14 16
1.0 1.5 2.0 2.5 3.0	0.067 0.103 0.174 0.182 0.190	Standard Dev. 0.032 0.049 0.072	Low 0.022 0.032 0.035	0.163 0.288 0.307	47 48 14 16 8
1.0 1.5 2.0 2.5 3.0 3.5	0.067 0.103 0.174 0.182 0.190 0.261	0.032 0.049 0.072 0.081 0.039 0.017	Low 0.022 0.032 0.035 0.086 0.134 0.249	0.163 0.288 0.307 0.383 0.239 0.273	47 48 14 16 8 2
1.0 1.5 2.0 2.5 3.0 3.5 4.0	0.067 0.103 0.174 0.182 0.190	0.032 0.049 0.072 0.081 0.039	Low 0.022 0.032 0.035 0.086 0.134	0.163 0.288 0.307 0.383 0.239	47 48 14 16 8
1.0 1.5 2.0 2.5 3.0 3.5	0.067 0.103 0.174 0.182 0.190 0.261	0.032 0.049 0.072 0.081 0.039 0.017	Low 0.022 0.032 0.035 0.086 0.134 0.249	0.163 0.288 0.307 0.383 0.239 0.273	47 48 14 16 8 2

### ATLANTIC

Color(SFA)	Average	Standard Dev.	Low	High	#Samples				
1.0									
1.5	0.007	0.006	0.002	0.022	17				
2.0	0.013	0.006	0.004	0.030	56				
2.5	0.014	0.007	0.003	0.029	28				
3.0	0.033	0.028	0.008	0.108	19				
3.5	0.079	0.043	0.041	0.126	3				
4.0	0.058	0.035	0.035	0.109	4				
4.5	0.102	0.040	0.057	0.132	3				
5.0									
% Sucrose									
		% Sucro	se						
Color(SFA)	Average	% Sucros Standard Dev.	se Low	High	#Samples				
Color(SFA) 1.0	Average			High	#Samples				
	Average 0.081			High 0.158	#Samples				
1.0		Standard Dev.	Low						
1.0 1.5	0.081	Standard Dev. 0.040	Low 0.019	0.158	17				
1.0 1.5 2.0	0.081 0.087	0.040 0.047	0.019 0.025	0.158 0.292	17 56 28 19				
1.0 1.5 2.0 2.5	0.081 0.087 0.119	0.040 0.047 0.079	0.019 0.025 0.028	0.158 0.292 0.303	17 56 28				
1.0 1.5 2.0 2.5 3.0	0.081 0.087 0.119 0.145	0.040 0.047 0.079 0.070	0.019 0.025 0.028 0.054	0.158 0.292 0.303 0.301	17 56 28 19 3 4				
1.0 1.5 2.0 2.5 3.0 3.5	0.081 0.087 0.119 0.145 0.255	0.040 0.047 0.079 0.070 0.061	0.019 0.025 0.028 0.054 0.185	0.158 0.292 0.303 0.301 0.299	17 56 28 19 3				

<sup>&#</sup>x27;% weight on a fresh weight basis.

<sup>&</sup>quot;SFA, Snackfood Association color rating.

Figure 4.1 shows a plot of chip color versus % glucose for all Snowden samples in the late season storage sweetening experiment.

## 4.1.3 Discussion of Chip Color and Sugars in Field Storage Experiments

The correlation between chip color and glucose levels was fairly high for the bin storages which verified glucose levels as a good indicator of chip color. A poorer correlation was found between chip color and sucrose levels. From Figure 4.1, it can be seen that the correlation between chip color and glucose level is not linear, but for chip colors below 2.5 or 3 this relationship can be used.

To assure acceptability of potatoes for chipping, a Snackfood Association (SFA) rating of 1 or 1.5 is required. A rating of 2 is considered marginal, being acceptable under some market conditions and not under others. For the Snowden potatoes stored in 1992-1993, a sample with a glucose level of 0.0075% (fresh weight basis) will have 90% probability of having a color of 1 or 1.5 (from Figure 4.2). A sample with a glucose level of 0.01% will have a 90% probability of having a color of 1, 1.5 or 2.

# 4.1.4 Discussion of Chip Color and Sugars in Late Storage Season Sweetening Experiments

The tubers in the late storage season sweetening experiment were subjected to more stresses (sprout inhibitor treatment, heat treatments and rapid temperature changes), and would be expected to have a larger variation and between samples. This would lead to a poorer correlation between the chip color and glucose. The correlations between chip color and glucose levels

for the Snowden potatoes in the late storage season sweetening experiment were somewhat lower than in the field storage experiments. The correlation between chip color and sucrose was similar.

The correlation coefficients of the Atlantic samples were lower than those of the Snowden. The sugar levels and quality of the Atlantic tubers at harvest were marginal in quality for long term storage. During the heat treatments, approximately 20% of the Atlantic tubers had to be discarded to prevent them from rotting other tubers. Approximately 7% of the Snowden tubers were discarded.

The average glucose levels of samples with chip color (SFA) 1 were the same for the late storage season sweetening experiment and the field research bins. At higher color levels, the samples from the physiological aging experiment were slightly higher in glucose. This is probably due to the overall higher sugar levels and higher variability in this experiment. The sucrose levels corresponding to the color ratings were also higher in the late storage season sweetening experiments than for the field storage bins.

The average glucose and sucrose values for the Atlantic potatoes were comparable to the Snowden, but the variation about the average was larger.

# 4.2 VARIABILITY IN SAMPLE SUGAR LEVELS FROM THE FIELD STORAGE BINS

The research bins had a sample taken at each of four levels. Figure 4.3 displays the glucose levels at four heights from the floor - 0.6, 1.7, 3.0 and 4.3 meters for the 1992-1993 storage season.

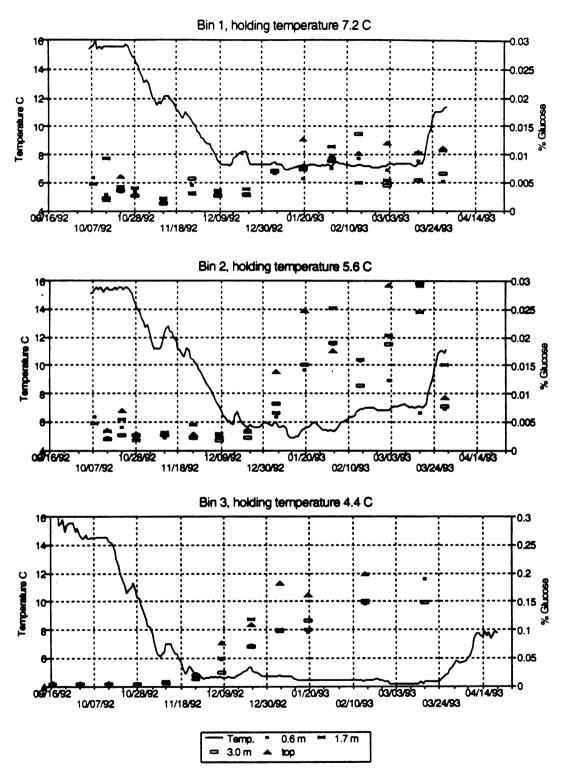


Fig. 4.3 Bin temperature and glucose levels at 0.6, 1.7, 3.0 and 4.3 m (top) above bin floor. Note: Glucose scale is different for bin 3.

Figure 4.4 displays the sucrose levels.

The Michigan Bin Monitoring Program uses a sample from the top of the bin as a representative sample of the bin. If a single sample from a potato bin is going to be used in monitoring the sugar levels in a bin, it is important to understand the variability that can be expected from a sample and to know how representative the sample is of the entire bin.

### 4.2.1 T Test for Difference between Means

A statistical paired t test was performed to test the hypothesis that the difference between paired means of sample locations was zero at a 0.05 level of significance. Appendix D.1 contains the results of the paired t test for all the samples in the three bins during the 1992-1993 storage season. The variability of the glucose readings increased as the glucose levels increased. At a chip color of 1, the standard deviation of the glucose reading was 0.001 and at a chip color of 2.5, the standard deviation was 0.007 (from table 4.3). When bin sugar levels are to be used as an aid in storage management, the primary range of interest is for low sugar levels (anticipating increases leading to problems). A second paired t test was performed on a trimmed set of data for each bin for lower glucose levels (below 0.02% glucose or harvest through 1/19/93 for bins 1 and 2, and through 11/25/92 for bin three (Appendix D.2)).

Summaries of the paired 2-tail probabilities and the signs of the t values (a negative sign indicates a larger mean by the second sampling level in the paired test) are displayed in Table 4.5.

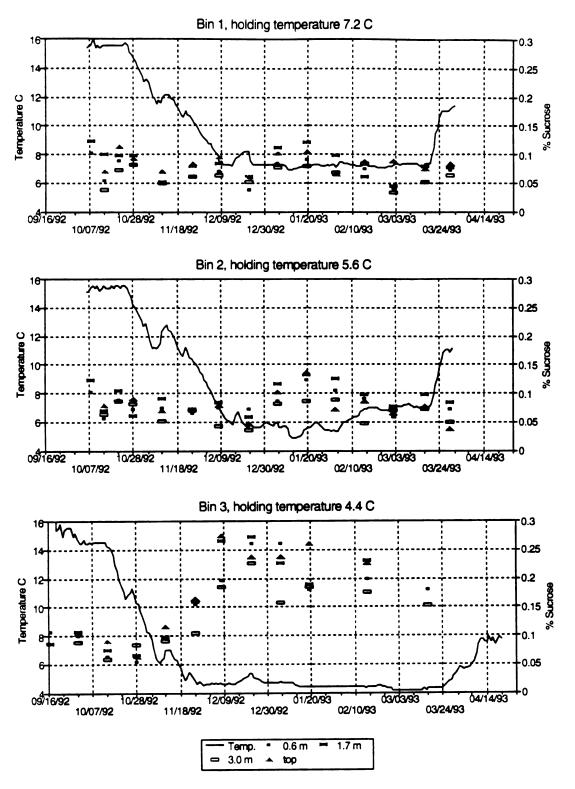


Fig. 4.4 Bin temperature and sucrose levels at 0.6, 1.7, 3.0 and 4.3 m (top) above bin floor.

for						
t test n means.	4.3 m (-).334 .819 (-).313	4.3 m (-).000 .815 (-).000	4.3 m (-).087 (-).164 (-).037	4.3 m (-).266 .692 (-).006	4.3 m (-).651 (-).865 (-).062	4.3 m (-).033 (-).182 (-).177
of paired ces between	3.0 m (-).645	3.0 m .190 .003	3.0 m .776 .130	3.0 m .075 .020	3.0 m .439	3.0 m .595 .293
TABLE 4.5b. Summary of differences	350	Bin 1 Sucrose 1.7 m 0.6 m (-).001 1.7 m 3.0 m	Bin 2 Glucose 1.7 m 0.6 m (-).084 1.7 m 3.0 m	Bin 2 Sucrose 1.7 m 0.6 m (-).115 1.7 m 3.0 m	Bin 3 Glucose 1.7 m 0.6 m (-).276 1.7 m 3.0 m	Bin 3 Sucrose 1.7 m 0.6 m (-).015 1.7 m 3.0 m
t test for n means.	4.3 m (-).031 (-).513 (-).083	4.3 m (-).000 (-).726 (-).000	4.3 m (-).027 (-).183 (-).073	4.3 m .969 .061	4.3 m (-).024 (-).071 (-).016	4.3 m (-).092 (-).352 (-).005
Summary of paired differences between	3.0 m (-).770 .361	3.0 m .181 .002	3.0 m (-).332 .092	3.0 m .023 .001	3.0 m .837 .229	3.0 m .116
oa. Summary differenc	Bin 1 Glucose 1.7 m 0.6 m (-).176 1.7 m 3.0 m	Bin 1 Sucrose 1.7 m 0.6 m (-).001 1.7 m 3.0 m	Bin 2 Glucose 1.7 m 0.6 m (-).032 1.7 m 3.0 m	Bin 2 Sucrose 1.7 m 0.6 m (-).004 1.7 m 3.0 m	Bin 3 Glucose 1.7 m 0.6 m (-).196 1.7 m 3.0 m	Bin 3 Sucrose 1.7 m 0.6 m (-).148 1.7 m 3.0 m

'Trimmed data - Glucose levels < 0.02%, Harvest though 1/19/93 for bins 1 and 2, and through 11/25/92 for bin 1.

1. Sign (-) indicates row < column.
2. 2 tailed probability < 0.005 = evidence that means are different.

#### 4.2.2 Results of t test

For the trimmed data, there was no evidence of differences, at the 0.05 level of significance, in the means of glucose or sucrose between 0.6 and 3.0 m or between 1.7 and 4.3 m. For all the paired t tests between 0.6 and 3.0 m, the sign of the t value (given in Table 4.5), is negative indicating that the means difference of 0.6 m paired to 1.7 m is negative (1.7 m means are greater than the 0.6 m means). A similar situation exits between samples at 3.0 m and 4.3 m with means at 4.3 m being higher than means at 3.0 m.

# 4.2.3 Discussion of Variability in Tuber Sugar Levels in Samples from Storage Bins

Plots of the sugar levels at the 4 sampling levels (Figures 4.3 and 4.4) show that samples from a given sampling location follow trends similar to trends of the other sampling locations. The trimmed data was more representative of the sugar levels that would be found in a bin stored for chipping potatoes as the temperatures and sugar levels correspond to those of commercial storages.

The findings that samples from heights of 0.6 and 3.0 m show no evidence of differences and samples from heights of 1.7 and 4.3 m show no difference from each other but are greater than 0.6 and 3.0 m, can be attributed to an early assumption in the sampling techniques. The order in which the potato samples from the four locations in the bins were juiced, was kept the same. Cleaning and changing the filter is a time consuming process. As the samples were all from a given bin (replicate samples) the filter was changed

every two samples. Therefore juice from heights of 1.7 and 4.3 m would be rinsed through pulp from samples at 0.6 and 3.0 m respectively.

For the trimmed data from the three research bins (found in Appendix D.2), the average increase of 1.7 m over 0.6 m was 0.001% (s=0.0005) for glucose and 0.16% (0.07) for sucrose. The average increase of 4.3 m over 3.0 m was 0.002% (s=0.0009) for glucose and 0.17 (0.08) for sucrose. The increases in sugar levels at 1.7 and 4.3 m due to sampling procedures were nearly the same and without the sampling difference the four sampling locations would all be equivalent. Therefore, tuber samples from the top of a potato bin will provide a representative sample as long as recommended storage procedures are followed.

Analysis of the sugar levels in the field research bins in later sections of this chapter use the average of the four sampling locations as the bin sugar level. The increase in sugar levels added due to the error in sampling procedures, would be one-half of the increases given above, or approximately 6.5% for glucose and 8.5% for sucrose (using average glucose at 0.01% by weight and sucrose at 0.1% by weight). The effect on the results and recommendations would be negligible.

Bin 3 (holding temperature 4.4°C) had elevated glucose levels from the top of the bin (4.3 m level was at least 20% above the other three levels), after intermittent fan operation was initiated. Bin 2 (holding temperature 5.5°C) also experienced higher glucose levels on the top level when the temperature was at the holding temperature and fans were being operated intermittently. These

higher glucose levels can be attributed to above pile temperature fluctuations the potatoes were exposed to during intermittent fan operation. Commercial operators should be aware of this if a bin is being stored near the lower temperature limits for a variety. This problem is amplified in the scaled down research bins as compared to commercial storages due to the smaller size of the bin.

### 4.3 LATE SEASON STORAGE SWEETENING EXPERIMENT

The recommended procedures for the application of sprout inhibitor allows the tubers to suberize and wound heal for at least two weeks before treatment. However in this experiment, the storages were 90 minutes from the facility for sprout inhibitor treatment. The treatments in the experiment would require four different times for CIPC application, so the CIPC was applied before the heat treatments and the suberization took place.

In this experiment it was assumed that this would not be of any major consequence. The difficulty in applying the sprout inhibitor to small batches was avoided but the wound healing of the tubers was sacrificed. The early treatment with sprout inhibitor had a negative effect on the wound healing ability of the tubers. This was most evident in the Atlantic potatoes which were of marginal quality for long term storage when they were harvested.

In the later months of this experiment, tubers were becoming soft due to moisture loss in the 10 and 12.5°C storages. The tubers were much softer than in a commercial storage where higher humidities are maintained. This did not appear to have an effect on the sugar level or chip color, but did make the

potatoes more difficult to slice.

## 4.3.1 Snowden Variety Late Storage Sweetening

#### 4.3.1.1 Results of Snowden stored at 7.2°C

Plots of the glucose and sucrose for heat treatments of 0, 1, 2 and 4 weeks are displayed in Figures 4.5a, 4.5b, 4.5c and 4.5d. Treatment 1 (no heat treatment) sugar levels, especially glucose, jumped immediately after being transferred from the 15.5°C to the 7.2°C. Glucose levels remained well above 0.01% and tubers produced unacceptable colored chips (Table 4.2a) for 12 weeks (through 1/18/93) after the transfer, but did drop below 0.01% after 14 weeks. Both the glucose and sucrose levels declined until late in March. Sucrose started to rise on 4/12/93 and the glucose levels started to rise 2 weeks later. Sucrose levels had risen above 0.1% on 4/26/93. Glucose levels rose above 0.01% (chip color 2) on 6/7/93 (8 weeks after a rise in sucrose and 6 weeks after a rise in glucose were detected).

Treatment 2 (1 week heat treatment) had glucose levels rise to above 0.014% on 12/21/93 and 1/14/93 (7 and 9 weeks after transfer from 15.5 to 7.2°C). Sucrose and glucose levels started to decline on 1/18/93 (11 weeks after the transfer) and glucose levels had fallen below 0.01% and sucrose below 0.1% 2 weeks later. Sucrose levels held or fell through 3/28/93. On 4/12/93 sucrose levels had started to rise and on 4/26/93 had risen to 0.15% and continued to rise. Glucose continued to fall until a rise on 4/26/93. Both the glucose and sucrose continued to rise with the chip color (Table 4.2a) becoming unacceptable 8 weeks after the sucrose had started to rise and 6

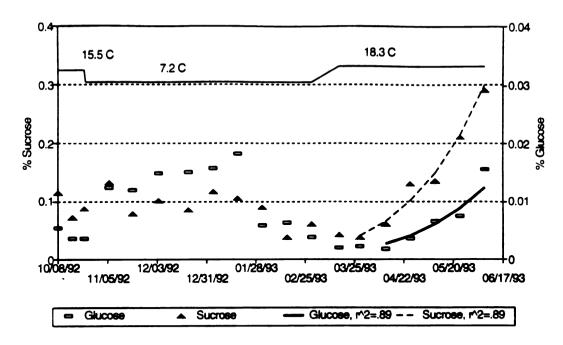


Fig. 4.5a Sugar levels for Snowden variety with no heat treatment and 7.2°C holding temperature.

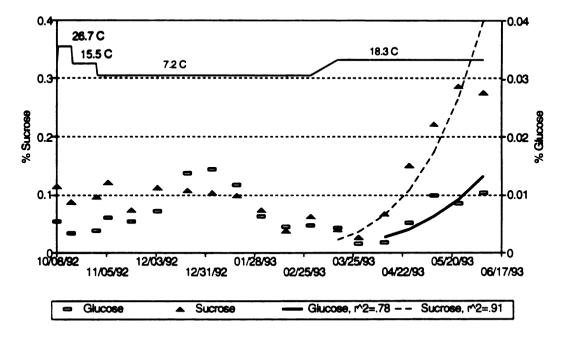


Fig. 4.5b Sugar levels for Snowden variety with 1 week heat treatment at 26.7°C and 7.2°C holding temperature.

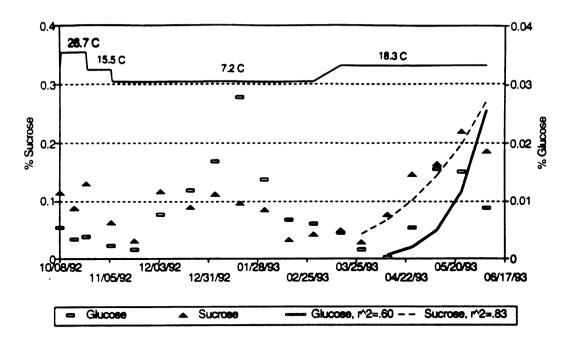


Fig. 4.5c Sugar levels for Snowden variety with 2 week heat treatment at 26.7°C and 7.2°C holding temperature.

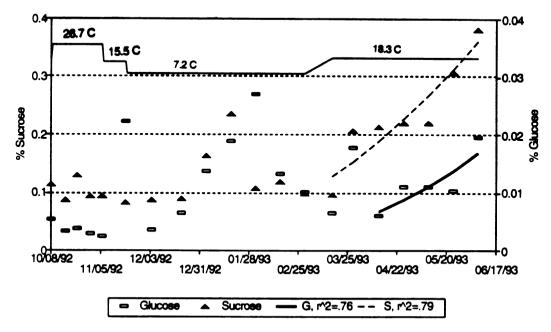


Fig. 4.5d Sugar levels for Snowden variety with 4 week heat treatment at 26.7°C and 7.2°C holding temperature.

weeks after the glucose started to rise.

Treatment 3 (2 week heat treatment) had sucrose levels jump to around 0.1% on 12/4/92 (4 weeks after transfer to 7.2°C) and hold near that level for about 8 weeks (through 2/1/93) before declining. Glucose levels also jumped 4 weeks after the transfer, but continued to climb for 6 weeks more to a level above 0.025% on 1/18/93, before they declined to levels below 0.01%. Chip colors (Table 4.2a) declined to marginal levels as glucose increased, and then improved as sugars decreased. Sucrose levels started to rise on 4/12/93, were above 0.1% 2 weeks later and continued to rise. Glucose levels started to rise 4/26/93 and 2 weeks later levels rose above 0.01% and chip color declined.

Glucose levels for treatment 4 (4 week heat treatment) reacted similarly to levels in treatment 3 with a rise starting on 12/4/92 (4 weeks after the temperature transfer). Sucrose levels never fell much below 0.1% and 6 weeks after transfer to 7.2°C, started to rise and were above 0.2% 2 weeks later. Sucrose and glucose fell on 2/1/93 and 2/15/93 respectively. Sucrose levels started to rise on 3/28/93 and glucose started to rise on 4/26/93. Glucose levels were above 0.01% on 4/26/93 and chip color was marginal at best throughout the much of the storage.

Plots of power curves (of the form: sugar level = time<sup>a</sup> + b, Appendix E) fitted to the rises in sugar levels in late storage for the 4 treatments are displayed in Figures 4.5a-d and are repeated in Figures 4.6a and 4.6b. The curves were fit to points following a 'local' minimum sugar value. It can be seen that glucose levels for treatments 1 and 2 increased at the same time.

Treatment 3 intersected the glucose level of 0.01% about 7 days before the lines for treatments 1 and 2. Treatment 4 glucose levels increased above 0.01% approximately 25 days before treatments 1 and 2. The sucrose lines for treatments 1, 2 and 3 all passed through the 0.1% line very close to each other and treatment 4 was offset by more than a month but never was as low as 0.1%.

### 4.3.1.2 Results of Snowden stored at 10.0°C

Plots of the glucose and sucrose for treatments 1, 2, 3 and 4 are displayed in Figures 4.7a, 4.7b, 4.7c and 4.7d. Treatment 1 (no heat treatment) had glucose levels generally falling gradually (to below 0.003%) over the duration of the storage until 3/28/93 when an increase started. On 5/10/93 (8 weeks later) glucose levels had risen to 0.015% and chips were unacceptable in color (SFA color = 2, Table 4.2a). Sucrose levels gradually fell from levels around 0.075 early in the storage to 0.03% on 2/15/93 and then started to rise at the same time that glucose levels had risen and were above 0.1% on 5/10/93.

Treatment 2 (1 week heat treatment) glucose held nearly constant through storage (0.004%) and started to rise on 3/16/93. On 4/26/93 (6 weeks later) glucose levels had risen to 0.02% and chips had darkened (SFA color = 2). Sucrose levels were more variable throughout the storage time but did drop down to levels comparable to treatment 1 on 2/15/93. Rises in sucrose corresponded to rises in glucose and sucrose levels rose above 0.1% on 4/26/93.

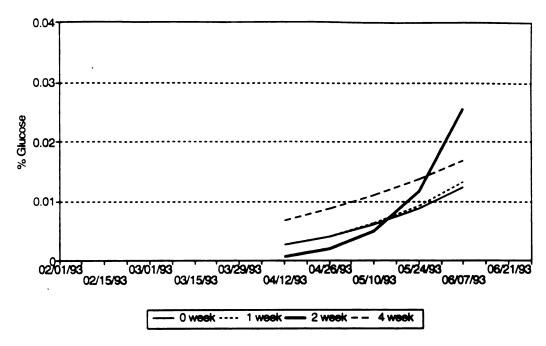


Fig. 4.6a Glucose late storage season sweetening for Snowden variety stored at 7.2°C. (18.3°C after 3/16/93)

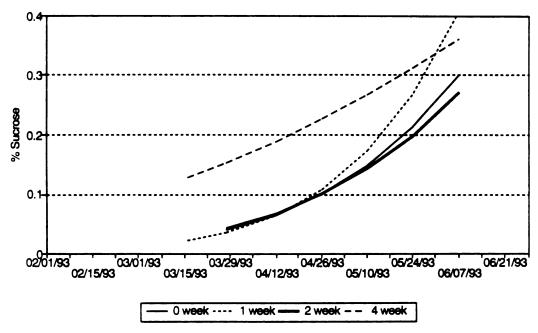


Fig. 4.6b Sucrose late storage season sweetening for Snowden variety stored at 7.2°C. (18.3°C after 3/16/93)

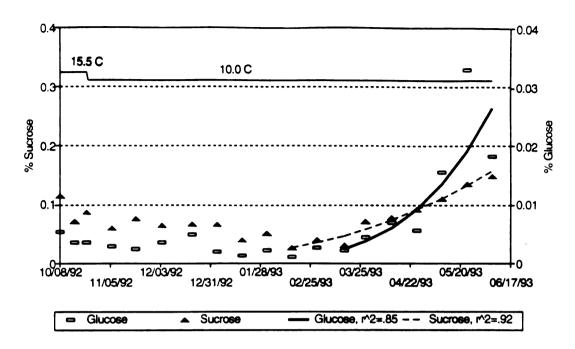


Fig. 4.7a Sugar levels for Snowden variety with no heat treatment and 10.0°C holding temperature.

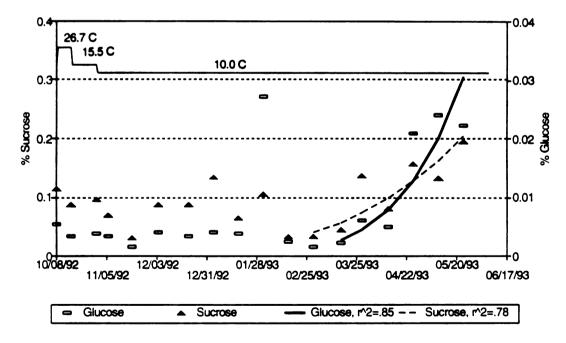


Fig. 4.7b Sugar levels for Snowden variety with 1 week heat treatment at 26.7°C and 10.0°C holding temperature.

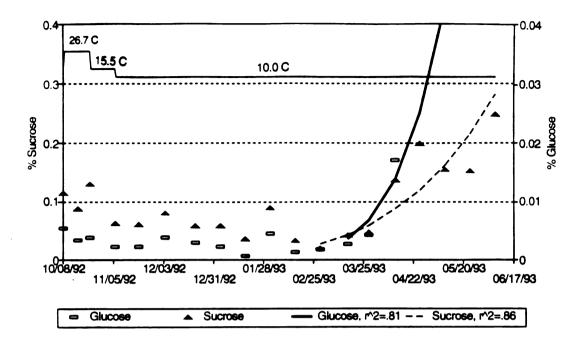


Fig. 4.7c Sugar levels for Snowden variety with 2 week heat treatment at 26.7°C and 10.0°C holding temperature.

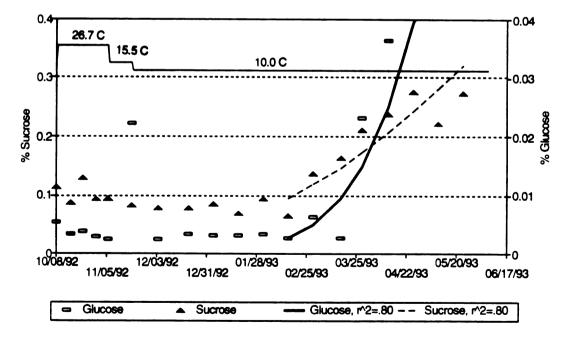


Fig. 4.7d Sugar levels for Snowden variety with 4 week heat treatment at 26.7°C and 10.0°C holding temperature.

Glucose levels for treatment 3 (2 weeks heat treatment) were down to 0.002% on 3/1/93. Sucrose levels fell gradually during storage from around 0.1% down to 0.03% on 3/1/93. Both the glucose and sucrose rose gradually for 4 weeks after 3/1/93 and on 4/12/93 (6 weeks later) the glucose had risen to 0.017% and sucrose had risen to 0.14%. SFA chip color was 2 on 4/12/93 and 2 weeks chip color was 3 and glucose had risen to 0.05%.

The glucose level for treatment 4 (4 weeks heat treatment) held at around 0.003% until 3/1/93 when it started to rise. Sucrose held around 0.09% until 3/1/93 when it rose to 0.14%. The sucrose level had continued to rise and 2 weeks later the chip color was 2.5.

Plots of power curves fitted to the rises in sugar levels in late storage for the 4 treatments are displayed in Figures 4.8a and 4.8b. The glucose curves for treatments 4, 3 and 2 cross the 0.01% glucose level ahead of treatment 1 by approximately 44, 26 and 11 days respectively. The sucrose levels for treatments 4, 3 and 2 reach 0.1% approximately 79, 15, and 19 days before treatment 1.

# 4.3.1.3 Discussion of Temperature Transfer

The transfer of the tubers from 15.5 to 7.2°C appeared to cause an increase in the glucose levels and a darkening of chips for all treatments. All four treatments were able to recover to glucose levels below 0.01% with acceptable chips but this took approximately 14 weeks.

Treatments 1 and 2 resulted in similar glucose levels (0.018 and 0.014% respectively) though treatment 1 reacted much more rapidly. The 1 week heat

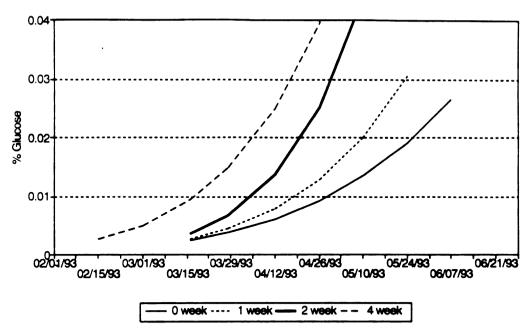


Fig. 4.8a Glucose late storage season sweetening for Snowden variety stored at 10.0°C.

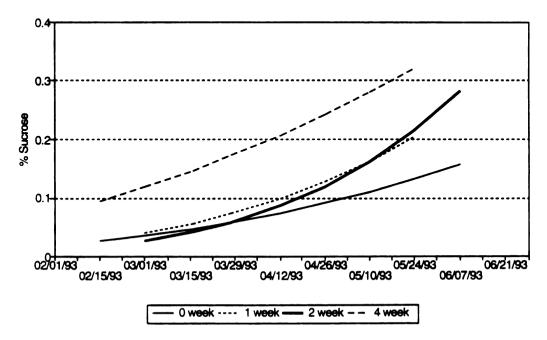


Fig. 4.8b Sucrose late storage season sweetening for Snowden variety stored at 10.0°C.

treatment for treatment 2 appeared to delay the rise in glucose, and to a limited degree, reduced the magnitude of the rise.

The glucose levels that resulted from the temperature transfer for treatments 3 and 4 both were above 0.025%. It is uncertain why these two glucose levels would be higher than treatments 1 and 2. Treatment 4 also had an increase in sucrose accompanying the rise in glucose.

The Snowden potatoes transferred from 15.5°C to 10.0°C had no detectable response in the sugar levels, other than a single reading in treatment 4 two weeks after the transfer. This reading corresponded to an acceptable chip sample and was not considered important.

## 4.3.1.4 Discussion of Snowden at 7.2°C

The inadvertent rise in temperature that started on 3/1/93 and warmed the tubers to 18.3 over 3 weeks time was not intended but once it had occurred the decision was made to maintain that temperature rather than to recool the tubers. The main effect of the warming was probably to increase the respiration rate of the tubers and to advance late storage season sweetening

The rises in the sucrose levels for 0, 1 and 2 week heat treatments were first detected on 4/12/93. The rises in glucose levels for the 0, 1 and 2 week treatments were first detected on 4/26/93. The rate of increase of glucose for the 0 and 1 week heat treatment were the same and the 2 week heat treatment increased above 0.01% about a week earlier. Treatment 4 (4 weeks heat treatment) increased the initial sucrose levels and advanced the late storage season sweetening much more than the shorter treatments. Glucose levels for

treatment 4 were never as low as for the other treatments. Treatment 4 did rise above 0.01% about 25 days before treatments 1 and 2, but the rate of increase was comparable to the rates for 1 and 2.

The rise in sucrose levels was detected 2 weeks before the rise in glucose for all treatments with a holding temperature of 7.2°C (later warmed to 18.3°C). For the heat treatments of 0 and 1 week, the chips went off color 8 weeks after sucrose started to rise and 6 weeks after glucose levels started to rise.

## 4.3.1.5 Discussion of Snowden at 10.0°C

The time at which the glucose levels for the four treatments reached 0.01% were quite distinct and evenly spread. Samples from the heat treatments of 0, 1 and 2 weeks started to increase in sugars at roughly the same time. Increasing the length of the heat treatment increased the rate at which the glucose levels rose. This may also apply to other stresses imposed on potatoes in early storage or during harvest.

The time at which the sucrose rose above 0.1% for treatment 4 was about 80 days before treatment 1. Treatments 2 and 3 preceded treatment 1 by around 15 and 19 days respectively. The 0.1% level is probably not a very relevant level of interest for treatment 4 as the sucrose levels were not that far below 0.1% to start with. The sucrose levels for treatment 2 increased to above 0.1% before treatment 3. Figures 4.7b and 4.7c show that the sucrose levels were variable for both these treatments. Visual inspection of Figure 4.8a shows that the slopes on the glucose curves increase with increasing treatment.

For treatment 1 (no heat treatment) the rises in glucose and sucrose were detected 8 weeks before the chip samples went off color. For treatments 2 and 3 (1 and 2 week heat treatments) both the glucose and sucrose started to rise 6 weeks before the chips went off color.

Treatment 4 (4 week heat treatment) rises in glucose and sucrose were detected 4 weeks before the chips went off color.

The longer the length of heat treatment the higher the rate of sugar accumulation.

# 4.3.1.6 Comparison of Late Storage Season Snowden Sweetening at 7.2°C and 10.0°C

For the potatoes that received no heat treatment, the Snowden tubers stored at 7.2°C sweetened approximately 4 weeks after the tubers stored at 10.0°C (glucose above 0.01% and colored chip >1.5 on 6/7/93 and 5/10/93 respectfully). Both sets of tubers were transferred to holding temperature on 10/23/93. The tubers stored at 7.2°C were gradually warmed to 18.3°C between 3/1/93 and 3/21/93. The rate of aging would have been faster at the 18.3°C than at 7.2°C, and without this warming it is assumed that the tubers would have stored longer without sweetening. It can be concluded that Snowden tubers at 7.2°C age at least 4 weeks slower than tubers at 10.0°C over 8-9 months of storage. A value of 8 weeks may be closer to the actual difference but no evidence to support this was collected.

Commercial storages will probably experience lower sugar levels than in this experience (personal communication with managers sampling bins in Michigan). This should have a positive effect on using the sugars as predictors of the onset of sweetening associated with late season storage. The lower sugar levels will allow a larger increase in sugars before unacceptable chip result, and allow easier detection of increases. The rate at which the sugars will rise should be lower or similar as long as no additional stresses have been imposed on the tubers.

# 4.3.2 Atlantic Variety Late Storage Sweetening

The quality of the Atlantic potatoes for chipping was the highest at harvest and thereafter only a limited number of samples were much better than marginal. The variability of the Atlantic samples was high.

#### 4.3.2.1 Results of Atlantic Stored at 10.0°C

Plots of the glucose and sucrose for treatments 1, 2, 3 and 4 are displayed in Figures 4.9a, 4.9b, 4.9c and 4.9d. Glucose and sucrose levels for all treatments rose 2 to 4 weeks after the transfer from 15.5 to 10.0°C.

Treatment 1 (no heat treatment) glucose levels fell to about 0.01% on 2/15/93 and gradually rose thereafter. Sucrose levels for treatment 1 fell to below 0.05% on 3/1/93 and gradually increased after that.

Glucose levels for treatment 2 (1 week heat treatment) dropped below 0.004% on 1/4/93 and gradually rose thereafter reaching 0.01% on 3/1/93. Sucrose levels dropped to 0.05% on 2/15/93 and slowly increased after that.

Glucose and sucrose levels for treatment 3 (2 week heat treatment) dropped below 0.01% and 0.05% respectively on 3/1/93 but after that wide variations in samples occurred.

Treatment 4 (4 week heat treatment) followed similar trends as the other treatments with a large variations between samples.

Plots of the curves (Appendix C) fitted to the glucose and sucrose levels for the four treatments are displayed in Figures 4.10a and 4.10b. The glucose curves show an increasing slope with increase in heat treatment weeks.

Limited conclusions should be drawn from this data as the correlation coefficients for these lines are low.

#### 4.3.2.2 Results of Atlantic stored at 12.5°C

Plots of the glucose and sucrose for treatments 1, 2, 3 and 4 are displayed in Figures 4.11a, 4.11b, 4.11c and 4.11d. Treatment 1 (0 week heat treatment) reached a minimum for glucose and sucrose on 2/15/93. Both started to rise on 3/1/93 and the chips went off color 10 weeks later.

Treatment 2 (1 week heat treatment) had glucose and sucrose reach minimums on 2/15/93 and both started to rise 2 weeks later. On 4/12/93 (6 weeks after rise starts) the chips were off color.

Treatment 3 (2 weeks heat treatment) reached minimums on 2/15/93 for sucrose and on 2/28/93 for glucose. Sucrose levels rose steadily after 2/15/93. Glucose levels remained below 0.01% until 5/10/93 but chip were off color on 4/12/93 (6 weeks later).

Treatment 4 (4 weeks heat treatment) had glucose and sucrose reach minimums on 2/15/93 and both started to rise 2 weeks later. On 3/28/93 (4 weeks after rise starts) the chips were off color.

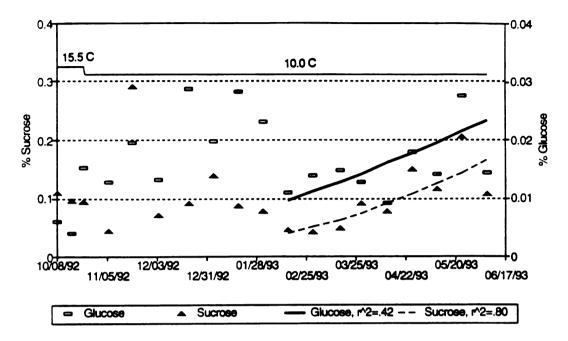


Fig. 4.9a Sugar levels for Atlantic variety with no heat treatment and 10.0°C holding temperature.

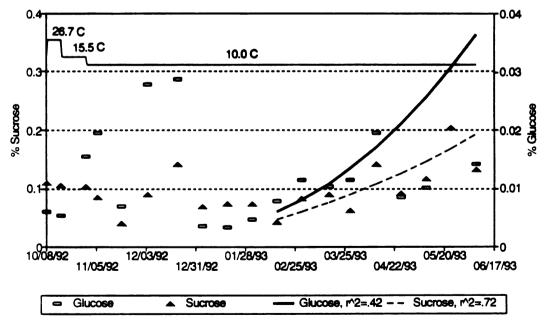


Fig. 4.9b Sugar levels for Atlantic variety with 1 week heat treatment at 26.7°C and 10.0°C holding temperature.

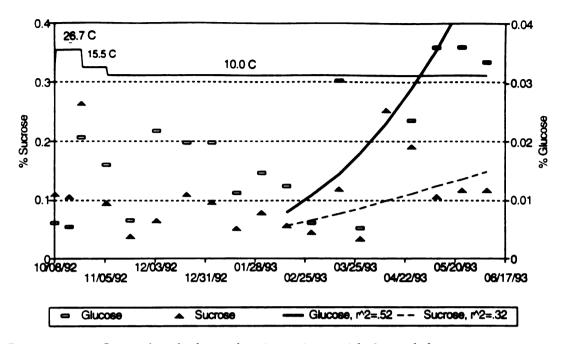


Fig. 4.9c Sugar levels for Atlantic variety with 2 week heat treatment at 26.7°C and 10.0°C holding temperature.

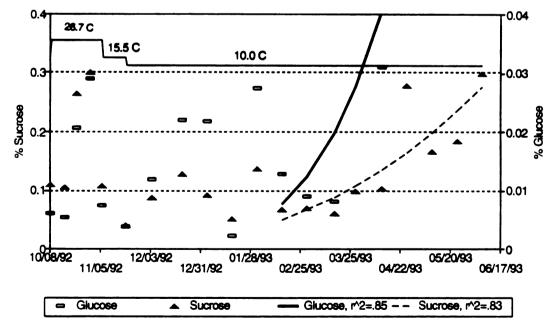


Fig. 4.9d Sugar levels for Atlantic variety with 4 week heat treatment at 26.7°C and 10.0°C holding temperature.

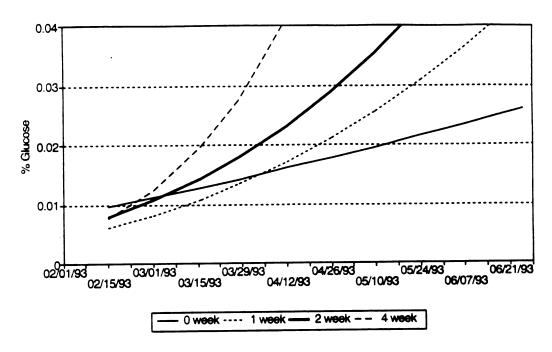


Fig. 4.10a Glucose late storage season sweetening for Atlantic variety stored at 10.0°C.

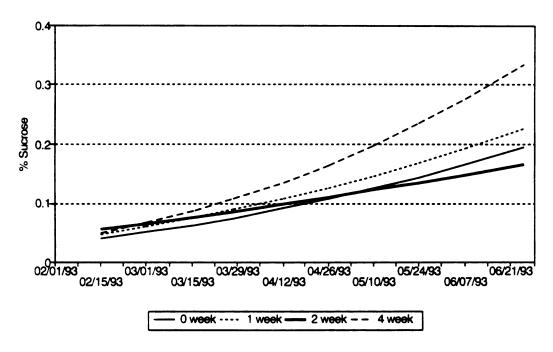


Fig. 4.10b Sucrose late storage season sweetening for Atlantic variety stored at 10.0°C.

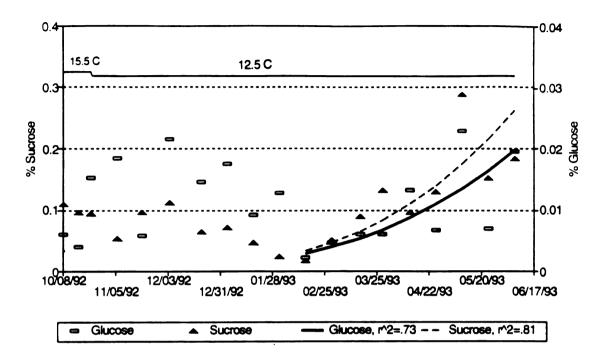


Fig. 4.11a Sugar levels for Atlantic variety with no heat treatment and 12.5°C holding temperature.

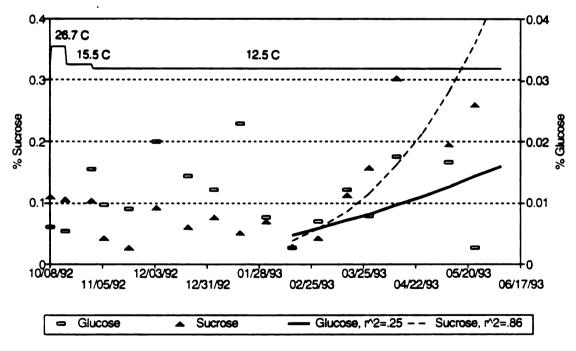


Fig. 4.11b Sugar levels for Atlantic variety with 1 week heat treatment at 26.7°C and 12.5°C holding temperature.

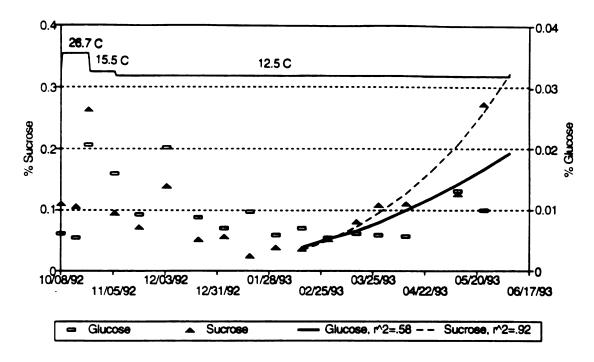


Fig. 4.11c Sugar levels for Atlantic variety with 2 week heat treatment at 26.7°C and 12.5°C holding temperature.

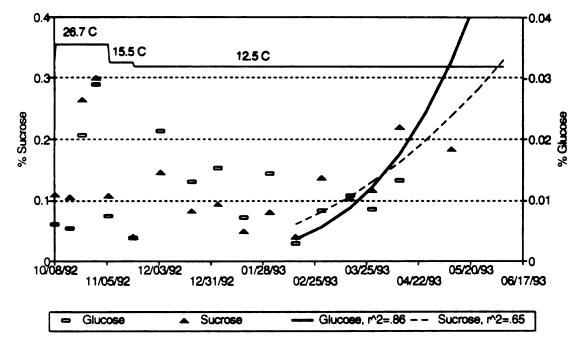


Fig. 4.11d Sugar levels for Atlantic variety with 4 week heat treatment at 26.7°C and 12.5°C holding temperature.

Plots of the curves fitted to the glucose and sucrose levels for the four treatments are displayed in Figures 4.12a and 4.12b. The curves of glucose levels for treatments 1, 2 and 3 are all roughly the same. The glucose for treatment 4 rises much more sharply. The curves for sucrose follow similar lines.

#### 4.3.2.3 Discussion of Atlantic at 10.0°C and 12.5°C

The transfer of the Atlantic tubers from 15.5°C to 10.0°C had a similar effect on the sugar levels to that of transferring the Snowden tubers from 15.5°C to 7.2°C. This would indicate that the Atlantic is more sensitive to low temperature sweetening than Snowden.

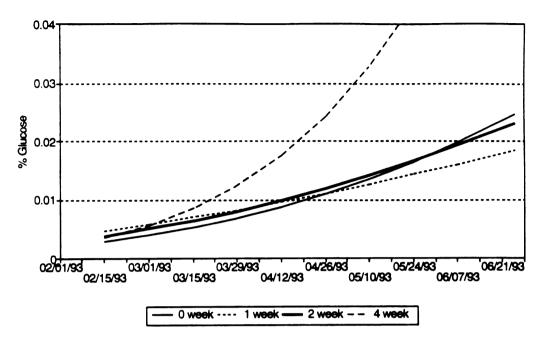


Fig. 4.12a Glucose late storage season sweetening for Atlantic variety stored at 12.5°C.

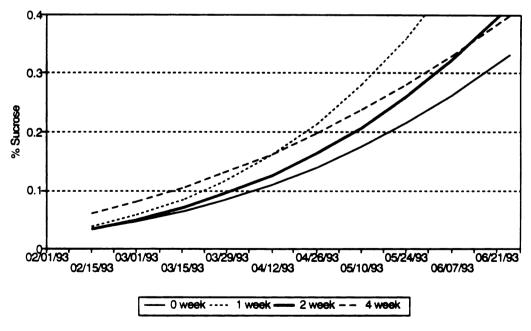


Fig. 4.12b Sucrose late storage season sweetening for Atlantic variety stored at 12.5°C.

#### 4.4 FIELD STORAGE BINS

# 4.4.1 Atlantic vs Snowden in 1990-1991 Storage Season

#### 4.4.1.1 Results 1990-1991

Sucrose and glucose in the Snowden potatoes stored at 7.2°C and the Atlantic potatoes stored at 10.0°C remained low. Both varieties had sucrose levels below 0.1% and glucose levels below 0.02% for the entire storage period. All samples during the storage season had acceptable fry color. Data for the 1990-1991 season are listed in Appendix A.

#### 4.4.1.2 Discussion 1990-1991

The Snowden potatoes stored at 7.2°C appear to respond to storage management in a manner similar to the Atlantic variety potatoes stored at 10.0°C.

It appears from limited observations that the Snowden variety potatoes sprouted earlier than did the Atlantic variety potatoes which would indicate that they should be managed with a faster cooling rate.

# 4.4.2 Snowden Storage for 1991-1992

# 4.4.2.1 Results of Cooling Rate Comparison

The set cooling rates of 0.1°C/day (bin 1), 0.3°C/day (bin 2), and 0.5°C/day (bin 3) resulted in actual cooling rates of 0.09, 0.16, and 0.27°C/day. Bins 1 and 2 were located in Bay County, MI and bin 3 was located in Kalkaska County, MI. Data for the 1991-1992 season are listed in Appendix B.

On January 15 bin 1 was at 8.3°C and bin 2 was at 5.5°C. Both bins had low sugar levels and were acceptable in color. The color and sugars for Bin 3

remained at acceptable levels until mid-November, when the pulp temperatures had lowered to 3.9°C. After one week at 39°F the chips started darkening and sugar levels increased.

# 4.4.2.2 Discussion of Cooling Rates

The differences between the set and actual cooling rates are dependent on the cooling that outside conditions allow. The set point for the cooling is calculated from the actual bin temperature, so the maximum cooling per day will be the set cooling rate. Bin 3 which was cooled at 0.5°C/day produced dark colored chips after reaching a holding temperature of 3.9°C, but the cooling rate did not appear to adversely effect chip color. The higher cooling rates did not appear to lead to sugars until temperatures below 7.2°C were reached.

# 4.4.2.3 Results of Sprout Control

Sprout control within the bins was measured by determining the number of sprouts greater than 0.95 cm (3/8 in.) from the 60 tuber sample taken from each bin. The faster cooling rates in bins 2 and 3 resulted in lower temperatures and fewer sprouts than in bin 1, which was treated with a sprout inhibitor (see Figure 4.13).

#### 4.4.2.4 Discussion of Sprout Control

The lower temperatures in bins 2 and 3 regulated sprout growth better that bin 1 which had the added control of a sprout inhibitor applied on 11/20/91. The combination of a sprout inhibitor and lower temperatures should result in a higher level of sprout control.

# 4.4.2.5 Results of Reconditioning

Figure 4.14 displays the chip colors for the four reconditioning temperatures (8.3°C, 11.7°C, 15.5°C, and steps of one week at each of the three temperatures).

# 4.4.2.6 Discussion of Reconditioning

Reconditioning at 15.5°C for 3 weeks resulted in acceptable colored chip samples. The tubers reconditioned at 11.7°C produced marginal chips (SFA color 2). It appears that reconditioning of Snowden variety potatoes will not normally be necessary, but the feasibility does exist if temperatures near 11°C are used. Warming to this temperature may result in higher weight losses as it is difficult to maintain a high relative humidity without getting condensation on the tubers.

#### 4.4.2.7 Discussion of Bin Exhaust Problems

A problem with the ventilation controllers (fans were off for a number of days) the first week in December was followed by increases in the glucose levels in both bins. This may have resulted from low oxygen or high carbon dioxide concentrations. Figures 4.15a and b show the sugar levels observed as a result of the problem. Chip color remained marginally acceptable (SFA color = 2) as glucose levels increased to around 0.02%. On approximately 1/18/92 the exhaust louver for the building enclosing bins 1 and 2 malfunctioned and the experiment had to be ended as the control of the ventilation system was lost. The glucose levels for bins 1 and 2 rose to above 0.05% and 0.09% within 2 weeks and chips became unacceptable. Sucrose levels increased to above

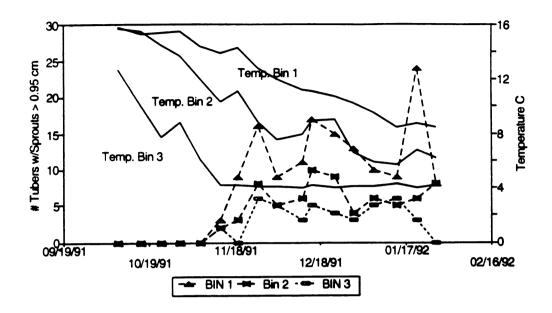


Fig. 4.13 Sprout control for samples of 60 tubers, 15 at each level, 1991-1992. Bin 1 was treated with sprout inhibitor on 11/20/91.

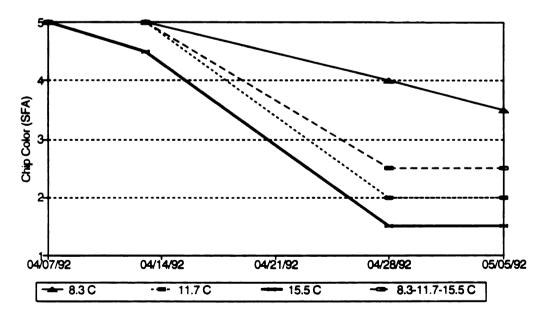


Fig. 4.14 Color (SFA) of reconditioned potatoes. 1992. Reconditioned at 8.3, 11.7, 15.5°C and at 1 week steps of 8.3, 11.7 and 15.5°C.

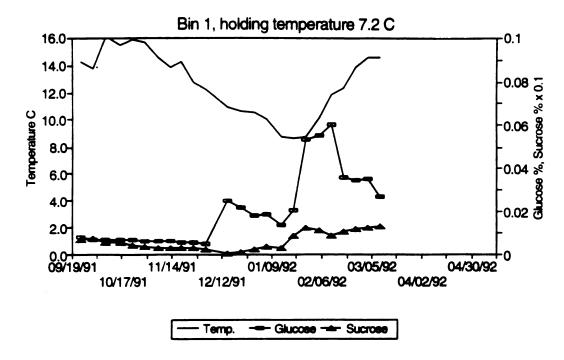


Fig. 4.15a Bin temperature and sugars for bin 1, 1991-1992.

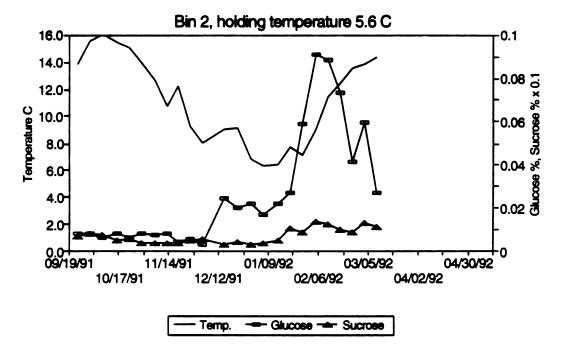


Fig. 4.15b Bin temperature and sugars for bin 2, 1991-1992.

0.1%. Attempts to recondition the potatoes were unsuccessful. It is assumed that the rises in glucose were a result of oxygen starvation.

# **4.4.3 Snowden Storage for 1992-1993**

#### 4.4.3.1 Results of Cooling Rates and Storage Temperature

Plots of the temperatures and the tuber sugar levels for the three bins are displayed in Figures 4.16a, 4.16b and 4.16.c. Bin 1 was cooled to 7.2°C at a programmed rate of 0.3°C/day (actual rate 0.17). After 2 weeks at 7.2°C, no increases in sugars were noted. After 4 weeks at 7.2°C, both the glucose and sucrose had doubled, (to 0.007% and 0.09% on a fresh weight basis). The glucose levels rose slightly more over the next month and then declined slightly, but remained below 0.01% for the 4 months they were held at 7.2°C. Acceptable color levels were maintained throughout. The sucrose levels reached 0.1% after 6 weeks and then decreased and remained around 0.075 for the remaining storage time.

Bin 2 was cooled to 5.5°C at a set rate of 0.3°C/day (actual rate 0.19).

One week after reaching 5.5°C, no increases in sugars were noted, glucose was at 0.003% and sucrose was at 0.05%. Two weeks later, the glucose had risen to 0.08% and the sucrose to 0.1%. After 3 weeks at 5.5°C, bin 2 was lowered to 5°C over a weeks time, and then held there for 2 weeks. After one week at 5°C, the glucose levels had risen to 0.017% and the chips were marginal in color (SFA rating 2). The sucrose level was 0.12%. After 2 weeks at 5.0°C, bin 2 was allowed to warm gradually to 7.2°C over the next 4 weeks, then held at that temperature for 8 weeks. The glucose levels during this time were just

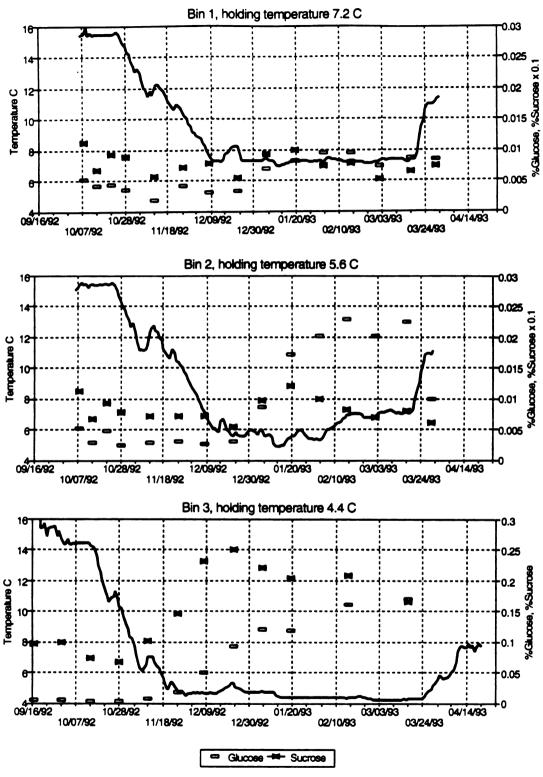


Fig. 4.16 Temperatures and sugar levels for field research bins. Note: change in scale and sucrose units for bin 3. 1992-1993.

above .02% and the sucrose levels declined slowly from 0.1%. Chips were unacceptable in color with color ratings (SFA) of 2.5-3.0.

After reconditioning for 1.5 weeks at 11°C, the glucose levels dropped below 0.01% and chips were acceptable (SFA color 1.5).

Bin 3 was cooled to 4.4°C at 0.5°C/day (0.26). As the tubers reached 5 to 6°C, an increase in glucose and sucrose were noted. 4 weeks later sucrose levels had risen above 0.2%, but remained constant afterwards. Glucose levels were above 0.04% and continued to rise as they were held in storage.

#### 4.4.3.2 Discussion of 1992-1993 Cooling Rates and Storage Temperatures

The cooling rate of 0.3°C/day and a holding temperature of 7.2°C appear to be close to the limits for storing the Snowden variety without increasing sugars to a level that will adversely affect chip color. A preferred storage strategy would be one that cools the tubers to a minimum holding temperature as quickly as possible while maintaining low sugar levels, similar to the strategy used on bin 1. Bin 1 (holding temperature 7.2°C) was cooled allowing a plenum to pile temperature differential of 2.0°C, which allowed cooling temperatures as low as 5.2°C. To prevent the rises in sugars that occurred in bin 1, the cooling rate should be slowed as the temperature approaches 7.2°C and a lower limit (7.0°C) placed on the cooling air.

#### 4.4.3.3 Results for Reconditioning

On April 21 bin 3 was marketed for seed and samples were warmed to 12.5°C for reconditioning. Sugar levels declined, but after 4 weeks reconditioning, chips from the tubers were still unacceptable in color.

# 4.4.3.4 Discussion of Reconditioning

If Snowden potatoes are stored at temperatures where low temperature sweetening takes place, reconditioning may not be able to remove enough of the sugars to market the potatoes for processing as chips.

### 4.4.3.5 Results of Weight Loss in Storage

The weight loss in tubers from bins 1, 2 and 3 were 7.1%, 7.8% and 7.4% respectively. The humidifiers were in operation more than 97% of the time during the cool down period. Potatoes in bin 3 were held for one month longer than bins 1 and 2.

# 4.4.3.6 Discussion of Weight Loss in Storage

The humidifiers in the field research bin were evidently undersized. The weight losses (over 7% for all 3 bins) was higher than the target of 3-4% recommended by Hunter (1986).

# 4.4.3.7 Results for Sprout Growth

Bins 1 and 2 were treated with MH30 in the field and no other sprout inhibitor was applied. Sprout growth was minimal for tubers in all bins.

# 4.4.3.8 Discussion of Sprout Growth

None of the bins were treated with inhibitors after harvest. The cooling rate of 0.3°C to 7.2°C was enough to control sprouting through March.

#### 5. CONCLUSIONS

- 1. Glucose levels of potatoes provide a quantitative measure of the chip processing quality.
- 2. For the Snowden potatoes stored in 1992-1993, a sample with a glucose level of 0.0075% (fresh weight basis) will have 90% probability of having a color of 1 or 1.5 (from Figure 4.2). A sample with a glucose level of 0.01% will have a 90% probability of having a color of 1, 1.5 or 2. Glucose levels for Atlantic variety potatoes were similar to those of Snowden.
- 3. Sampling from the top of the bin provides a representative sample of the bin.
- 4. Snowden tubers stored at 7.2°C went "off color" 4 weeks later than the tubers stored at 10.0°C. The tubers stored at 7.2°C were warmed to 18.3°C after 5 months storage and if left at 7.2°C may have lasted longer before sweetening.
- 5. Heat treatments had a minimal effect on the initiation date of late storage sweetening. Increasing the length of heat treatment increased the rate at which sugars rose.
- 6. Based on biweekly sampling of Snowden tubers from the 1992-1993 storage season, late storage season sweetening problems can be anticipated by rises in sugar levels. Increases in glucose can be detected 6 to 8 weeks before chips go off color and increases in sucrose can be detected 8 weeks before chips go off color. Additional stresses imposed on potatoes in early storage or during harvest may increase the rate of sweetening.

- 7. The Snowden variety potatoes stored at 7.2°C respond to storage management in a manner similar to Atlantic variety potatoes stored at 10°C for an extended storage season.
- 8. Faster cooling rates and lower temperatures such as those used for Snowden can reduce the need for sprout inhibitors in long-term storage and may eliminate the need for sprout inhibitors in shorter term storage.
- 9. The Snowden variety can be cooled at faster rates to 9°C than are normally recommended for processing potatoes in Michigan without causing chip discoloration or rises in sugar levels.
- 10. Care should be taken to assure that the difference between pile and plenum temperatures does not exceed 2.0°C to prevent excessive moisture loss. Smaller differences (1.5°C) may be better if an acceptable cooling rate can be maintained.
- 11. Snowden potatoes stored below 4.4°C with low temperature induced sweetening were successfully reconditioned 1 of the 2 years of the laboratory study. Reconditioning can be successful if temperatures above 10°C are used but storage at temperatures below the lower limit for the variety are not recommended.

# 6. RECOMMENDATIONS FOR THE STORAGE OF SNOWDEN

Based on past works, observations and data from the 1990-1993 storage years, and observations from growers in Michigan, recommendations for the storage of Snowden variety potatoes include (following suberization and preconditioning):

- (a) Cool tubers quickly at a rate of up to 0.3°C/day to a temperature of 9°C.
- (b) Cooling to 7.2°C should be continued at a slower rate (0.15°C/day).
- (c) Use air temperatures not less than 7°C.

# 7. SUGGESTIONS FOR FUTURE WORK

Differences between the storage parameters for the Snowden and previously stored varieties have been noted in this work. The Michigan potato industry could benefit from information on storage temperatures and cooling rates that new varieties are able to withstand.

The Michigan Bin Monitoring Program is monitoring a larger number of bins in its second year with favorable feedback from users. The research bins located at Bishop Farms in Pinconning, Michigan offer an excellent opportunity for testing the lower storage temperature limits for the Snowden and other varieties in an actual bin situation without risking the loss of a large bin of potatoes. These bins could also be used to monitor the oxygen and carbon dioxide levels in bins and the effects of limiting the fresh air to potatoes.

Additional data would also be beneficial in evaluating the storability of bins based on their sugar levels.

On the laboratory scale, the holding of lots of potatoes at different temperatures and cooling rates until late storage season sweetening leads to unacceptable sugar levels for chipping, could verify the best storage temperatures.

# LIST OF REFERENCES

#### 8. REFERENCES

- Allen, E.L., O'Brian, P.J. and Firman, D. 1992. Seed tuber production and management. In: The Potato Crop. Ed. Harris, P. Chapman and Hall, London.
- ASAE Standards. 1993. Design and management of storages for bulk, fall-crop, Irish potatoes. EP475.4.3:587.
- Barichello, V., Yada, R.Y., Coffin, R.H. and Stanley, D.W. 1990. Low temperature sweetening in susceptible and resistant potatoes: starch structure and composition. J. Food Sci. 55:1054-1059.
- Barichello, V., Yada, R.Y., Coffin, R.H. and Stanley, D.W. 1990. Respiratory enzyme activity in low temperature sweetening of susceptible and resistant potatoes. J. Food Sci. 55:1060-1063.
- Boe, A.A., Woodbury, G.W. and Lee, T.S. 1974. Respiration studies on Russet Burbank potato tubers: effects of storage temperature and chemical treatments. Am. Potato J. 51:355-360.
- Burton, W.G., van Es, A. and Hartmans, K.J. 1992. The physics and physiology of storage. In: The Potato Crop. Ed. Harris, P. Chapman and Hall, London.
- Burton, W. G. 1974. The oxygen uptake, in air and in 5% O<sub>2</sub>, and the carbon dioxide out, of stored potato tubers. Potato Res. 17:113-37.
- Cargill, B. F., Price, K. C. and Forbush, T. D. 1989. Requirements and recommendations for potato storage in the midwest USA. In: Potato Storage Technology and Practice, Cargill, B.F., Brook, R.C., and Forbush, T.D., eds. ASAE, St. Joseph, Michigan, USA. pp 271-283.
- Claassen, P.A.M., Budde, M.A.W., de Ruyter, H.J., van Calker, M.H. and van Es, A. 1991. Potential role of pyrophosphate: fructose 6-phosphate phosphotransferase in carbohydrate metabolism of cold stored tubers of Solanum tuberosum cv Bintje. Plant Physiol. 95:1243-1249.
- Dwelle, R.B. 1990. Source/sink relationships during tuber growth. Am. Potato J. 67:829-834.
- Ehlenfeldt, M.K., Lopez-Portilla, D.F., Boe, A.A. and Johansen, R.H. 1990. Reducing sugar accumulation in progeny families of cold chipping potato clones. Am. Potato J. 67:83-91.

- Forbush, T.D. and Brook, R. C. (1993). Influence of airflow on chip potato storage management. Am. Potato J. 70:869-883.
- Gould, W.A. 1989. Factors affecting the oil content of potato chips. In: Chipping Potato Handbook. Snackfood Association, Alexandria, VA. USA.
- Hunter, J.H. 1986. Heat of respiration and weight loss in storage. In: Engineering for potatoes, ASAE, St. Joseph, MI, USA. pp 511-550.
- Hughes, J.C. and Fuller, T.J. 1984. Factors influencing the relationships between reducing sugars and fry colour of potato tubers of cv. Record. J. Food Technology. 19:455-467.
- Iritani, W.M. and Weller, L.D. 1977. Changes in sucrose and reducing sugar content of Kennebec and Russet Burbank tubers during growth and post harvest holding temperatures. Am. Potato J. 54:395-404.
- Isherwood, F.A. 1976. Mechanism of starch-sugar interconversion in Solanum tuberosum. Phytochem. 15:33-41.
- Isherwood, F.A and Burton, W.G. 1975. The effect of senescence, handling, sprouting and chemical sprout suppression upon the respiratory quotient of stored potato tubers. Potato Res. 18:98-104.
- Leszkowiat, M.J., Barichello, V., Yada, R.Y., Coffin, R.H., Lougheed, E.C. and Stanley, D.W. 1990. Contribution of sucrose to nonenzymatic browning in potato chips. J. Food Sci. 55:279-280.
- Lulai, E.C., Sowokinos, J.R. and Knoper, J.A. 1986. Transslucent tissue defects in *Solanum tuberosum* L. Plant Physiol. 80:424-428.
- Mazza, G. and Siemens, A.J. 1990. Carbon dioxide concentration in commercial potato storages and its effect on quality of tubers for processing. Am. Potato J. 67:121-132.
- Mazza, G., Hung, J. and Dench, M.J. 1983. Processing/nutritional quality changes in potato tubers during growth and long term storage. Can. Inst. Food Sci. Technol. J. 16:39-44.
- Morrell, S. and ap Rees, T. 1986. Sugar Metabolism in developing tubers of *Solanum tuberosum*. Phytochem. 25:1579-1585.
- Murata, T. 1972. Sucrose phosphate synthase from various plant origins. Agricultural Biol. Chem.36:1877-1884.

- National Potato Council. 1993. Potato Statistical Yearbook, National Potato Council, Denver, Colorado. USA.
- Niederhauser, J.S. 1993. International cooperation and the role of the potato in feeding the World. Am. Potato J. 70:385-403.
- Orr, P. 1990. A procedure to correlate color measuring systems using potato chip samples. Am. Potato J. 67:647-654.
- Plissey, E.S. 1993. Maintaining tuber health during harvest, storage, and post-storage handling. In: Potato Health Management. The American Phytopathological Society, St. Paul, MN. Rowe, R.C. ed. 41-54.
- Pollock, C.J. and ap Rees, T. 1975. Activities of enzymes of sugar metabolism in cold-stored tubers of *Solanum tuberosum*.
- Pressey, R. 1969. Role of invertase in the accumulation of sugars in cold stored potatoes. Am. Potato J. 46:292-297.
- Pressey, R. 1970. Changes in sucrose synthetase and sucrose phosphate synthetase activities during storage of potatoes. Am. Potato J. 47:245-251.
- Reust, W. and Aerny, J. 1985. Determination of physiological age of potato tubers with using sucrose, citric and malic acid as indicators. Potato Res. 28:251-261.
- Richardson, D.L., Davies, H.V., Ross, H.A. and Mackay, G.R. 1990. Invertase activity and its relation to hexose accumulation in potato tubers. J. Exp. Botany. 41(222):95-99.
- Ross, H.A. and Davies, H.V. 1992. Sucrose metabolism in tubers of potato (Solanum tuberosum L.). Effects of sink removal and sucrose flux on sucrose-degrading enzymes. Plant Physiol. 98:287-293.
- Santerre, C.R., Cash, J.N. and Chase, R.W. 1986. Influence of cultivar, harvest-date and soil nitrogen on sucrose, specific gravity and storage stability of potatoes grown in Michigan. Am. Potato J. 63: 99-110.
- Schaper, L.A. and Preston, D.A. 1989. Requirements and recommendations for potato storage in the Red River Valley and the North Central Region. In: Potato Storage Technology and Practice, ASAE, St. Joseph, Michigan, USA. pp 253-272.

- Shekhar, V.C. and Iritani, W.M. 1978. Starch to sugar interconversion in Solanum tuberosum L. I. influence of inorganic ions. Am. Potato J. 55:345-350.
- Sinha, N., Cash, J. and Chase, R. 1990. Activities of PPi and ATP dependent phosphofructokinases (PFK) in CIPC treated stored potatoes. Personal Communication.
- Snackfood Association Color Chart. Purchased by writing: SFA, 1711 King Street, Suite One, Alexandria, VA 22314.
- Sowokinos, J. 1990. Effect of stress and senescence on carbon partitioning in stored potatoes. Am Potato J. 67 (12) p. 849-857.
- Sowokinos, J. and Preston, D. 1988. Maintenance of potato processing quality by chemical maturity monitoring (CMM). Minnesota Agricultural Experiment Station. University of Minnesota, St. Paul, MN. Station Bulletin 586:1-11.
- Sowokinos, J.R., Orr, P.H., Knoper, J.A. and Varns, J.L. 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.
- Sowokinos, J.R. and Preiss, J. 1982. Pyrophosphorylases in *Solanum tuberosum* L. III. Purification, physical and catalytic properties of ADPglucose pyro phosphorylase in potatoes. Plant Physiol. 69:1459-1466.
- Sowokinos, J.R. 1978. Relation of harvest sucrose to processing maturity and storage life of potatoes. Am. Potato J. 50:333-334.
- Schwimmer, S., Makower, R.U. and Rorem, E.S. 1961. Invertase and invertase inhibitor in potato. Plant Physiol. 36:313-316.
- Thorton, R. 1989. Potato storage requirements and management in the Pacific Northwest, In: Potato Storage Technology and Practice, ASAE, St. Joseph, MI, USA.
- van Ittersum, M.K., Scholte, K. and Kupers, L.J.P. 1990. A method to assess cultivar differences in rate of physiological aging of seed tubers. Am. Potato J. 67:603-613.
- Wurr, D.C.E. 1978. Seed tuber production and management. In: The Potato Crop, P.H. Harris(Ed.) Chapter 8. Chapman and Hall, London.

# **APPENDICES**

#### APPENDIX A

#### Sugar and temperature for research bins for 1990-1991 season.

Bin 1 - Snowden, 1990-91, Bishop Farms. Bin 2 - Atlantic

Height from floor

A = 0.6 m, B = 1.7 m, C = 3.0 m, D = 4.3 m (top)

Blank data were negative measurements for sucrose (measurement errors).

Table A.1 Potato sugar and temperature data for 1990-1991.

DATE	VARIETY	GLUCOSE	SUCROSE	PULP	TEMPERATURE
	& LEVEL	8	8	°℃	°F
10/03/90	Coore D	0.006	0.045	57	13.9
10/03/90				67	
10/10/90	Atla_D	0.008 0.010	0.053 0.080	5 <i>7</i>	19. <b>4</b> 15.0
10/10/90	Snow_A Snow_B	0.010	0.069	59	15.0
	Snow_B	0.009	0.033	59	15.0
	Snow_C Snow_D	0.010	0.061	60	15.6
	Atla_A	0.010	0.078	60	15.6
	Atla_B	0.011	0.078	60	15.6
	Atla_C	0.008	0.041	61	16.1
	Atla_D	0.009	0.074	61	16.1
10/17/90		0.009	0.072	62	16.7
	Atla_D	0.009	0.057	62	16.7
10/23/90		0.015	0.012	59	15.0
	Snow_B	0.010	0.025	59	15.0
	Snow_C	0.009	0.054	59	15.0
	Snow_D	0.013	0.032	59	15.0
	Atla_A	0.013	0.012	61	16.1
	Atla_B	0.012	0.017	61	16.1
	Atla_C	0.012	0.006	62	16.7
	Atla_D	0.011	0.011	62	16.7
10/31/90		0.008	0.016	59	15.0
	Snow_B	0.005	0.014	58	14.4
	Snow_C	0.011	0.006	59	15.0
	Snow_D	0.008	0.006	59 50	15.0
	Atla_A	0.008	0.012	59 59	15.0 15.0
	Atla_B Atla_C	0.01 <b>4</b> 0.006	0.002 0.016	59	15.0
	Atla_D	0.000	0.010	59	15.0
11/07/90		0.009	0.010	59	15.0
11/0//50	Snow_B	0.011		59	15.0
	Snow_C	0.014		59	15.0
	Snow_D	0.012		59	15.0
	Atla_A	0.011		59	15.0
	Atla_B	0.010		59	15.0
	Atla_C	0.008	0.004	59	15.0
	Atla_D	0.009	0.049	59	15.0
11/14/90	Snow_A	0.008	0.082	57	13.9
	Snow_B	0.011	0.088	57	13.9
	Snow_C	0.012	0.063	57	13.9
	Snow_D	0.015	0.076	57	13.9
	Atla_A	0.015	0.061	57	13.9
	Atla_B	0.013	0.084	57 57	13.9
	Atla_C	0.015	0.080	5 <i>7</i>	13.9
	Atla_D	0.011	0.098	57	13.9

DATE	VARIETY & LEVEL	GLUCOSE	SUCROSE	PULP °C	TEMPERATURE °F
11/20/90	Snow_A Snow_B Snow_C Snow_D Atla_A Atla_B Atla_C	0.006 0.006 0.006 0.006 0.008 0.010	0.053 0.057 0.061 0.067 0.080 0.063 0.059	56 56 56 56 56	13.3 13.3 13.3 13.3 13.3 13.3
11/28/90	Atla_D	0.006 0.008 0.008 0.008 0.008 0.008	0.063 0.047 0.067 0.059 0.051 0.057 0.080 0.057	56 56 56 56 56 56	13.3 13.3 13.3 13.3 13.3 13.3 13.3
12/04/90	Snow_B Snow_C Snow_D Atla_A Atla_B Atla_C	0.006 0.006 0.005 0.008 0.006 0.012	0.098 0.035 0.029 0.033 0.067 0.043 0.076	57 53 53 53 54 54	13.9 11.7 11.7 11.7 11.7 12.2 12.2
12/12/90	Snow_B Snow_C Snow_D Atla_A Atla_B Atla_C	0.009 0.006 0.008 0.008 0.009 0.006	0.051 0.061 0.018 0.057 0.061 0.045 0.039 0.049	54 53 53 53 53 53 53	12.2 11.7 11.7 11.7 11.7 11.7 11.7 11.7
12/19/90	Snow_B Snow_C Snow_D Atla_A Atla_B Atla_C	0.004 0.011 0.017 0.019 0.012 0.009 0.011	0.041 0.031 0.000 0.016 0.026 0.049 0.022	51.5 51.5 51.5 51.5 51.5 51.5 51.5	10.8 10.8 10.8 11.1 10.8 10.8
12/26/90	Atla_D Snow_A Snow_B Snow_C Snow_D Atla_A Atla_B Atla_C	0.011 0.003 0.012 0.008 0.006 0.010 0.009 0.011	0.078 0.055 0.045 0.031 0.002 0.047 0.025 0.027 0.039	49.5 49.5 49.5 49.5 51.5 51.5	10.8 9.7 9.7 9.7 9.7 10.8 10.8 11.1
01/03/91	Atla_D Snow_A Snow_B Snow_C Snow_D Atla_A Atla_B Atla_C Atla_D	0.012 0.012 0.011 0.013 0.009 0.009 0.012 0.010	0.039 0.008 0.022 0.016 0.041 0.033 0.039 0.022 0.031	48 48 48 50 50	8.9 8.9 8.9 10.0 10.0

DATE	VARIETY & LEVEL	GLUCOSE	SUCROSE	PULP	TEMPERATURE °F
01/09/91	Snow_A Snow_B Snow_C Snow_D Atla_A Atla_B Atla_C Atla_D	0.009 0.009 0.008 0.009 0.008 0.008 0.014	0.074 0.037 0.029 0.067 0.045 0.027 0.029 0.057	48.6 47.5 47.5 47.5 50.9 50.4 50.4	9.2 8.6 8.6 8.6 10.5 10.2 10.2
01/16/91	Snow_A Snow_B Snow_C Snow_D Atla_A Atla_B Atla_C Atla_D	0.009 0.009 0.012 0.015 0.011 0.011 0.009	0.078 0.090 0.072 0.078 0.086 0.098 0.084 0.094	47.1 46.4 46.2 50.2 50.2 50.2	8.4 7.8 8.0 7.9 10.1 10.0 10.1
01/23/91	_	0.009 0.010 0.012 0.010 0.010 0.009 0.006	0.076 0.053 0.035 0.041 0.047 0.033 0.047 0.069	46.9 45.1 45.1 45.3 50.7 50.5 50.5	8.3 7.3 7.3 7.4 10.4 10.3 10.3
01/30/91	_	0.014 0.012 0.015 0.012 0.010 0.010 0.011	0.047 0.027 0.039 0.020 0.037 0.045 0.039 0.033	46.9 45.1 45.3 50.9 50.4 50.5	8.3 7.2 7.3 7.4 10.5 10.2 10.3
02/06/91	_	0.019 0.014 0.016 0.016 0.017 0.014 0.014	0.074 0.094 0.074 0.059 0.049 0.082 0.076 0.074	45.8 45.5 45.7 46 50.5 50.4 50.5	7.7 7.5 7.6 7.8 10.3 10.2 10.3
02/13/91		0.019 0.006 0.012 0.010 0.013 0.011 0.010 0.008	0.045 0.045 0.049 0.045 0.031 0.049 0.029	45.5 45.3 45.3 45.3 49.8 49.6 50	7.5 7.4 7.4 7.4 9.9 9.8 10.0
02/20/91	Snow_A Snow_B Snow_C Snow_D Atla_A Atla_B Atla_C Atla_D	0.015 0.013 0.016 0.017 0.012 0.015 0.013	0.102 0.087 0.097 0.096 0.065 0.082 0.061 0.088	45 44.8 44.8 45.1 48.9 49.5 48.9	7.2 7.1 7.1 7.3 9.4 9.7 9.4 9.1

DATE	VARIETY & LEVEL	GLUCOSE	SUCROSE	PULP °C	TEMPERATURE °F
02/27/91	Snow_B Snow_C Snow_D Atla_A Atla_B Atla_C Atla_D	0.011 0.015 0.013 0.013 0.015 0.015 0.013 0.013 0.016 0.015	0.086 0.110 0.082 0.090 0.059 0.078 0.069 0.057	45 44.8 44.6 49.1 50.4 51.1 51.6 45.3 44.8	7.2 7.1 7.1 7.0 9.5 10.2 10.6 10.9 7.4 7.1
03/14/91	Snow_C Snow_D Atla_A Atla_B Atla_C Atla_D	0.017 0.019 0.017 0.017 0.015 0.017 0.010 0.014 0.017	0.112 0.131 0.086 0.084	45.1 45.7 48.7 51.3 53.1 44.6 43.9 44.6	7.3 7.6 9.3 10.7 11.1 11.7 7.0 6.6 7.0
03/19/91	Atla_A Atla_B Atla_C Atla_D Snow_A Snow_B Snow_C Snow_D Atla_A	0.015 0.020 0.014 0.016 0.014 0.013 0.008 0.028 0.008	0.035 0.078 0.059 0.086 0.092 0.121 0.096 0.082 0.092	50 50.9 51.4 52 48.9 46.4 46.4 45 51.1 52.3	10.0 10.5 10.8 11.1 9.4 8.0 8.0 7.2 10.6
03/26/91	Atla_B Atla_C Atla_D Snow_A Snow_B Snow_C Snow_D Atla_A Atla_B Atla_C	0.014 0.012 0.013 0.013 0.016 0.011 0.022 0.017 0.014 0.011	0.090 0.072 0.061 0.080 0.104 0.078 0.063 0.033 0.082 0.055	52.3 52.7 53.2 48.6 48.7 49.3 49.1 51.8 52.5 53.1	11.3 11.5 11.8 9.2 9.3 9.6 9.5 11.0 11.4
04/02/91	Atla_D Snow_A Snow_B Snow_C Snow_D Atla_A Atla_B Atla_C Atla_D	0.013 0.016 0.017 0.012 0.014 0.011 0.019 0.015	0.069 0.078 0.116 0.100 0.082 0.053 0.074 0.069 0.059	52.8 49.1 49.3 49.1 52.3 52.3 52.5 52.7	11.6 9.5 9.6 9.5 9.5 11.3 11.4 11.5
04/09/91	Snow_A Snow_B Snow_C Snow_D Atla_A Atla_B Atla_C Atla_D	0.015 0.015 0.015 0.017 0.008 0.011 0.013	0.069 0.098 0.094 0.096 0.086 0.082 0.088 0.094	53.1 53.2 54.1 51.4 54.5 55.6 54.3 55.9	11.7 11.8 12.3 10.8 12.5 13.1 12.4 13.3

# APPENDIX B

Sugar, temperature and agtron color for research bins, 1991-1992.

Potato sugar and temperature data for bin 1, 1991-1992. Table B.1a

7
Ξ.
5
7
Ä
0
9
-
•
2
_
α.
8
ă
7
4
4
•
7
_
무
귰
Д

			Height	above fl	oor					Agtr	uo	Color	
	9.0	m	1.7	ш	3.0 ш		4.3 m	=	نِ	Heigh	ht ab	pove	floor
DATE	& Glu	Su	ပ	Su	Gl	& Suc	& Glu	Suc 8		0.6	1.73	0.	<u>س</u>
/24/9	900.	0.055	9	0.065	8	٠.	900.	0	4.4	99	99	G	<u> 26</u>
/01/9	.008	.07	•	. 09	00.	90.	0.0043	. 08		53	28		89
0/08/6	.008	90.	900.	90.	900.	. 05	900.	. 05	15.8	28	63	•	5.7
0/16/9	•	.07	900.	90.	٥.	. 03	.008	. 04	15.3	99	57	<b>~</b>	99
0/23/9	900.	.04	900.	. 05	.008	.03	900.	.04	15.4	99	53	_	99
/30/9	900.	.03	•	.04	.007	.02	0.0054	. 04	15.5	57	99	G	57
1/06/9	.007	. 03	.004	.04	900.	.02	.007	.03	14.4	99	53	S	99
1/13/9	.004	. 04	900.	. 03	٥.	.02	.008	. 02	13.9	57	57	۵	99
1/19/9	900.	. 02	900.	.03	٥.	. 02	.003	.03	14.3	54	52	2	55
1/26/9	.005	. 02	.005	.04	.005	.02	900.	٥.	12.8	54	52	2	99
2/03/9	.004	. 02	.004	.03	.005	.02	90.	.02	12.0	57	52	9	57
2/15/9	.025	80.	.024	0.	٥.	0.	.02	00.		52	52	7	55
2/23/9	.023		.026		٥.	0.	.01	.02		28	54	9	55
/30/9	.021	.01	.019	.03	.015	.02	.01	.02	•	52	52	~	53
1/06/9	.019	٥.	.020	. 05	.018	.02	.01	.03	•	52	54	7	99
1/14/9	.015	. 02	.021	. 02	.008	.02	.01	. 05		52	52	4	99
1/21/9	.023	٥.	.017	. 12	.019	. 08	. 02	.07	•	54	53	<u>س</u>	52
1/28/9	.041	. 12	.050	.15	.063	.09	. 05	. 12		49	47	6	48
2/04/9	.050	٦.	.051	.1	.057	. 10	90.	. 10		47	46	0	20
2/11/9	.041	. 09	.079	. 11	.074	. 08	.04	. 05	7	20	46	9	618
2/18/9	.023		.038	. 13	.045	60.	.03	0.	5.	47	47	6	618
02/25/92	0.0290	0.121	0.0355	0.153	0.0301	0.098	0.0430	0.102	14.2	49	49		49
3/03/9	.040	. 13	.032	. 15	.027	. 10	.03	. 12	4	53	20	_	49
/10/9	.019	. 11	.035	. 17	.023	.09	. 03	. 14	4.	48	46	9	46
/11/9	.022	٦.	.037	. 18	.029	. 12	. 05	. 15	4	51	49	6	49
/24/9	.051	. 13	.034	. 18	.054	. 17	.04	. 14	4	46	48	6	49
/31/9	.036	. 18	.032	?	.051	. 17	.04	.16	4	47	48	~	20
6/10/	.024	. 19	.049	. 22	.047	٦.	•	. 20	δ.	46	47	~	46
	.047	. 22	.047	7	.036	7	. 058	. 20	<u>.</u>	45	48	7	44
Agtron color													
שארו יוחדו הע	•												

1. For unpeeled chips.

2. Agtron color and approximate corresponding (Snackfood Association color)

2. Agtron color and approximate corresponding (Snackfood Association color)

54-56 (SFA = 1)

51-53 (SFA = 2)

48-50 (SFA = 2.5)

45-47 (SFA = 3)

"% Glu and % Suc are the % of glucose and sucrose on a fresh weight basis.

Blank spots are missing data or dates not collected.

Table B.1b Potato sugar and temperature data for bin 2, 1991-1992.

~
_
-
5
Ţ
ᅼ
9
ω.
7
•
9
E
•
•
ō
ā
7
₩
0
_
•
a
- •
q
掃
ä
_

Height 1.7 1	Height 1.7 m	# Glu # Suc   # Glu   1.7   # Glu # Suc   # Glu   1.7   # Glu # Suc   # Glu   1.7   # Glu # Suc   # Glu   # Glu # Suc   # Glu   # Glu # Glu   # Glu   # Glu # Glu # Glu   # Glu # Glu # Glu   # Glu # Glu # Glu # Glu   # Glu #
Height 1.7  1.3  1.7  1.7  0.0086  0.0086  0.00864  0.00864  0.00864  0.00864  0.00864  0.00864  0.00864  0.00864  0.00864  0.008664  0.	Height above floor    Column	Height above floor  0.6 m  1.7 m 3.0 m 3.0 m  61u' \$ Suc' \$ Glu \$ Suc \$ Glu \$ \$  0.064 0.072 0.0086 0.094 0.0064 0 0.0086 0.072 0.0064 0.096 0.0064 0 0.0086 0.051 0.0064 0.074 0.0064 0 0.0086 0.051 0.0064 0.074 0.0064 0 0.0086 0.037 0.0086 0.043 0.0064 0 0.097 0.039 0.0064 0.043 0.0086 0 0.054 0.043 0.0086 0.043 0.0075 0 0.054 0.043 0.0064 0.063 0.0075 0 0.054 0.043 0.0053 0.0064 0 0.054 0.047 0.0032 0.053 0.0043 0 0.054 0.047 0.0053 0.0064 0 0.054 0.047 0.0053 0.0053 0.0051 0 0.054 0.014 0.0204 0.053 0.0193 0 0.059 0.014 0.0204 0.053 0.0193 0 0.012 0.013 0.013 0.0193 0.0193 0 0.012 0.0193 0.0193 0.0193 0.0193 0 0.012 0.012 0.0193 0.0182 0.0193 0 0.0441 0.09 0.0473 0.084 0.0656 0 0.0451 0.102 0.1053 0.114 0.0365 0 0.0451 0.105 0.0387 0.182 0.0150 0 0.0451 0.105 0.0387 0.184 0.0430 0 0.050 0.117 0.059 0.118 0.0387 0 0.050 0.118 0.0387 0.0387 0.0387 0 0.050 0.118 0.0387 0.0387 0.0387 0 0.050 0.118 0.0387 0.0387 0.0387 0.0590 0 0.050 0.108 0.0398 0.0198 0.0387 0 0.050 0.019 0.0398 0.0387 0.0590 0 0.050 0.0000 0.00000 0 0.050 0.00000 0 0.0000000000
Height above floor  1.7 m	Height above floor    Height above floor   Suc.   Star   Suc.   Star	#eight above floor    0.6 m
Height above 11.7 m & Glu 1.7	Height above the control of the cont	#eight abov    0.6 m
	He Suc 1. 1. 1. 1. 1. 1. 1. 1. 1. 1. 1. 1. 1.	# Glu: # Suc. # He 0.6 m
	E	0.0086 0.00886 0.00886 0.00886 0.00886 0.00886 0.00886 0.00886 0.00886 0.00886 0.00886 0.00886 0.00886 0.00888 0.008888 0.008889 0.008892 0.008892 0.008892 0.008892 0.008892 0.00892 0.00892 0.00892 0.00892 0.009986 0.00

'Agtron color:

1. For unpeeled chips.

2. Agtron color and approximate corresponding (Snackfood Association color)

54-56 (SFA = 1)

51-53 (SFA = 2)

48-50 (SFA = 2.5)

48-50 (SFA = 3.5)

"\$ Glu and \$ Suc are the \$ of glucose and sucrose on a fresh weight basis.

Blank spots are missing data or dates not collected.

Table B.1c Potato sugar and temperature data for bin 3, 1991-1992.

a
O
992
•
٠.
┥.
199
a
-
٠.
_
9
7
Ä
1
u
u
6
H
• •
_
m
ø
4

Bin 3, lott farms, 1991-1994	rare, th	PART-TAI											
			Height	above f1	floor					Agt	ron (	Agtron Color	
	m 9.0	E	1.7	E	3.0 ш	-	4.3	E	ب	Height		above	floor
DATE	& Glu	Suc.	& Glu	& Suc	& Glu	& Suc	& Glu	Suc	Temp	9.0	1.7	3.0 4	ا.
10/03/91	0.0064	60.0	0.0064	0.067	0.0107	0.069	0.0064	0.067	14.7				ì
10/08/91	0.0064	0.072			0.0043	0.088	0.0064	0.082	9.5	58	28	28	69
10/16/91	0.0064	0.074	0.0064	0.076	0.0064	0.059	0.0021	0.08	9.8	57	99	54	53
10/23/91	0.0064	0.074	0.0086	0.078	0.0086	0.049	0.0064	0.082	8.0	54	23	52	99
10/30/91	0.0064	0.084	0.0064	0.088	9800.0	0.074	9800.0	0.084	9.3	99	54	99	53
11/06/91	0.0064	0.078	0.0054	0.102	0.0075	0.065	0.0054	0.082	6.4	99	99	54	55
11/13/91	0.0107	0.059	0.0107	0.102	0.0075	0.086	0.0075	0.084	4.2	55	53	52	55
11/19/91	0.0236	0.151	0.0118	0.139	0.0247	0.147	0.0247	0.155	4.3	53	54	53	51
12/03/91	0.0430	0.135	0.0441	0.184	0.0333	0.143	0.0613	0.147	4.0	45	45	48	46
12/15/91	0.1408	0.192	0.0924	0.188	0.1139	0.172	0.1548	0.311	4.1	37	35	43	38
12/30/91	0.1064	0.184	0.1193	0.229	0.1182	0.19	0.1903	0.221	4.0	36	35	35	35
01/14/92	0.0957	0.092	0.0860	0.098	0.1817	0.221	0.1107	0.088	4.0	33	34	31	30
01/28/92	0.0892	80.0	0.0817	0.104	0.1247	0.163	0.2107	0.217	3.9	33	32	59	30
02/11/92	0.1892	0.151	0.1698	0.192	0.1956	0.233	0.2666	0.196	<b>4</b> .0	32	32	30	31
02/25/92	0.1602	0.129	0.1806		0.1559	0.125	0.2214	0.143	4.1	35	34	28	30
03/10/92	0.1376	0.176	0.1440	0.18	0.1720	0.106	0.1784	0.127	4.7	34	34	59	27
03/24/92	0.1892	0.168	0.1505	0.221	0.1870	0.119	0.2171	0.208	4.1	34	34	34	35
04/07/92	0.3365	0.3	0.2580	0.262	0.1784	0.2	0.2558	0.249	5.8	30	33	32	31
05/07/92	0.2021	0.196	0.2386	0.249	0.2515	0.204	0.1860	0.178	9.1	31	30	34	33

Agtron color:

1. For unpeeled chips.

2. Agtron color and approximate corresponding (Snackfood Association color)

5. 57 (SFA = 1)

54-56 (SFA = 1.5)

51-53 (SFA = 2.5)

48-50 (SFA = 2.5)

45-47 (SFA = 3)

"% Glu and % Suc are the % of glucose and sucrose on a fresh weight basis.

Blank spots are missing data or dates not collected.

#### APPENDIX C

#### Equations for Figure 4.2 (acceptable samples versus glucose level).

All the samples from the research bins were sorted by glucose in ascending order and divided into intervals. The percent of acceptable samples/interval were calculated for each interval using an acceptable color of 1.5 and 2.0 (SFA). The interval width started at 0.001% for low sugar levels (0.004-0.005%) and was increased as the sugar level rose above 0.01%. This was necessary to incorporate a number of samples in each interval. Each interval had a least 5 samples. The percent of acceptable samples per interval versus glucose level are plotted in Figure 4.2 using the equations below.

Table C.1 Acceptable chips and glucose levels for intervals, 1992-93.

Acceptable Chips in Interval

	THE PERSON	*** **** ****
<pre>% Glucose'</pre>	SFA 1.5	SFA 2.0
0.004	10/10	
0.004	10/10	
0.005	8 / 8	
0.006	7/7	7/7
0.0075	10/11	11/11
0.0085	4/5	5/5
0.01	4/8	
0.011		6/7
0.0115	3/6	
0.013		4/6
0.014	2/9	
0.015		4/7
0.02	0/5	1/10
0.026	0/6	0/5

## PlotIT output for 1.5 SFA color.

```
--- PlotIT Non-Linear Regression Analysis ---
MODEL: Y = B(1)/(1. + B(2) * EXP(-(B(3) * X + B(4) * X **2)))
```

12 Observations used from PlotIT file: B:\COLOR2.SDF

Employing method: MARQUARDT COMPROMISE

Final sum of squares of residuals: 332.3907

Coefficient of Determination: .984

Degrees of Freedom: 8

B(I)	Parameter estimate	Standard Error
1	372.208200	965.132200
2	4.88292300	17.5425700
3	246.414100	94.5012000
4	-25233.4800	9309.51400

Approximate confidence limits for non-linear model parameters

B(I)	Lower	Upper /
1	-1558.05600	2302.47300
2	-30.2022200	39.9680600
3	57.4116700	435.416400
4	-43852.5100	-6614.45300

Parameter Correlation Matrix

	1	2	3	4
1	1.000			
2	.996	1.000		
3	315	230	1.000	
4	.784	.728	826	1.000

WARNING: Extremely high correlation among parameters. Results may be nonsense. Removal of a parameter from your model may help alleviate this problem.

# ANALYSIS OF RESIDUALS

Number of positive residuals: 6
Largest positive residual: 8.99739

Number of negative residuals: 6
Largest negative residual: -10.2227

Number of sign runs: 6
Significance of sign runs test: .3810

Average absolute residual: 3.44316 Residual sum of squares: 332.391

Residual mean square: 41.5488
Residual standard deviation: 6.44584

Durbin-Watson statistic: 2.62648 Auto-correlation coefficient: .000

\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*

# PlotIT output for 2.0 SFA color.

--- PlotIT Non-Linear Regression Analysis --MODEL: Y = B(1)/(1. + B(2) \* EXP(-(B(3) \* X + B(4) \* X \*\*2)))

Search terminated after 29 iteration(s) TOL4 value caused iteration termination!

11 Observations used from PlotIT file: B:\COLOR25.SDF

Employing method: MARQUARDT COMPROMISE

Final sum of squares of residuals: 63.23429

Coefficient of Determination: .997

Degrees of Freedom: 7

D/T\	Parameter estimate	Standard Error
D(1)	rarameter estimate	Scandard Error
1	144.370200	29.5670000
2	.745460900	.577491000
3	191.383000	43.3230100
4	-16546.1500	2505.28800

Approximate confidence limits for non-linear model parameters

B(I)	Lower	Upper
1	85.2361900	203.504200
2	409521200	1.90044300
3	104.737000	278.029100
4	-21556.7200	-11535.5700

#### Parameter Correlation Matrix

	1	2	3	4
1	1.000			
2	.968	1.000		
3	.156	.390	1.000	
4	.541	.332	731	1.000

WARNING: Extremely high correlation among parameters. Results may be nonsense. Removal of a parameter from your model may help alleviate this problem.

# ANALYSIS OF RESIDUALS

Number of positive residuals: Largest positive residual:	4 4.60349
Number of negative residuals: Largest negative residual:	7 -4.99266
Number of sign runs: Significance of sign runs test:	6 .6116
Average absolute residual: Residual sum of squares:	1.77624 63.2343
Residual mean square: Residual standard deviation:	9.033 <b>4</b> 7 3.00557
Durbin-Watson statistic:	2.67787

Auto-correlation coefficient: .000

\*\*\*\*\*\*\*\*\*

### APPENDIX D

T test for the difference between means of samples at 0.6, 1.7, 3.0 and 4.3 m above the floor in the three research bins for the 1992-1993 storage season, Snowden variety.

The output of the t test run using SPSS/PC+ Studentware is presented here. D.1 is the t test for all data and D.2 is for the trimmed data.

5.1.1.0	1 2			55-1		-
Bins 1 ar				Bin 3	_	
10/14/92				09/30/9		
10/21/92				10/10/9		
10/28/92				10/28/9		
11/11/92				11/11/9	92	
11/25/92				11/25/9	92	
12/08/92				12/08/9	92	
12/22/92				12/22/9	92	
01/05/93				01/05/9	93	
01/19/93				01/19/9	93	
01/02/93				02/16/9		
02/16/93				00, 20, 3		
03/02/93						
03/02/93						
03/17/93						
03/29/93						
SAMPLING	DAMEC	EOB	DIME	TICTNIC T	T T MM E D	משגם
	DATES	FOR	KUNS			DAIA
10/14/92				09/30/9		
10/21/92				10/10/9		
10/28/92				10/28/9		
11/11/92				11/11/9		
11/25/92				11/25/9	92	
12/08/92						
12/22/92						

01/05/93 01/19/93

SAMPLING DATES FOR RUNS USING ALL DATA

# A.1 T Test for All Data

MOTE: A, B, C and D correspond to samples from 0.6, 1.7, 3.0 and 4.3 m above the bin floor.

BIN 1 GLUC	OSE - ALL DA	<b>TA</b>	D				
.00301 .00344 .00366 .00172 .00452 .00301 .00301 .00667 .00559 .00753 .00946 .00731	.00925 .00430 .00409 .00237 .00323 .00366 .00387 .00710 .00731 .01140 .00495 .00538 .01032	.00366 .00280 .00129 .00559 .00258 .00301 .00710 .00753 .00882 .01376 .00452 .00538	00194 00602 00323 00194 00323 00344 00301 00710 01290 00989 01032 01204 01054 01118				
Paired sam	ples t-test:	A B					
Variable	Number of Cases		tandard viation	Standa Erro			
A B	14 14	.0052	.002	.00			
(Difference Mean	e) Standard Deviation	Standard Error	Corr.	2-Tail Prob.	t Value	Degrees of Freedom	2-Tail Prob.
0011	.003	.001	.494	.073	-1.43	13	.176
Paired sam	ples t-test:						
		A C					
Variable	Number of Cases	c s	tandard viation	Standa Erro			
Variable A C		C S			or )1		
A C	of Cases	C S Mean De	.002 .003	Erro .00 .00	or )1	Degrees of Freedom	2-Tail Prob.
A C (Difference	of Cases  14 14 e) Standard Deviation	C SMean De .0052 .0054 Standard	.002 .003	Erro .00 .00	or 01 01		
A C (Difference Mean 0002	of Cases  14 14 e) Standard Deviation	C  Mean De  .0052 .0054  Standard Error	.002 .003 Corr.	Erro .00 .00 2-Tail Prob.	or 01 01 t Value	Freedom	Prob.
A C (Difference Mean 0002	of Cases  14 14 e) Standard Deviation .002	C Mean De .0052 .0054 Standard Error .001 A D	.002 .003 Corr.	Erro .00 .00 2-Tail Prob.	t Value 30	Freedom	Prob.
A C (Difference Mean 0002 Paired samp	of Cases  14 14 e) Standard Deviation .002 ples t-test: Number	C Mean De .0052 .0054 Standard Error .001 A D	.002 .003 Corr. .814	2-Tail   Prob.   .000	t Value30	Freedom	Prob.
A C (Difference Mean 0002 Paired samp Variable A D	of Cases  14 14 e) Standard Deviation .002 ples t-test:  Number of Cases 14	C  Mean De  .0052 .0054  Standard Error .001  A D  Mean De  .0052	Corr814 tandard viation .002 .004	Erro .00 .00 2-Tail Prob000 Standa Erro .000	t Value30	Freedom	Prob.

		С					
Variable	Number of Cases	_	tandard viation	Standa Erro			
B C	14 14	.0063 .0054	.003	.00	_		
(Differenc Mean	e) Standard Deviation	Standard Error	Corr.	2-Tail Prob.	t Value	Degrees of Freedom	2-Tail Prob.
.0009	.004	.001	.344	.228	.95	13	.361
Paired sam	ples t-test:	B D					
Variable	Number of Cases		tandard viation	Standa Erro			
B D	14 14	.0063 .0069	.003 .00 <b>4</b>	.00			
(Differenc Mean	e) Standard Deviation	Standard Error	Corr.	2-Tail Prob.	t Value		2-Tail Prob.
0006	.004	.001	.554	.040	67	13	.513
Paired sam	ples t-test:	C D					
Variable	Number of Cases	_	tandard viation	Standa Erro			
C D	14 14	.005 <b>4</b> .006 <b>9</b>	.003 .00 <b>4</b>	.00			
(Differenc Mean	e) Standard Deviation	Standard Error	Corr.	2-Tail Prob.	t Value	Degrees of Freedom	2-Tail Prob.
0016	.003	.001	.670	.009	-1.87	13	.083

raired sam	pies t-test.	C					
Variable	Number of Cases		tandard viation	Standa Erro			
B C	14 14	.0063 .0054	.003	.00	_		
(Difference Mean	e) Standard Deviation	Standard Error	Corr.	-Tail   Prob.	t Value	Degrees of Freedom	2-Tail Prob.
.0009	.004	.001	.344	.228	. 95	13	.361
Paired samp	ples t-test:	B D					
Variable	Number of Cases		tandard viation	Standa Erro			
B D	14 14	.0063 .0069	.003 .004	.00	_		
(Difference Mean	e) Standard Deviation	Standard Error	_	-Tail Prob.	t Value	Degrees of Freedom	2-Tail Prob.
0006	.004	.001	.554	.040	67	13	.513
Paired samp	oles t-test:	C D					
Variable	Number of Cases		andard viation	Standa Erro			
C D	14 14	.005 <b>4</b> .0069	.003 .00 <b>4</b>	.00	_		
(Difference Mean	e) Standard Deviation	Standard Error	Corr.	-Tail Prob.	t Value	Degrees of Freedom	2-Tail Prob.
0016	.003	.001	.670	.009	-1.87	13	.083

BIN 1 SUCROSE - ALL DATA

DIM I DOCE	COM - ALLE DA	••					
А	В	С	D				
.54610 .89225 .81700 .49020 .60415 .69660 .39560 .81485 .91805 .64930 .76110 .40635 .53105	1.01480 .98685 .98685 .52030 .79550 .84280 .61705 1.11370 1.20400 .97610 .61920 .44505 .78690 .77185	.73315 .82130 .50095 .61275 .64285 .51385 .77615 .78475	.69445 1.14165 .93095 .70950 .84280 .95675 .61705 1.03200 1.03845 .65360 .88150 .88365 .73960 .84280				
Paired sam	mples t-test:	A B					
Variable	Number of Cases	Mean 1	Standard Deviation	Standa Erre			
A B	14 14	.6608 .83 <b>44</b>	.171 .226	.04			
(Differenc Mean	e) Standard Deviation	Standard Error	Corr.	2-Tail Prob.	t Value	Degrees of Freedom	2-Tail Prob.
1735	.155	.041	.731	.003	-4.20	13	.001
Paired sam	mples t-test:	A C					
Variable	Number of Cases	Mean 1	Standard Deviation	Standa Erro			
A C	14 14	.6608 .629 <b>5</b>	.171 .155	.04			
(Differenc Mean	e) Standard Deviation	Standard Error	Corr.	2-Tail Prob.	t Value	Degrees of Freedom	2-Tail Prob.
.0313	.083	.022	.876	.000	1.41	13	.181
Paired sam	mples t-test:	<b>A</b> D					
Variable	Number	Woon 1	Standard	Standa			

	of Cases	Mean	Deviation	Error		
A	14	.6608	.171	.046		
D	14	.8546	.158	.042		
(Differe	ence) Standard an Deviation	Standaro Error	d Corr	2-Tail Prob.	t Value	D

(Difference	) Standard	Standard	2-Tail	1	Degrees of	2-Tail
Mean	Deviation	Error	Corr. Prob.		Freedom	Prob.
1938	.109	.029	.785 .001	-6.67	13	.000

		•					
Variable	Number of Cases		tandard Viation	Standa Erro			
B C	14 14	.83 <b>44</b> .6295	.226 .155				
(Difference Mean	e) Standard Deviation	Standard Error		2-Tail Prob.	t Value	Degrees of Freedom	2-Tail Prob.
.2049	.195	.052	.532	.050	3.94	13	.002
Paired samp	ples t-test:	B D					
Variable	Number of Cases		andard viation	Standa: Erro:			
B D	1 <b>4</b> 1 <b>4</b>	.83 <b>44</b> .85 <b>4</b> 6	.226 .158		-		
(Difference Mean	e) Standard Deviation	Standard Error		2-Tail Prob.		Degrees of Freedom	
0203	.211	.057	.439	.117	36	13	.726
Paired samp	ples t-test:	C D					
Variable	Number of Cases		andard viation	Standa: Erro			
C D	14 14	.6295 .85 <b>4</b> 6	.155 .158	.04:			
(Difference Mean	e) Standard Deviation	Standard Error		2-Tail Prob.	t Value	Degrees of Freedom	2-Tail Prob.
2251	.144	.038	.577	.031	-5.85	13	.000

BIN 2 GLUCOSE - ALL DATA	BIN	2	GLUC	OSE	_	ALL	DATA
--------------------------	-----	---	------	-----	---	-----	------

A	В	С	D
.00237	.00344	.00194	.00366
.00409	.00538	.00280	.00710
.00301	.00172	.00258	.00237
.00237	.00323	.00280	.00302
.00237	.00452	.00237	.00302
.00280	.00301	.00172	.00280
.00366	.00344	.00215	.00345
.00581	.00667	.00817	.01398
.01419	.01505	.01505	.02473
.01871	.02516	.01892	.01763
.01570	.01591	.01140	.04902
.01226	.02042	.01871	.02946
.00667	.02451	.02967	.02946

Paired samples t-test: A B

Variable	Number of Cases	Mean	Standard Deviation	Standard Error
A	14	.0072	.006	.002
B	14	.0105	.009	

(Difference	) Standard	Standard	2-Tail	t	Degrees of	2-Tail
Mean	Deviation	Error	Corr. Prob.	Value	Freedom	Prob.
0033	. 005	.001	.810 .000	-2.40	13	.032

Paired samples t-test: A C

Variable Number Standard Standard of Cases Mean Deviation Error

A 14 .0072 .006 .002 C 14 .0090 .009 .002

	) Standard Deviation	Standard Error	2-Tail Corr. Prob.	t Value	Degrees of Freedom	2-Tail Prob.
0018	.007	.002	.655 .011	-1.01	13	.332

Paired samples t-test:

Variable	Number of Cases	Mean	Standard Deviation	Standa Erro			
A D	14 14	.0072 .01 <b>4</b> 2	.006 .01 <b>4</b>	.00			
(Difference Mean	ce) Standard Deviation	Standard Error	Corr.	2-Tail Prob.	t Value	Degrees of Freedom	2-Tail Prob.
0070	.011	.003	.768	.001	-2.49	13	.027

		C					
Variable	Number of Cases		andard viation	Standa Erro			
B C	14 14	.0105 .0090	.009	.00			
(Difference Mean	e) Standard Deviation	Standard Error		2-Tail Prob.	t Value	Degrees of Freedom	2-Tail Prob.
.0015	.003	.001	.933	.000	1.82	13	.092
Paired sam	ples t-test:	B D					
Variable	Number of Cases		andard viation	Standa Erro			
B D	14 14	.0105 .01 <b>4</b> 2	.009 .014	.00			
(Differenc Mean	e) Standard Deviation	Standard Error		2-Tail Prob.	t Value	Degrees of Freedom	
0037	.010	.003	.735	.003	-1.41	13	.183
Paired sam	mples t-test:	C D					
Variable	Number of Cases		andard viation	St <b>a</b> nda Erro			
C D	14 14	.0090 .01 <b>4</b> 2	.009 .01 <b>4</b>	.00			
(Differenc Mean	e) Standard Deviation	Standard Error	Corr.	2-Tail Prob.	t Value	Degrees of Freedom	2-Tail Prob.
0052	.010	.003	.716	.004	-1.95	13	.073

# BIN 2 SUCROSE - ALL DATA

А	В	С	D				
.56545	.70950		80625				
.89225 .73100	1.05995 .60630		90300 91805				
.75465 .67080	.90515 .72025		70090 73745				
.75680	.84065 .58695	.44075 .	78475 47300				
.86215 1.22120	1.15670	.81485 1.	03200 36955				
1.05780	1.26420	.89870 .	73530 87505				
.58480	.77830	.71165 .	66005				
.72240 .72885	.96965 .8 <b>44</b> 95		78045 38270				
Paired sam	nples t-test:	A B					
Variable	Number of Cases		tandard viation	Standa Erro			
A	14	.7990	.178	.04			
В .	14	.9124	.232	.06	52		
(Differenc Mean	e) Standard Deviation	Standard Error	1	2-Tail Prob.	t Value	Degrees of Freedom	2-Tail Prob.
1133	.123	.033	.851	.000	-3.44	13	.004
Paired sam	mples t-test:	A C					
Variable	Number of Cases		tandard viation	Standa Erro			
	or cases	Mean De	V 1 4 0 1 0 1 1				
A C	14	.7990	.178	.04			
С	14 14	.7990 .6653	.178	.04	19	Degrees of	2- <b>m</b> ail
С	14	.7990	.178	.04 .04 2-Tail		Degrees of Freedom	2-Tail Prob.
C (Difference	14 14 e) Standard Deviation	.7990 .6653 Standard	.178 .182	.04 .04 2-Tail	19 t		
C (Difference Mean .1338	14 14 e) Standard Deviation	.7990 .6653 Standard Error	.178 .182	.04 .04 2-Tail   Prob.	t Value	Freedom	Prob.
C (Difference Mean .1338	14 14 ee) Standard Deviation	.7990 .6653 Standard Error .052 A	.178 .182	.04 .04 2-Tail   Prob.	t Value 2.58	Freedom	Prob.
C (Difference Mean .1338 Paired sam	14 14 2e) Standard Deviation 2 .194 3ples t-test:	.7990 .6653 Standard Error .052 A	.178 .182 Corr. .421	.04 .04 2-Tail   Prob.   .134	t Value 2.58	Freedom	Prob.
C (Difference Mean .1338) Paired same Variable A D	14 14 2e) Standard Deviation 2 .194 3ples t-test:  Number of Cases 14	.7990 .6653 Standard Error .052 A D SMean De	.178 .182 Corr. .421	.04 .04 2-Tail   Prob. .134   Standa Erro .04 .06	t Value 2.58	Freedom	Prob.

		С					
Variable	Number of Cases	-	tandard viation	Standa Erro			
B C	14 14	.912 <b>4</b> .6653	.232 .182	.06 .04			
(Differenc Mean	e) Standard Deviation	Standard Error	i	2-Tail Prob.	t Value	Degrees of Freedom	2-Tail Prob.
. 2471	.203	.054	.542	.045	4.56	13	.001
Paired sam	ples t-test:	B D					
Variable	Number of Cases		tandard viation	Standa Erro			
B D	14 14	.912 <b>4</b> .7970	.232 .237	.06 .06	_		
(Differenc Mean	e) Standard Deviation	Standard Error	1	2-Tail Prob.	t Value	Degrees of Freedom	2-Tail Prob.
.1153	.211	.056	.595	.025	2.05	13	.061
Paired sam	ples t-test:	C D					
Variable	Number of Cases	_	tandard viation	Standa Erro			
C D	14 14	.6653 .7970	.182 .237	.04 .06	-		
(Differenc Mean	e) Standard Deviation	Standard Error	1	2-Tail Prob.	t Value	Degrees of Freedom	2-Tail Prob.

-.1318 .192 .051 .604 .022 -2.56 13 .024

BIN 3	GLUCOSE	- ALL	DATA
-------	---------	-------	------

BIN 3 GLUC	OSE - ALL DAT	ra				
A	В	С	D			
.00387 .00301 .00172	.00495 .00409 .00280	.00323 . .003 <b>44</b> .	00710 00581 00387			
.00839 .02150 .04816	.00817 .02086 .05010	.01333 .	00688 01806 07805			
.07203 .09697 .09589	.11976 .10127 .10084	.07117 .	10815 18340 16211			
.14641	.14964		19974			
Paired sam	ples t-test:	A B				
Variable	Number of Cases		tandard Stand viation Err			
A B	10 10	.0498 .0562		16 18		
(Differenc Mean	e) Standard Deviation	Standard Error	2-Tail Corr. Prob.	t Value	Degr <b>ees</b> of Freedom	2-Tail Prob.
0065	.015	.005	.968 .000	-1.40	9	.196
Paired sam	ples t-test:	<b>A</b> C				
Variable	Number of Cases		tandard Stand viation Err			
A C	10 10	.0498 .0491		16 17		
(Differenc Mean	e) Standard Deviation	Standard Error	2-Tail Corr. Prob.	t Value	Degrees of Freedom	2-Tail Prob.
.0007	.011	.003	.983 .000	.21	9	.837
Paired sam	ples t-test:	<b>A</b> D				,
Variable	Number of Cases		tandard Stand viation Err			
A D	10 10	.0498 .0773	.051 .0 .080 .0			
(Differenc Mean	e) Standard Deviation	Standard Error	2-Tail Corr. Prob.	t Value	Degrees of Freedom	2-Tail Prob.

-.0275 .032 .010 .980 .000 -2.70 9

.024

Paired samples t-test:

c

		C					
Variable	Number of Cases		tandard viation	Standa Erro			
B C	. 10 10	.0562 .0491	.056 .055	.01 .01	-		
(Differenc Mean	e) Standard Deviation	Standard Error	1	2-Tail Prob.	t Value	Degrees of Freedom	2-Tail Prob.
.0072	.018	.006	.951	.000	1.29	9	.229
Paired sam	ples t-test:	B D					
Variable	Number of Cases	_	tandard Viation	Standa Erro			
B D	10 10	.0562 .0773	.056 .080	.01	-		
(Differenc Mean	e) Standard Deviation	Standard Error		2-Tail Prob.	t Value	Degrees of Freedom	2-Tail Prob.
0211	.032	.010	. 948	.000	-2.05	9	.071
Paired sam	ples t-test:	C D					
Variable	Number of Cases		andard viation	Standa Erro			
C D	10 10	.0491 .0773	.055 .080	.01			
(Differenc Mean	e) Standard Deviation	Standard Error		2-Tail Prob.	t Value	Degrees of Freedom	2-Tail Prob.
0282	.030	.010	. 970	.000	-2.96	9	.016

# BIN 3 SUCROSE - ALL DATA

BIN 3 SUCR	OSE - ALL DAY	ra					
A	В	С	D				
1.00405 .63210 .54395 .96750 1.54585 1.97585 2.60150 2.62300 1.79525 1.99090	2.66600 1 2.73050 2 2.27900 1 1.90705 1	.59985 . .85570 . .91590 1. 1.05135 1. 1.85330 2. 2.27900 2. 1.57595 2.	04060 92020 63855 15670 64475 75200 38650 60150 25750				
Paired sam	ples t-test:	A B					
Variable	Number of Cases		tandard viation	Standa Erro			
<b>A</b> B	10 10	1.5680 1.6974	.759 .79 <b>4</b>	. 24 . 25			
(Differenc Mean	e) Standard Deviation	Standard Error	Corr.	-Tail Prob.	t Value	Degrees of Freedom	2-Tail Prob.
1294	.258	.082	.946	.000	-1.58	9	.148
Paired sam	ples t-test:	<b>A</b> C					
Variable	Number of Cases	-	tandard viation	Standa Erro			
<b>A</b> C	10 10	1.5680 1.3655	.759 .566	. 24 . 17	-		
(Difference Mean	e) Standard Deviation	Standard Error	Corr.	-Tail Prob.	t Value	Degrees of Freedom	2-Tail Prob.
.2025	.368	.116	.886	.001	1.74	9	.116
Paired sam	ples t-test:	A D					
Variable	Number of Cases		tandard viation	Standa Erro			
A D	10 10	1.5680 1.7785	.759 .787	. 24 . 24			
(Difference Mean	e) Standard Deviation	Standard Error	Corr. <sup>2</sup>	-Tail Prob.	t Value	Degrees of Freedom	2-Tail Prob.
2105	.353	.112	.896	.000	-1.89	9	.092

Variable	Number of Cases		tandard viation	Standa Erro			
B C	10 10	1.697 <b>4</b> 1.3655	.79 <b>4</b> .566	.25 .17	_		
(Difference Mean	e) Standard Deviation	Standard Error		2-Tail Prob.	t Value	Degrees of Freedom	2-Tail Prob.
.3320	.331	.105	.936	.000	3.17	9	.011
Paired samp	oles t-test:	B D					
Variable	Number of Cases		tandard viation	Standa Erro			
B D	10 10	1.6974 1.7785	.79 <b>4</b> .787	. 25 . 2 <b>4</b>			
(Difference Mean	e) Standard Deviation	Standard Error	Corr.	2-Tail Prob.	t Value	Degrees of Freedom	2-Tail Prob.
0811	.261	.083	.945	.000	98	9	.352
Paired samp	oles t-test:	C D					
Variable	Number of Cases		andard viation	Standa Erro			
C D	10 10	1.3655 1.7785	.566 .787	.17 .24			
(Difference Mean	e) Standard Deviation	Standard Error	Corr.	2-Tail   Prob.	t Value	Degrees of Freedom	2-Tail Prob.
4130	.356	.113	.912	.000	-3.66	9	.005

# D.2 T Test for Trimmed Data

# NOTE: GA, GB, GC and GD correspond to samples from 0.6, 1.7, 3.0 and 4.3 m above the bin floor.

BIN	1	GLUCOSE	-	TRIMMED	DATA
-----	---	---------	---	---------	------

GA	GB	GC	GD
.00301 .00344 .00366 .00172 .00452 .00301 .00301	.00925 .00430 .00409 .00237 .00323 .00366 .00387	.00237 .00366 .00280 .00129 .00559 .00258 .00301	.00194 .00602 .00323 .00194 .00323 .00344 .00301
.00559	.00731	.00753	.01290

Paired samples t-test: GA GB

Variable	Number of Cases	Mean	Standard Deviation	Standard Error
GA	9	.0038	.002	.001
GB	9	.0050	.002	.001

	) Standard	Standard	2-Tail	t	Degrees of	2-Tail
	Deviation	Error	Corr. Prob.	Value	Freedom	Prob.
0012	.002	.001	.480 .191	-1.71	8	.126

Paired samples t-test: GA GC

Variable	Number of Cases	Mean	Standard Deviation	Standard Error
GA	9	.0038	.002	.001
GC	9	.00 <b>4</b> 0		.001

(Difference)	Standard	Standard	2-Tail		Degrees of	2-Tail
Mean	Deviation	Error	Corr. Prob.		Freedom	Prob.
0001	.001	.000	.952 .000	48	8	. 645

Variable	Number of Cases	Mean	Standard Deviation	Standard Error
GA	9	.0038	.002	.001
GD	9	.0048	.004	.001
			1	

(Difference	) Standard	Standard	2-Tail	1	Degrees of	2-Tail
Mean	Deviation	Error	Corr. Prob.		Freedom	Prob.
0009	.003	.001	.718 .030	-1.03	8	.334

		GC					
Variable	Number of Cases	_	tandard viation	Standa Erro			
GB GC	9 9	.0050 .00 <b>4</b> 0	.002	.00	_		
(Differenc Mean	e) Standard Deviation	Standard Error		2-Tail Prob.	t Value	Degrees of Freedom	2-Tail Prob.
.0010	.002	.001	.403	.282	1.25	8	.247
Paired sam	ples t-test:	GB GD					
Variable	Number of Cases	_	tandard viation	Standa Erro			
GB GD	9 9	.0050 .00 <b>48</b>	.002 .00 <b>4</b>	.00			
(Differenc Mean	e) Standard Deviation	Standard Error	1	2-Tail Prob.	t Value	Degrees of Freedom	2-Tail Prob.
.0003	.003	.001	.405	.280	. 24	8	.819
Paired sam	ples t-test:	GC GD					
Variable	Number of Cases	_	tandard viation	St <b>a</b> nda Erro			
GC GD	9 9	.0040 .0048	.002 .00 <b>4</b>	.00	_		
(Differenc Mean	e) Standard Deviation	Standard Error		2-Tail Prob.	t Value	Degrees of Freedom	2-Tail Prob.
0008	.002	.001	.817	.007	-1.08	8	.313

#### BIN 1 SUCROSE - TRIMOED DATA

GA	GB	GC	GD
.54610 .89225 .81700 .49020 .60415 .69660 .39560 .81485 .91805	1.01480 .98685 .98685 .52030 .79550 .84280 .61705 1.11370 1.20400	.39560 .73315 .82130 .50095 .61275 .64285 .51385 .77615	.69445 1.14165 .93095 .70950 .84280 .95675 .61705 1.03200

Paired samples t-test: GA GB

Number of Cases	Mean	Standard Deviation	Standard Error
9	.6861	.187	.062
9	.8980	.225	.075
	of Cases	of Cases Mean 9 .6861	of Cases Mean Deviation 9 .6861 .187

	) Standard Deviation	Standard Error	2-Tail Corr. Prob.	1	Degrees of Freedom	2-Tail Prob.
2119	.129	.043	.820 .007	-4.94	8	.001

Paired samples t-test: GA GC

Variable	Number of Cases	Mean	Standard Deviation	Standard Error
GA	9	.6861	.187	.062
GC	9	.6 <b>424</b>	.149	.050

	) Standard Deviation	Standard Error	2-Tail Corr. Prob.		Degrees of Freedom	2-Tail Prob.
.0437	.092	.031	.875 .002	1.43	8	.190

Variable	Number of Cases	Mean	Standard Deviation	Standard Error
GA	9	.6861	.187	.062
GD	9	.8848	.180	.060

	) Standard Deviation	Standard Error		-Tail Prob.	t Value	Degrees of Freedom	2-Tail Prob.
1988	.056	.019	.954	.000	-10.65	8	.000

		GC					
Variable	Number of Cases	_	tandard viation	Standa Erro			
GB GC	9 9	.8980 .6424	.225 .149	.07	-		
(Difference Mean	e) Standard Deviation	Standard Error		2-Tail Prob.	t Value	Degrees of Freedom	2-Tail Prob.
. 2556	.181	.060	.599	.089	4.24	8	.003
Paired sam	ples t-test:	GB GD					
Variable	Number of Cases		tandard viation	Standa Erro			
GB GD	9 9	.8980 .88 <b>4</b> 8	.225 .180	.07	-		
(Difference Mean	e) Standard Deviation	Standard Error		2-Tail Prob.	t Value	Degrees of Freedom	2-Tail Prob.
.0131	.163	.054	.696	.037	.24	8	.815
Paired samp	ples t-test:	GC GD					
Variable	Number of Cases	_	tandard viation	Standa Erro			
GC GD	9 9	.642 <b>4</b> .8848	.149 .180	.05	-		
(Difference Mean	e) Standard Deviation	Standard Error	1	2-Tail Prob.	t Value	Degrees of Freedom	2-Tail Prob.
2425	.096	.032	.844	.004	-7.54	8	.000

BIN 2	GLUCOSE	- TRINGCED	DATA
-------	---------	------------	------

GA	GB	GC	GD
.00237 .00409 .00301 .00237 .00237 .00280 .00366 .00581	.00344 .00538 .00172 .00323 .00452 .00301 .00344 .00667	.00194 .00280 .00258 .00280 .00237 .00172 .00215	.00366 .00710 .00237 .00302 .00302 .00280 .00345 .01398

GB

Variable	Number of Cases	Mean	Standard Deviation	Standa Erre			
G <b>A</b> GB	9 9	.00 <b>4</b> 5 .0052	.004 .004	.00			
(Difference) Mean	ce) Standard Deviation	Standard Error	i i	2-Tail Prob.	t Value	Degrees of Freedom	2-Tail Prob.
000	.001	.000	. 969	.000	-1.98	8	.084

Paired samples t-test: GA

GC

Variable	Number of Cases	Mean	Standard Deviation	Standard Error
GA	9	.0045	.004	.001
GC	9	.0044	.004	.001

(Difference Mean	) Standard Deviation	Standard Error	Corr. P	Tail rob.		Degrees of Freedom	2-Tail Prob.
.0001	.001	.000	. 969	.000	.29	8	.776

Paired samples t-test: GA GD

Variable Number Standard Standard Mean Deviation of Cases Error .004 .001 GA .0045 .0071 GD .008 .003

	) Standard Deviation	Standard Error	2-Tail Corr. Prob.		Degrees of Freedom	2-Tail Prob.
0026	.004	.001	.967 .000	-1.95	8	.087

		GC					
Variable	Number of Cases	_	tandard viation	Standa Erro			
GB GC	9 9	.0052 .0044	.004	.00	_		
(Difference Mean	e) Standard Deviation	Standard Error		2-Tail Prob.	t Value	Degrees of Freedom	2-Tail Prob.
.0008	.001	.000	.954	.000	1.69	8	.130
Paired samp	oles t-test:	GB GD					
Variable	Number of Cases		tandard viation	Standa Erro			
GB GD	9 9	.0052 .0071	.00 <b>4</b> .008	.00	-		
(Difference Mean	e) Standard Deviation	Standard Error	Corr.	2-Tail Prob.	t Value	Degrees of Freedom	2-Tail Prob.
0020	.004	.001	.968	.000	-1.53	8	.164
Paired samp	oles t-test:	GC GD					
Variable	Number of Cases	_	tandard viation	Standa Erro			
GC GD	9 9	.0044 .0071	.00 <b>4</b> .008	.00			
(Difference Mean	e) Standard Deviation	Standard Error	Corr.	2-Tail Prob.	t Value	Degrees of Freedom	2-Tail Prob.
0027	.003	.001	.985	.000	-2.50	8	.037

BIN	2	SUCROSE	_	TRINGCED	DATA
-----	---	---------	---	----------	------

GA	GB	GC	GD
.56545 .89225 .73100 .75465 .67080 .75680 .72670 .86215	.70950 1.05995 .60630 .90515 .72025 .84365 .58695 1.15670 1.33515	.63210 .87290 .81915 .52675 .69875 .44075 .35045 .81485	.80625 .90300 .91805 .70090 .73745 .78475 .47300 1.03200

Variable	Number of Cases	Mean	Standard Deviation	Standard Error
GA	9	.7979	.186	.062
GB	9	.8801	.258	.086

	e) Standard Deviation	Standard Error	2-Tail Corr. Prob.		Degrees of Freedom	2-Tail Prob.
0822	.139	.046	.853 .003	-1.77	8	.115

Paired samples t-test: GA

GC

Variable	Number of Cases	Mean	Standard Deviation	Standard Error
GA	9	.7979	.186	.062
GC	9	.668 <b>4</b>	.193	.064

(Difference	) Standard	Standard	2-Tail	t	Degrees of	2-Tail
Mean	Deviation	Error	Corr. Prob.	Value	Freedom	Prob.
. 1295	.190	.063	.497 .173	2.05	8	.075

Variable	Number of Cases	Mean	Standard Deviation	Standard Error
GA	9	.7979	.186	.062
GD	9	.8583	.248	.083

	) Standard Deviation	Standard Error				Degrees of Freedom	
0604	.151	.050	.794	.011	-1.20	8	.266

		GC					
Variable	Number of Cases	Mean I	Standard Deviation	Standar Error			
GB GC	· 9 9	.8801 .6684	.258 .193	.086 .064			
(Difference Mean	e) Standard Deviation	Standard Error	Corr.	2-Tail Prob.	t Value	Degrees of Freedom	2-Tail Prob.
.2117	.219	.073	.560	.117	2.89	8	.020
Paired samp	oles t-test:	GB GD					
Variable	Number of Cases	Mean I	Standard Deviation	Standar Error			
GB GD	9 9	.8801 .8583	.258 .248	.086 .083			
(Difference Mean	e) Standard Deviation	Standard Error	Corr.	2-Tail Prob.	t Value	Degrees of Freedom	2-Tail Prob.
.0217	.159	.053	.804	.009	.41	8	.692
Paired samp	oles t-test:	GC GD					
Variable	Number of Cases	Mean I	Standard Deviation	Standar Error	d		
GC GD	9 9	.668 <b>4</b> .858 <b>3</b>	.193 .248	.06 <b>4</b> .083			
(Difference Mean	e) Standard Deviation	Standard Error	Corr.	2-Tail Prob.	t Value	Degrees of Freedom	2-Tail Prob.
1899	.153	.051	.786	.012	-3.71	8	.006

### BIN 3 GLUCOSE - TRIMORD DATA

GA	GB	GC	GD
.00387 .00301 .00172 .00839	.00495 .00409 .00280 .00817 .02086	.00430 .00323 .00344 .00667	.00710 .00581 .00387 .00688 .01806

Paired samples t-test: GA GB

Variable	Number of Cases	Mean	Standard Deviation	Standard Error
GA	5	.0077	.008	.004
GB	5	.0082	.007	

(Difference	) Standard	Standard	2-Tail	t	Degrees of Freedom	2-Tail
Mean	Deviation	Error	Corr. Prob.	Value		Prob.
0005	.001	.000	.999 .000	-1.26	4	.276

Paired samples t-test: GA GC

Variable	Number of Cases	Mean	Standard Deviation	Standard Error
GA	5	.0077	.008	.004
GC	5	.0062	.00 <b>4</b>	.002

(Difference	) Standard	Standard	2-Tail	t	Degrees of	2-Tail
Mean	Deviation	Error	Corr. Prob.	Value	Freedom	Prob.
.0015	.004	.002	.997 .000	.86	4	.439

Variable	Number of Cases	Mean	Standard Deviation	Standard Error
GA	5	.0077	.008	.004
GD	5	.0083	.006	.002
(Difference	ce) Standard	Standard	a   2	2-Tail

(Difference	) Standard	Standard	2-Tail	_	Degrees of	2-Tail
Mean	Deviation	Error	Corr. Prob.		Freedom	Prob.
0006	.003	.001	.975 .005	49	4	.651

		90					
Variable	Number of Cases		tandard viation	Standa Erro			
GB GC	5 5	.0082 .0062	.007 .004	.00			
(Difference Mean	e) Standard Deviation	Standard Error		2-Tail Prob.	t Value	Degrees of Freedom	2-Tail Prob.
.0020	.003	.001	.995	.000	1.38	4	.239
Paired samp	ples t-test:	GB GD					
Variable	Number of Cases		tandard viation	Standa Erro			
GB GD	5 5	.0082	.007 .006	.00	-		
(Difference Mean	e) Standard Deviation	Standard Error	Corr.	Prob.	t Value	Degrees of Freedom	2-Tail Prob.
0002	.002	.001	.984	.002	18	4	.865
Paired samp	oles t-test:	GC GD					
Variable	Number of Cases		andard viation	Standa Erro			
GC GD	5 5	.0062	.00 <b>4</b> .006	.00			
(Difference Mean	e) Standard Deviation	Standard Error	Corr.	2-Tail Prob.	t Value	Degrees of Freedom	2-Tail Prob.
0021	.002	.001	.965	.008	-2.57	4	.062

### BIN 3 SUCROSE - TRIMOGED DATA

G,	A GB	GC	GD
1.0040 .6321 .5439 .9675	0 .75895 5 .6 <b>4</b> 715 0 .98900	.85570 .91590	1.04060 .92020 .63855 1.15670
1.5458	5 1.61250	1.05135	1.64475

Paired samples t-test: GA GB

Variable	Number of Cases	Mean	Standard Deviation	Standard Error
GA	5	.9387	.395	.177
GB	5	1.0139	.37 <b>4</b>	.167

(Difference Mean	) Standard Deviation	Standard Error	2-Tail Corr. Prob.	l	Degrees of Freedom	2-Tail Prob.
0753	.041	.018	.996 .000	-4.11	4	.015

Paired samples t-test: GA

Variable	Number of Cases	Mean	Standard Deviation	Standard Error
GA	5	.9387	.395	.177
GC	5	.86 <b>4</b> 7	.165	.07 <b>4</b>

•	) Standard	Standard	2-Tail	t	Degrees of	2-Tail
	Deviation	Error	Corr. Prob.	Value	Freedom	Prob.
.0740	.287	.128	.775 .124	.58	4	.595

Variable	Number of Cases	Mean	Standard Deviation	St <b>anda</b> : Erro			
G <b>A</b> GD	5 5	.9387 1.0802	.395 .370	.17° .16			
(Difference Mean	ce) Standard Deviation	Standard Error		2-Tail Prob.		Degrees of Freedom	2-Tail Prob.
1415	.098	.044	.969	.007	-3.21	4	.033

		GC					
Variable	Number of Cases		tandard viation	Standa Erro			
GB GC	5 5	1.0139 .86 <b>4</b> 7	.37 <b>4</b> .165	.16			
(Differenc Mean	e) Standard Deviation	Standard Error	!	2-Tail Prob.	t Value	Degrees of Freedom	2-Tail Prob.
.1492	.276	.123	.740	.153	1.21	4	.293
Paired sam	ples t-test:	GB GD					
Variable	Number of Cases		tandard viation	Standa Erro			
GB GD	5 5	1.0139 1.0802	.37 <b>4</b> .370	.16 .16			
(Differenc Mean	e) Standard Deviation	Standard Error		2-Tail Prob.	t Value	Degrees of Freedom	2-Tail Prob.
0662	.092	.041	.970	.006	-1.61	4	.182
Paired sam	ples t-test:	GC GD					
Variable	Number of Cases		tandard viation	Standa Erro			
GC GD	5 5	.8647 1.0802	.165 .370	.07 .16	_		
(Differenc Mean	e) Standard Deviation	Standard Error		2-Tail Prob.	t Value	Degrees of Freedom	2-Tail Prob.
2154	. 295	.132	. 632	.253	-1.63	4	. 177

#### APPENDIX E

# Curves of late storage season sweetening, 1992-1993.

The sugar data in the 1992-1993 late storage season sweetening experiment were fit to power curves of the form: sugar level = time $^a$  + b starting at the 'local' minimum leading to late season sweetening. The resulting coefficients of the resulting curves are listed below in Table E.1

Table E.1 Coefficients for sweetening curves, 1993. Snowden stored at  $7.2^{\circ}\text{C}$ 

Showden Stored a				_	
wks o	f trmt	<u> </u>	<u>a</u>	r <sup>2</sup>	<u>Minimum Date</u>
glucose	0	2.65E-16	5.735	0.89	04/12/93
•	1	7.25E-17	5.982	0.78	04/12/93
н	2	5.72E-34	13.278	0.60	04/12/93
Ħ	4	8.03E-11	3.491	0.76	04/12/93
sucrose	0	5.2E-14	5.773	0.97	03/28/93
W	1	1.28E-16	6.922	0.91	03/16/93
w	2	8.56E-13	5.245	0.83	03/28/93
•	4	4.42E-06	2.481	0.79	03/16/93
Snowden stored a	t 10.0°C				00, 20, 00
glucose	0	1.8E-15	5.524	0.85	03/16/93
9140050	ĺ	8.94E-18	6.587	0.85	03/16/93
	2	1.99E-21	8.301	0.82	03/16/93
	4	1.41E-16	6.278	0.80	02/15/93
sucrose	0	2.59E-07	2.846	0.92	02/15/93
sucrose	1	9.37E-09	3.536	0.78	03/01/93
	2	5.01E-11	4.511	0.76	03/01/93
 			2.180		· · · · · · · · · · · · · · · · · · ·
	4 at 10.0	2.34E-05	2.180	0.80	02/15/93
Atlantic stored			1 420	0.40	00/15/00
glucose	0	9.26E-06	1.428	0.42	02/15/93
	1	4.99E-09	2.879	0.42	02/15/93
	2	3.06E-09	3.032	0.53	02/15/93
•	4	1.19E-12	4.643	0.85	02/15/93
sucrose	0	7.17E-06	2.250	0.80	02/15/93
	1	9.69E-06	2.224	0.72	02/15/93
	2	0.000258	1.578	0.32	02/15/93
W	4	9.06E-07	2.720	0.83	02/15/93
Atlantic stored	at 12.5	°C			
glucose	0	8.86E-10	3.083	0.74	02/15/93
н	1	4.39E-07	1.914	0.25	02/15/93
н	2	1.56E-08	2.556	0.58	02/15/93
н	4	1.68E-12	4.416	0.87	02/15/93
sucrose	0	3.34E-08	3.312	0.82	02/15/93
N	1	1.61E-09	3.966	0.86	02/15/93
•	1 2	9.88E-09	3.572	0.93	02/15/93
•	4	1.3E-06	2.686	0.65	02/15/93
	-	-			