

# **FACTORS DETERMINING POTATO CHIPPING QUALITY**

Therese M. Work, Alan S. Kezis and Ruth H. True

**LIFE SCIENCES AND AGRICULTURE EXPERIMENT STATION  
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## TABLE OF CONTENTS

	<u>PAGE</u>
INTRODUCTION	1
OBJECTIVES OF EXPERIMENT	2
REVIEW OF LITERATURE	2
Potato Varieties and Chip Color	2
Sucrose Content of Potatoes and Chip Color	3
The Effect of Storage Temperature and Length of Storage on Chip Color.	3
Model Formulation	5
MATERIALS AND PROCEDURES	5
Sucrose Determination	5
Frying Technique.	6
Sensory Evaluation.	7
Photoelectric (Agtron) Measurements	7
Color Designations and Agtron Index Readings.	7
The Statistical Model and Incorporation of Binary Variables	9
RESULTS AND DISCUSSION	11
Final Model	14
Potato Varieties and Chip Color	20
The Effect of Storage Temperature and Length of Storage on Chip Color.	21
Sucrose Content and Chip Color	22
Farm Locations and Chip Color	22
Interaction of Dummy Variables and Quantitative Variables	23
Applications of the Final Model	23
CONCLUSIONS AND RECOMMENDATIONS.	24
LITERATURE CITED	26



## FACTORS DETERMINING POTATO CHIPPING QUALITY

Therese M. Work, Alan S. Kezis, and Ruth H. True\*

### INTRODUCTION

Agricultural resource economists, Edward F. Johnston and Edward S. Micka, University of Maine at Orono, estimate that approximately 5 percent of the total potato crop in the State of Maine is grown for the United States potato chip industry. Approximately 75 percent of the potatoes produced for chips within the State are raised in the central and western sections of the State. Slightly higher temperatures during the growing season and at harvest are the major reasons for growing chipping varieties in these areas as opposed to Aroostook County (Northern section). Based upon figures obtained from the Maine Potato Commission, the total potato production for the 1979 crop was 28,750,000 hundredweight. Utilizing the estimated percentage, approximately 1,437,500 hundredweight of Maine potatoes will be processed as chips.

The potato chip industry in the United States depends on potatoes from storage for nearly 30 weeks during the processing year, generally from early October to mid-April (8). Potatoes for chipping are usually bought from the grower or storage warehouse under the stipulation that if the potatoes do not chip well, they will be returned. Therefore, the necessity of a uniform product in the chipping industry presents the problem of maintaining desirable chipping quality throughout the storage season. Tubers must be kept in the most desirable chipping condition to provide a uniform flow of tubers to the processing plant through fall, winter, and spring.

Chip quality may be defined by various parameters, however, the most common index is color. Consumer preference is predominately for an attractive light brown chip (27). Therefore, to meet the preference of the consumer and to produce a superior product, factors affecting chip quality are important to both the grower and the processor and must be well understood by both to maintain acceptable chip color throughout the chipping season.

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Changes in the chemical balance, primarily the reducing sugar content, of the potato prior to harvest and during storage are responsible for the subsequent quality of chipping potatoes. Quality of the raw product has been found to vary between and within varieties when grown under different cultural and environmental conditions (27). Tuber maturity, fertilization, sucrose content at harvest, growing season temperatures, and soil moisture are some of the factors that affect the resulting sugar accumulation in newly harvested tubers (1, 20, 31, 32). Much is written in the literature about the relationship between sugar accumulation and storage temperatures (26, 31, 39).

#### OBJECTIVES OF EXPERIMENT

The purpose of this investigation was:

1. To investigate the relationship of four varieties, the sucrose content at harvest, storage temperatures of  $7.2^{\circ}\text{C}$  ( $45^{\circ}\text{F}$ ),  $12.8^{\circ}\text{C}$  ( $55^{\circ}\text{F}$ ),  $18.3^{\circ}\text{C}$  ( $65^{\circ}\text{F}$ ), and  $7.2^{\circ}\text{C}$  ( $45^{\circ}\text{F}$ ) reconditioned for one month at  $21.1^{\circ}\text{C}$  ( $70^{\circ}\text{F}$ ) prior to chipping, and the length of storage time to the color of chips from potatoes grown in Central Maine.
2. To develop an equation which will help forecast the potential chipping quality of potatoes grown in Central Maine.

#### REVIEW OF LITERATURE

##### Potato Varieties and Chip Color

Varietal differences due to variations in chemical composition (13, 18) are known to be responsible for much of the variation in the quality of chips. Miller *et al.*, (19) reported that the content of the major sugars found in potatoes, glucose, fructose, and sucrose, varied among good and poor chipping varieties.

Varieties respond differently to storage temperatures. Some varieties stored at the most favorable temperatures may accumulate enough reducing sugars (glucose and fructose) within two weeks of storage to cause dark colored chips (38). Other varieties are capable of withstanding storage at low temperatures and can be reconditioned at higher temperatures to produce an acceptable chip color. Monona and Kennebec varieties have been shown to respond favorably to reconditioning (20, 26).

The major consideration in selecting varieties for the chipping industry is the ability of that variety to withstand unfavorable environmental and cultural factors and to maintain good chipping quality throughout the storage season.

#### Sucrose Content of Potatoes and Chip Color

Sucrose, a non-reducing sugar, has been found to be the most abundant soluble sugar in potatoes (2, 4). Although it does not participate directly in the Maillard reaction which causes development of chip color, it does serve as an intermediate product in the formation of reducing sugars from starch (16, 17). Sucrose and reducing sugar content vary under different storage conditions. Samotus *et al.*, (25) reported that the predominant sugar in tubers following short term storage at low temperatures was sucrose. However, upon prolonged storage they found the reducing sugar content increased and the sucrose content decreased. They attributed this shift in the sucrose to reducing sugar ratio to peak concentration of invertase after three weeks of storage, converting the sucrose to glucose and fructose.

It was suggested by Sowokinos (32) that the amount of sucrose at harvest may be used to predict the initial rate of reducing sugar formation. In one study he found that as physical growth ceased, poor processing potatoes contained 200 to 300 percent more sucrose than potatoes that were acceptable for chip processing (32). Later work showed a direct correlation between sucrose content at harvest and resulting chip color following storage at intermediate temperatures (11.7°C, 53°F) (33). However, Hair and Gould (9) found that correlation analysis for color and harvest sucrose content by variety and harvest date showed no statistical significance.

#### The Effect of Storage Temperature and Length of Storage on Chip Color

Potatoes held under various storage conditions differ greatly in sugar content (4, 24, 25). The optimum temperature for potato storage varies depending on variety, length of storage, tuber maturity, and other factors occurring prior to storage (19, 20, 26).

It is well known that at low temperatures potato starch is converted to sugar; however, the exact mechanism is not well known (3, 16, 17). Isherwood (16) showed that starch in mature tubers stored at 2°C (35.6°F)

was converted to sugar and that sucrose represented the first and major part of the increase in sugar. Pressey (23) reported that newly harvested mature Kennebec potatoes contained low levels of reducing sugars and a low concentration of the enzyme, invertase. However, upon exposure of the tubers to temperatures of  $4.4^{\circ}\text{C}$  ( $40^{\circ}\text{F}$ ), he discovered a rapid increase in reducing sugars along with increased invertase concentration and rate of activity. His data indicated that at low temperatures invertase was one of the enzymes involved in the formation of reducing sugars from sucrose.

Storage of potatoes at reduced temperatures minimizes weight loss due to respiration and, therefore, allows for prolonged storage (29). However, a period of reconditioning is necessary to convert the accumulation of reducing sugars back to starch before chip processing (26). Singh *et al.*, (26) recommend exposure of tubers to temperatures of  $12.8^{\circ}\text{C}$  to  $23.9^{\circ}\text{C}$  ( $55^{\circ}\text{F}$  to  $75^{\circ}\text{F}$ ) for a period of one to four weeks, thus increasing the respiration rate and resulting in a decrease in sugar content.

For most potato varieties, reconditioning can help restore quality required for processing of acceptable chips. Hair and Gould (10) reported Norchip, Monona, and Kennebec potatoes could be stored at  $5^{\circ}\text{C}$  ( $41^{\circ}\text{F}$ ) for seven months, and reconditioned for two to four weeks to successfully yield acceptable chip color. Stevenson and Cunningham (35) reported that varieties differed in their response to reconditioning. Later work by Samotus and co-workers (25) demonstrated that varieties accumulated sugars at different rates during cold storage.

Some researchers have found reconditioning to have little effect on restoring chip quality. Miller *et al.*, (19) found only slight improvement in Monona, Kennebec, and Red Pontiac varieties after reconditioning at  $21.1^{\circ}\text{C}$  ( $70^{\circ}\text{F}$ ). Iritani and Weller (15) found a decrease in sucrose content of Russet Burbank and Kennebec potatoes during reconditioning; however, the decrease in reducing sugars was statistically insignificant. They concluded that the color of chips produced from cold-stored tubers could not be significantly improved by reconditioning.

Temperatures between  $8.9^{\circ}\text{C}$  and  $12.8^{\circ}\text{C}$  ( $48^{\circ}\text{F}$  and  $55^{\circ}\text{F}$ ) are favorable for maintaining most potato varieties in nearly optimum condition for chipping (20, 22, 39). Ohad *et al.*, (22) reported that at these temperatures little starch to sugar interconversion occurred. However, prolonged storage at these temperatures has been shown to be conducive

to sprout formation, weight loss, and fungal disorders (30).

#### Model Formulation

Based upon prior observations by Singh *et al.*, (26), the functions of storage time and storage temperature on potato chip color seem to be semilogarithmic. The present authors, having no prior knowledge concerning the functions of variety and sucrose content, examined various linear and non-linear functional forms.

Sowokinos (33) reported that interactions between variety and sucrose content had an effect on chip color. Singh *et al.*, (26) reported that varieties respond differently under various storage temperatures and periods of storage in relation to chip quality. This points to the need for incorporating interaction terms into the model.

#### MATERIALS AND PROCEDURES

Four potato varieties, Monona, FL-657, Kennebec, and Norchip, were grown in Central Maine under cultural practices recommended for that area. The samples were harvested in mid-September of 1978 under the direction of Paul N. Mosher, Agricultural Consultant. Each variety was sampled from three planting locations except FL-657, which was sampled from two. At harvest the samples were brought to the Maine Life Sciences and Agriculture Experiment Station at Orono for sucrose determination and processed into chips for quality evaluation. Additional tubers of the 4 varieties were transported to Aroostook State Farm, Presque Isle, Maine for storage throughout the processing season at temperatures of 7.2°C (45°F), 12.8°C (55°F), 18.3°C (65°F) and 7.2°C (45°F) reconditioned at 21.1°C (70°F) for one month prior to chipping.

#### Sucrose Determination

The method used for the determination of sucrose content was developed by Van Handel (36) and was adapted for potatoes by Sowokinos (33). Ten tubers from each sample were washed and allowed to dry at room temperature. A longitudinal section from the center of each tuber was peeled, cut into approximately 1/2 inch cubes, which were selected at random to obtain a 200 g sample.

Juice was extracted from the 200 g sample using an Acme Juicerator and collected in a 600 ml chilled beaker. Three 100 ml cold distilled water washings were passed through the juicerator, allowing 2 to 3

minutes between washings. The extract volume was brought to 430 ml with cold, distilled water, mixed, covered and placed in a refrigerator at 4.4°C (40°F) to settle for one hour. Since equipment necessary to proceed with sucrose analysis was not immediately available, aliquots of the supernatant were frozen at -16.1°C (3°F) in 60 ml polyethylene bottles and held until assayed. Sowokinos (33) reported that the extracts are stable at -20°C (-4°F) for several months.

During the latter part of December, the samples were thawed and prepared for analysis. A 1:5 dilution was made by taking 1 ml of the sample aliquot and adding it to 4 ml distilled water. From this 0.1 ml was placed in a 16 mm test tube. For each set of determinations, two reagent blanks (0.1 ml distilled water) to standardize the spectrophotometer, and six sucrose standard solutions (5, 10, 12, 16, 18 and 20 µg sucrose/0.1 ml) to establish a standard curve were included. The determinations were repeated four times. To each tube, 0.1 ml of 30 percent aqueous KOH was added and the solutions were mixed using a Vortex mixer. Marbles were used to cover the tubes which were placed in a Fisher Isotemp dry bath at 100°C (212°F) for 15 minutes to destroy reducing sugars (33). The samples were allowed to cool and 3 ml anthrone reagent were added to each tube. The solutions were again mixed, covered with marbles and placed in the dry bath for 40 minutes at 40°C (104°F). The samples were transferred to cuvetts and absorbance was measured spectrophotometrically at 620 nm using a Hitachi Perkin-Elmer spectrophotometer.

The amount of sucrose in 0.1 ml extract was calculated using the linear regression equation obtained from the regression of µg sucrose in the standard solutions on absorbance. Correlation coefficients from the five replicated sets of determinations ranged from 0.97 to 0.99. A sample dilution factor was derived as follows:

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

Multiplying the µg sucrose/0.1 ml sample by the dilution factor and dividing by 1000 provides the mg sucrose present in a gram of potato sample.

### Frying Technique

At harvest and at two month intervals, the tubers were processed to evaluate potato chip color. For each sample ten tubers were washed,

peeled in an abrasive peeler, and hand trimmed. Approximately 6-8 cross sections from the central portion of each tuber were taken using a rotary food slicer. The slices were rinsed in lukewarm water, placed on paper towels to remove excess water, and fried in Frymax vegetable shortening at  $176.6^{\circ}\text{C}$  ( $350^{\circ}\text{F}$ ) until bubbling ceased (about 3 minutes), Murphy *et al.*, (21). Drained and allowed to cool, the chips were placed in polyethylene bags for storage at  $12.8^{\circ}\text{C}$  ( $55^{\circ}\text{F}$ ) until the sensory evaluation and photoelectric (Agtron) measurements were taken.

#### Sensory Evaluation

Five sensory tests were conducted on the fried products. At harvest 11 samples were presented to a sensory panel whereas 44 samples were presented at two, four, six, and eight month testing periods, each. The samples were presented in a randomized complete block design (5) with four replications to sensory panels of 13 to 16 members. Panelists were given a rating sheet (Figure 1) to record their evaluations of the samples. Each judge was instructed to compare the color of each sample to the color standard manual developed by the Potato Chip/Snack Food Association. Five visual chip color references are illustrated in the color standard manual and range from grades 1 to 5, with 1 as the lightest in chip color and 5 as the darkest.

Following the subjective evaluation, the samples were returned to their original sample bags and stored at  $12.8^{\circ}\text{C}$  ( $55^{\circ}\text{F}$ ) until the objective evaluation could be conducted using the Agtron.

#### Photoelectric (Agtron) Measurements

Chip color was evaluated objectively utilizing the Agtron M-30-A Reflectance Color Meter. The instrument was standardized using the red mode at 0 with the black reference disc (00) and at 90 with the white disc (90) (7). The chips, 20-25, were crushed by hand to provide even distribution of the sample when placed in the 16 cm diameter sample cup and positioned on the viewer. Samples were read in triplicate and the mean of the measurements calculated.

#### Color Designations and Agtron Index Readings

Potato chip visual color designations and the corresponding Agtron index readings taken from the Potato Chip/Snack Food Association standard color manual are shown in Figure 2. Samples given sensory scores equal

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NAME: \_\_\_\_\_

BLOCK \_\_\_\_\_

DATE: \_\_\_\_\_

Instructions: Compare the color of each sample to the standards and assign the grade (1 to 5) which best matches.

<u>Sample No.</u>	<u>Grade</u>	<u>Sample No.</u>	<u>Grade</u>
1	_____	23	_____
2	_____	24	_____
3	_____	25	_____
4	_____	26	_____
5	_____	27	_____
6	_____	28	_____
7	_____	29	_____
8	_____	30	_____
9	_____	31	_____
10	_____	32	_____
11	_____	33	_____
12	_____	34	_____
13	_____	35	_____
14	_____	36	_____
15	_____	37	_____
16	_____	38	_____
17	_____	39	_____
18	_____	40	_____
19	_____	41	_____
20	_____	42	_____
21	_____	43	_____
22	_____	44	_____

FIGURE 1. Score Sheet for Potato Chip Color Rating.

to or greater than 4 or index readings less than 45 were considered to have unacceptable chip color.

<u>Color Designations</u>	<u>Agtron Index Readings</u>		
1	65	and	Higher
2	55	to	64
3	45	to	54
4	35	to	44
5	25	to	34

FIGURE 2. Potato Chip Visual Color Designations and the Corresponding Agtron Index Readings

### The Statistical Model and Incorporation of Binary Variables

One objective of this study is to derive a prediction equation that related the dependent variable  $Q_c$  (chipping quality of potatoes grown in Central Maine) to a set of variables  $X$  that affects the chipping quality. Assuming linearity, a relationship can be defined as:

$$Q_c = b_0 + b_1 X_1 + b_2 X_2 + \dots + b_k X_k + U \quad (1)$$

where  $b_i$ ,  $i = 0, 1, 2, \dots, k$ , are regression coefficients and  $U$  is a random disturbance. Using Ordinary Least Squares and assuming the following about the probability distribution of the error term (18), parameters  $b_i$  were estimated.

1. We assume that the error term has a mean zero

$$E(U_i) = 0 \quad \text{for } i = 1, 2, \dots, n;$$

where  $i$  is the  $i^{\text{th}}$  sample of observations of size  $n$ . (2-1)

2. The variance of the error term is assumed to be constant.

$$V(U_i) = \sigma^2 \quad \text{for } i = 1, 2, \dots, n. \quad (2-2)$$

3. We assume that the various values of the error term are uncorrelated to each other; that is

$$E(U_i U_j) = 0 \quad \text{for } i \neq j \quad i \text{ and } j = 1, 2, \dots, n. \quad (2-3)$$

4. Finally, the independent variable  $X$ 's are assumed to be constants that can be obtained in repeated samples. Therefore, the  $X$ 's are uncorrelated to the error term. This implies

$$E(X_i U_i) = 0 \quad \text{for } i = 1, 2, \dots, n. \quad (2-4)$$

In order to evaluate the effect of a qualitative independent variable such as variety, binary variables or "dummy variables" were

incorporated in the regression equations. A binary variable is one which takes the value of 1 if a given characteristic exists and 0 otherwise. The use of these variables enables one to examine the effect of a qualitative variable on the dependent variable in relation to the other independent variables. To clarify the interpretation of a binary variable and its associated parameter in a regression equation, the following simplified equation will be used:

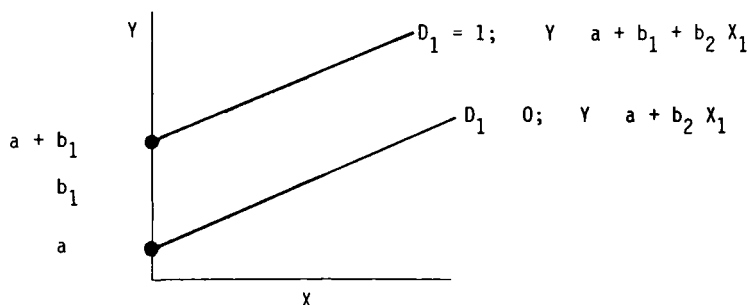
$$Y = a + b_1 D_1 + b_2 X_1 \quad (3)$$

Where  $Y$  dependent variable

$X$  independent variable

$D_1$  binary variable

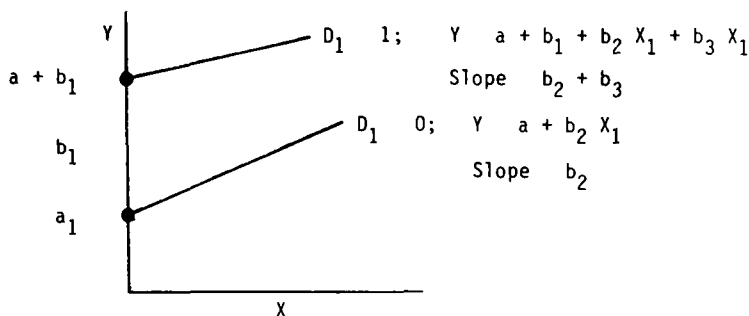
This equation can be conceived as two separate equations, one for the presence of the binary variable, where  $D_1 = 1$  and the other for when the binary variable is not present,  $D_1 = 0$ . A graphic representation illustrates that the addition of the binary variable in the equation causes a change in the intercept while the slope remains constant.



Circumstances where the binary variables interact with quantitative variables a change in both the intercept and the slope may occur. To observe the effect of the interaction of  $D_1$  with  $X_1$  on  $Y$ , an extension of equation (3) can be formulated.

$$Y = a + b_1 D_1 + b_2 X_1 + b_3 D_1 X_1$$

This equation can also be conceived as two separate equations which can be seen in the following illustration



### RESULTS AND DISCUSSION

Sensory mean scores and photoelectric (Agtron) measurements for potatoes chipped at harvest and following two, four, six and eight months' storage at 7.2°C (45°F), 12.8°C (55°F), 18.3°C (65°F), and 7.2°C (45°F) reconditioned at 21.1°C (70°F) for one month prior to chipping can be seen in Tables 1 to 4. Chips from all samples processed at harvest were of an acceptable light color.

Following 2, 4, 6 and 8 months of storage at 7.2°C (45°F) samples 1, 2, 3 (Monona), 5 (FL-657), 8 (Kennebec), 9, 10 and 11 (Norchip) were rated acceptable in chip color ( $\leq 3$ ) (Table 1). Sample 4 (FL-657) after 2 months' storage was scored unacceptable by the sensory panel; however, the Agtron reading corresponded to a score of 3, objectively acceptable. This discrepancy may have been due to panel error, where the samples were compared among themselves rather than to the PC/SFA color chart. Sample 4 was acceptable in chip color throughout the remaining storage period. Sample 6 (Kennebec) following 2 months' storage at 7.2°C (45°F), was subjectively scored unacceptable, but objectively graded acceptable in quality. At 4 and 8 months the quality of chips from sample 6 was maintained; however, at 6 months it was unacceptable. Sample 7 (Kennebec) was found to be of poor chipping quality at 2, 4, 6 and 8 months' storage when processed directly out of 7.2°C (45°F) storage.

With one exception (sample 7, Kennebec at 4 months), chips from potatoes held at 12.8°C (55°F) were acceptable throughout the storage period (Table 2). The Agtron reading (53) for this sample, however, corresponded to a grade of 3. Again, this discrepancy in objective and

TABLE 1. Sensory Mean Scores and Photoelectric (Agtron) Measurements for Chipping Potatoes at Harvest and Following Two, Four, Six and Eight Months of Storage at 7.2°C (45°F).

Sample	Harvest		2 Months		4 Months		6 Months		8 Months	
	Sensory Mean Score <sup>a</sup>	Agtron <sup>b</sup>	Sensory Mean Score	Agtron	Sensory Mean Score	Agtron	Sensory Mean Score	Agtron	Sensory Mean Score	Agtron
1 Monona	1	62	2	63	1	70	2	63	2	61
2 Monona	1	65	3	59	2	62	2	66	2	55
3 Monona	1	63	3	57	2	64	2	58	2	57
4 FL-657	1	64	4	54	3	54	3	51	3	55
5 FL-657	1	61	2	71	2	70	2	59	1	65
6 Kennebec	2	56	4	53	3	54	4	45	3	57
7 Kennebec	2	56	5	38	5	43	4	42	4	44
8 Kennebec	2	57	2	64	3	62	2	58	1	65
9 Norchip	2	57	2	65	2	63	3	59	1	*
10 Norchip	2	56	2	66	2	61	2	62	1	*
11 Norchip	1	62	3	62	3	56	2	56	1	*

<sup>a</sup>Mean score of 13-16 judges, 4 reps. Potato Chip/Snack Food Assoc. Color Chart, 1 = light, 5 = dark.

<sup>b</sup>Mean of 3 readings, 0 = dark, 90 = light.

\*Samples spoiled prior to reading.

TABLE 2. Sensory Mean Scores and Photoelectric (Agtron) Measurements for Chipping Potatoes at Harvest and Following Two, Four, Six and Eight Months of Storage at 12.8°C (55°F).

Sample	Harvest		2 Months		4 Months		6 Months		8 Months	
	Sensory Mean Score <sup>a</sup>	Agtron <sup>b</sup>	Sensory Mean Score	Agtron	Sensory Mean Score	Agtron	Sensory Mean Score	Agtron	Sensory Mean Score	Agtron
1 Monona	1	62	1	70	1	70	1	64	1	*
2 Monona	1	65	1	67	1	67	1	63	1	*
3 Monona	1	63	1	67	1	65	1	62	1	*
4 FL-657	1	64	2	73	2	64	2	62	1	*
5 FL-657	1	61	1	71	1	68	1	66	1	*
6 Kennebec	2	56	2	61	2	60	2	62	1	*
7 Kennebec	2	56	3	51	4	53	3	51	1	*
8 Kennebec	2	57	1	67	1	66	2	61	1	*
9 Norchip	2	57	1	68	1	67	1	65	1	*
10 Norchip	2	56	1	70	1	65	2	60	1	64
11 Norchip	1	62	1	70	1	67	1	61	1	63

<sup>a</sup>Mean score of 13-16 judges, 4 reps. Potato Chip/Snack Food Assoc. Color Chart, 1 = light, 5 = dark.

<sup>b</sup>Mean of 3 readings, 0 = dark, 90 = light.

\*Samples spoiled prior to reading.

subjective scores is hypothesized as panel error

All samples stored at 18.3°C (65°F) were of acceptable chipping quality throughout the examined storage periods (Table 3).

Reconditioning samples from 7.2°C (45°F) storage at 21.1°C (70°F) for one month prior to chipping did not show a marked increase in chipping quality since most of the samples were acceptable when processed directly from 7.2°C (45°F) storage. All the samples processed following reconditioning were of acceptable quality except samples 6 and 7 (Kennebec) (Table 4). Following 2 months' storage, samples 6 and 7 were graded unacceptable both subjectively and objectively. However, following 4, 6 and 8 months storage, the chipping quality of these samples improved. The Kennebec variety seems to improve in chipping quality over the storage period (37).

Samples scored unacceptable at some time during storage are summarized in Table 5. Although the sensory scores of these samples indicated poor chipping quality at some time during storage, only one sample, Kennebec # 7, processed from 7.2°C (45°F) storage was of poor chipping quality after 8 months. The remaining samples showed improvement and acceptable chip quality at the end of 8 months' storage. It should be noted that Kennebec sample 7 received a double application of nitrogen fertilizer at the time of planting. Increased nitrogen fertilization has been shown to delay tuber maturity, resulting in poor processing potatoes (11, 12, 20, 30). It has also been reported that potatoes receiving increased rates of nitrogen fertilizer contained more amino acids than tubers of similar maturity from low nitrogen plots (12). Reconditioning of sample 7 (Kennebec) did improve the chipping quality of the sample following 4 months of storage.

The sucrose content of freshly harvested potatoes grown in Central Maine is shown in Table 6. The values range from 1.236 to 2.098 and are below the 2.8 mg/g tuber maximum level for long term chip quality from storage proposed by Sowokinos (33).

#### Final Model

The data obtained from the experiment were used to estimate a regression equation to illustrate the relationship between chipping quality and the selected independent variables. The statistical model was also used to forecast chipping quality.

TABLE 3. Sensory Mean Scores and Photoelectric (Agtron) Measurements for Chipping Potatoes at Harvest and Following Two, Four, Six and Eight Months of Storage at 18.3°C (65°F).

Sample	Harvest		2 Months		4 Months		6 Months		8 Months	
	Sensory Mean Score <sup>a</sup>	Agtron <sup>b</sup>	Sensory Mean Score	Agtron	Sensory Mean Score	Agtron	Sensory Mean Score	Agtron	Sensory Mean Score	Agtron
1 Monona	1	62	2	60	2	58	1	57	3	55
2 Monona	1	65	2	60	2	60	1	55	2	54
3 Monona	1	63	1	62	1	61	2	57	1	55
4 FL-657	1	64	1	68	1	67	1	62	2	54
5 FL-657	1	61	1	68	1	68	1	65	1	*
6 Kennebec	2	56	2	64	1	65	1	65	2	55
7 Kennebec	2	56	2	62	1	66	1	63	3	51
8 Kennebec	2	57	1	68	1	66	2	62	2	58
9 Norchip	2	57	1	68	2	59	1	55	3	53
10 Norchip	2	56	1	69	1	65	1	58	1	65
11 Norchip	1	62	1	67	1	60	1	61	1	64

<sup>a</sup>Mean score of 13-16 judges, 4 reps. Potato Chip/Snack Food Assoc. Color Chart, 1 = light, 5 = dark.

<sup>b</sup>Mean of 3 readings, 0 = dark, 90 = light.

\*Samples spoiled prior to reading.

TABLE 5. Sensory Mean Scores and Photoelectric (Agtron) Measurements for Samples of Potato Chips Scored Unacceptable During Storage

Storage Temperature	Potato Variety	Sample Number	Length of Storage (Months)							
			2		4		6		8	
			Sensory Mean Score <sup>a</sup>	Agtron <sup>b</sup>	Sensory Mean Score	Agtron	Sensory Mean Score	Agtron	Sensory Mean Score	Agtron
7.2°C (45°F)	FL-657	4	4	54	3	54	3	51	3	55
	Kennebec	6	4	53	3	54	4	45	3	57
	Kennebec	7	5	38	5	43	4	42	4	44
12.8°C (55°F)	Kennebec	7	3	51	4	53	3	51	1	*
7.2°C (45°F)	Kennebec	6	4	45	2	58	2	60	2	58
Reconditioned one month at 21.1°C (70°F) prior to chipping	Kennebec	7	4	42	2	60	2	57	2	55

<sup>a</sup>Mean score of 13-16 judges, 4 reps. Potato Chip/Snack Food Assoc. Color Chart, 1 = light, 5 = dark. Samples given sensory scores  $\geq 4$  were considered unacceptable.

<sup>b</sup>Mean of 3 measurements. 0 = dark, 90 = light. Samples with Agtron measurements  $< 45$  were considered unacceptable.

\*Sample lost due to spoilage.

TABLE 6. Harvest Sucrose Content of Four Potato Chipping Varieties Grown in Central Maine During the 1978 Growing Season

Sample <sup>a</sup>	Harvest Sucrose mg/g tuber <sup>b</sup>
1 Monona	2.098
2 Monona	1.584
3 Monona	1.346
4 FL-657	1.336
5 FL-657	1.369
6 Kennebec	1.236
7 Kennebec	1.280
8 Kennebec	1.405 <sup>c</sup>
9 Norchip	1.725
10 Norchip	1.640
11 Norchip	1.482

<sup>a</sup> Each variety sampled from three locations except FL-657, which was sampled from two.

<sup>b</sup> Mean of 5 replications in duplicate.

<sup>c</sup> Mean of 4 replications in duplicate.

Since some chipped samples were lost due to spoilage prior to conducting the Agtron measurements, sensory scores were used to represent chip quality in the statistical analysis. The coefficient of correlation ( $r$ ) for Agtron index readings and sensory scores was -0.77 ( $P = 0.01$ ); therefore, the sensory scores were considered appropriate indicators of chipping quality.

The statistical model formulated to forecast chipping quality of potatoes grown in Central Maine was postulated as:

$$Q_c = b_0 + b_1 D_1 + b_2 D_2 + b_3 \ln \text{Stime} + b_4 \ln \text{Stemp} + b_5 \text{Recon} + b_6 \ln \text{SR} + b_7 D_3 + b_8 D_4 + b_9 D_5 + b_{10} \ln 1 + b_{11} \ln 2 + b_{12} \ln 3 + b_{13} \ln 4 + b_{14} \ln 5 \quad (1)$$

Where the variables are defined as:

$Q_c$	Chipping quality of potatoes grown in Central Maine
$b_0$	Intercept for the reference category, Monona + FL-657 and farm locations
$b_1$ to $b_{14}$	Regression coefficients
$D_1$	Dummy variable for Kennebec
$D_2$	Dummy variable for Norchip
$\ln \text{Stime}$	$\ln$ of storage time ( $^{\circ}\text{F}$ )
$\ln \text{Stemp}$	$\ln$ of storage temperature
Recon	Reconditioning
$\ln \text{SR}$	$\ln$ sucrose rating
$D_3$	Dummy variable for the farm location of sample 5, FL-657
$D_4$	Dummy variable for the farm location of sample 6, Kennebec
$D_5$	Dummy variable for the farm location of sample 7, Kennebec
$\ln 1$	Interaction of Kennebec and $\ln$ storage time
$\ln 2$	Interaction of Norchip and $\ln$ storage time
$\ln 3$	Interaction of Kennebec and $\ln$ storage temperature
$\ln 4$	Interaction of Norchip and $\ln$ storage temperature
$\ln 5$	Interaction of Norchip and $\ln$ sucrose rating

Regression coefficients ( $b$ ), standard error of  $b$ ,  $F$  values and coefficient of determination ( $R^2$ ) for the final model used to predict chipping quality of potatoes grown in Central Maine can be seen in Table 7.

The coefficient of determination ( $R^2$ ) was equal to 0.47 which indicated that 47 percent of the variation in chipping quality was explained by the variables operating jointly. Sources of variability,

TABLE 7. Regression Coefficients (b), Standard Error of b, F Values and Coefficient of Determination for the Final Model Used to Forecast Chipping Quality of Potatoes Grown in Central Maine

Variable	Regression	Coefficients	Standard Error of b	F <sup>a</sup>
Constant	b <sub>0</sub>	12.37	3.24	
Kennebec	b <sub>1</sub>	4.95	3.24	3.326**
Norchip	b <sub>2</sub>	0.19	3.33	0.002
ln Storage Time (Stime)	b <sub>3</sub>	0.23	0.15	2.432**
ln Storage Temp (Stemp °F)	b <sub>4</sub>	2.51	0.54	21.488**
Reconditioning	b <sub>5</sub>	0.03	0.14	4.495**
ln Sucrose Rating (SR)	b <sub>6</sub>	0.58	0.47	1.504
Farm Location of Sample 5, FL-657	b <sub>7</sub>	0.55	0.20	7.301**
Farm Location of Sample 6, Kennebec	b <sub>8</sub>	0.74	0.25	8.726**
Farm Location of Sample 7, Kennebec	b <sub>9</sub>	1.38	0.25	31.480**
Kennebec x ln Stime	b <sub>10</sub>	0.28	0.24	1.359
Norchip x ln Stime	b <sub>11</sub>	0.26	0.24	1.165
Kennebec x ln Stemp	b <sub>12</sub>	1.23	0.81	2.293**
Norchip x ln Stemp	b <sub>13</sub>	0.34	0.81	0.178
Norchip x ln SR	b <sub>14</sub>	1.90	1.64	1.34
Coefficient of Determination R <sup>2</sup> = 0.47				
Standard Error 0.69				

<sup>a</sup>The F values indicate the significance of each variable in the overall equation

F 14, 161 df	0.05	1.75*
	0.01	2.20**

uncontrolled or not evaluated in this experiment constituted the remaining 53 percent of the variation in chipping quality.

#### Potato Varieties and Chip Color

Through the use of dummy variables, the regression of potato varieties on chip quality was observed. In the simple regression the variety Monona was chosen as the reference category from which the

effects of the other varieties were judged and interpreted. Kennebec and Norchip differed significantly ( $P = 0.05$ ) in their chipping quality when compared to Monona. FL-657 showed no significant difference in chipping quality from Monona, therefore, in the final model (1),  $b_0$  includes both Monona and FL-657 as the reference category or Y intercept.

In the final model  $b_1$  is the difference in predicted chipping quality intercept for Kennebec as compared to Monona and FL-657. The positive regression coefficient for Kennebec in the final model indicated that Kennebec was slightly poorer in chipping quality than Monona and FL-657. The  $b_2$  in the final model (1) is the difference in predicted chipping quality intercept for Norchip as compared to Monona and FL-657. The negative regression coefficient for Norchip indicated that Norchip was slightly better in chipping quality when compared to Monona and FL-657. An illustration of these relationships is shown in Figure 3. These results substantiate previous studies which have indicated that varieties differ in processing quality (6, 18, 28, 34).

Poor Chipping Quality

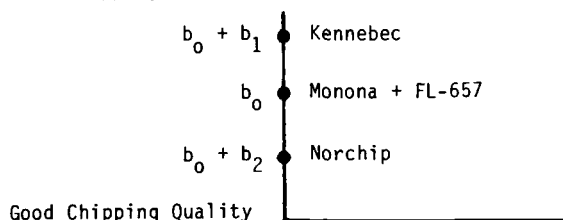


FIGURE 3. The Difference in Predicted Chipping Quality for Kennebec and Norchip Compared to Monona and FL-657

#### The Effect of Storage Temperature and Length of Storage on Chip Color

The relationship between storage temperature and chip color in this experiment is best described as a semilogarithmic function. In the final model storage temperature data were expressed in degrees fahrenheit. The negative regression coefficient for storage temperature in the final model indicated that chipping quality was maintained at higher storage temperatures,  $12.8^{\circ}\text{C}$  ( $55^{\circ}\text{F}$ ) and  $18.3^{\circ}\text{C}$  ( $65^{\circ}\text{F}$ ). These results substantiate previous studies which have shown better processing quality from intermediate storage temperatures (20, 26).

Reconditioning at 21.1°C (70°F) improved chip quality of potatoes stored at 7.2°C (45°F), indicated by a negative regression coefficient in the final model (Table 7).

The effect of storage time on the chipping quality of potatoes is best described by a semilogarithmic equation. It is apparent from these results that chipping quality improved during the storage period, as indicated by a negative regression coefficient (Table 7). Under controlled storage conditions, most tubers with acceptable chip color at harvest can maintain good quality. It is difficult to account for the "improvement" in chipping quality exhibited by some samples during the storage period of this experiment. FL-657, sample 4, Kennebec samples 6 and 7 all improved in chipping quality over storage, except for Kennebec sample 7 stored at 7.2°C (45°F) (Table 5).

#### Sucrose Content and Chip Color

The best fit relationship between sucrose content at harvest and chip quality is a semilogarithmic equation. The negative regression coefficient indicated better chipping quality from tubers high in sucrose. This result is somewhat misleading since the variation in sucrose content was small among the samples tested and the values were below the 2.8 mg/g maximum level for good quality for long term storage.

#### Farm Locations and Chip Color

Since each sample was harvested from a different farm, the farm location dummy variable was chosen to examine the chipping quality of the individual samples. In the simple regression of farm location on chipping quality, sample 1 (Monona) was chosen as the reference category from which the effects of the other samples were interpreted. Samples 5 (FL-657), 6 (Kennebec) and 7 (Kennebec) were found to differ significantly ( $P < 0.05$ ) when compared to Monona sample 1 in the simple regression. In the final model the intercept or constant has all farm locations, other than those defined by the dummy variables. Since no substantial conclusions can be drawn from the examination of these samples individually, the variables were added to the final model as proxies to account for undefined sources of variability.

Interaction of Dummy Variables and Quantitative Variables

The interaction terms  $\ln 1$  to  $\ln 5$  were created by multiplying the dummy variables,  $D_1$  and  $D_2$ , by the quantitative variables,  $\ln$  Stime,  $\ln$  Stemp and  $\ln$  SR. In the final model the reference point for the interactions was Monona + FL-657. The final model (1) can be used to write the separate equations for the interactions when all other variables are held constant. The regression equation for the interaction of Kennebec and  $\ln$  storage time would be

$$Q_c (b_0 + b_1) + (b_3 + b_{10}) \ln \text{Stime}$$

where  $b_0$  is the reference point, Y intercept,  $b_1$  the regression coefficient for Kennebec,  $b_3$  the regression coefficient for  $\ln$  storage time  $b_{10}$ , the regression coefficient for the interaction of Kennebec and  $\ln$  storage time. The addition of the Kennebec variety and the interaction changes both the intercept and the slope. The  $b_0 + b_1$  is the new intercept and  $b_3 + b_{10}$  is the change in slope due to the interaction of Kennebec and  $\ln$  storage time over time. An illustration of the relationship is shown in Figure 4.

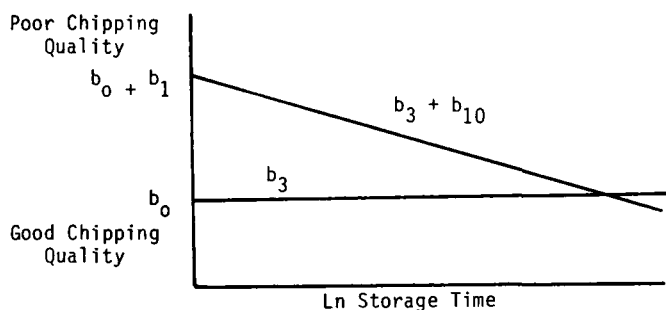


FIGURE 4. The Change in Slope and Intercept Due to the Interaction of Kennebec and  $\ln$  Storage Time Over the Storage Period

Applications of the Final Model

Application of this model in the chipping industry is not reliable due to the low coefficient of determination and the many extraneous sources of variability unaccounted for in the model. For future reference, a model similar to the one formulated here, with a higher coefficient of determination, could reliably predict chipping quality of potatoes for any combination of the variables affecting chipping quality.

To illustrate the use of the model formulated from this experiment to predict chipping quality (1) the  $b_0$  to  $b_{14}$  values given in Table 7 are employed. Consider the following example. The predicted chipping quality of a Kennebec sample, with a harvest sucrose content of 1.2 mg/g tuber, stored four months at 12.8°C (55°F), would be

$$Q_c = b_0 + b_1 (1) + b_2 (0) + b_3 (\ln 55) + b_5 (0) + b_6 (\ln 1.2) + b_7 (0) + b_8 (0) + b_{10} (1) (\ln 4) + b_{11} (0) (\ln 4) + b_{12} (1) (\ln 55) + b_{13} (0) (\ln 55) + b_{14} (0) (\ln 1.2)$$

By substituting the regression coefficients from Table 7

$$Q_c = 12.37 + 4.95 + (-0.23) (1.39) + (-2.51) (4.01) + (-0.58) (0.18) + (-0.28) (1.39) + (-1.23) (4.01)$$

Solving the equation the predicted chipping quality would be

$$Q_c = 1.51$$

The chipping quality of a Norchip sample with a harvest sucrose content of 1.5 mg/g tuber, stored three months at 12.8°C (55°F) would be predicted as

$$Q_c = b_0 + b_1 (0) + b_2 (1) + b_3 (\ln 3) + b_4 (\ln 55) + b_5 (0) + b_6 (\ln 1.5) + b_7 (0) + b_8 (0) + b_9 (0) + b_{10} (0) (\ln 3) + b_{11} (1) (\ln 3) + b_{12} (0) (\ln 55) + b_{13} (1) (\ln 55) + b_{14} (1) (\ln 1.5)$$

By substituting the regression coefficients from Table 7 and solving the equation, the predicted sensory score would equal 1.38.

### CONCLUSIONS AND RECOMMENDATIONS

The varieties examined were found to differ in processing quality. Kennebec and Norchip differed significantly ( $P = 0.05$ ) in chipping quality when compared to Monona. FL-657 showed no significant difference from Monona.

A semilogarithmic function best described the relationship between storage temperature and chip color. Better quality chips were processed from potatoes chipped from intermediate storage temperatures (12.8°C, 55°F and 18.3°C, 65°F). Reconditioning at 21.1°C (70°F) one month prior to chipping improved chip quality of potatoes stored at 7.2°C (45°F).

The effect of storage time on the chipping quality of potatoes best fits a semilogarithmic equation. Chipping quality was found to improve over the storage period.

Sucrose content among the 4 varieties at harvest ranged from 1.236 to 2.098 mg/g tuber

Since the variables in the final model account for only 47 percent of the variability in chipping quality, the final model would not be reliable for predicting chipping quality at this time. This indicates the need for further research to develop a more significant and dependable model for predicting chipping quality of potatoes grown in Central Maine. Further research should include the following recommendations in the experimental design.

1. Samples should be grown at one location and under the same cultural practices to control extraneous variables. Variables which cannot be controlled, such as soil temperature and soil moisture, should be measured.
2. Increase the number of varieties sampled, and include known "poor processing" varieties to obtain a wider spread in the sucrose values.
3. Process the potatoes at frequent intervals to document exactly when the tubers become unacceptable for chip processing.

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