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Donna H. Kells

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AN INVESTIGATION OF THE GENETICS OF CHIP COLOR IN STORED POTATOES (*Solanum tuberosum* L.)

By

Donna H. Kells

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ABSTRACT

AN INVESTIGATION OF THE GENETICS OF CHIP COLOR IN STORED POTATOES (*Solanum tuberosum* L.)

By

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Producers of chip-processing potatoes desire to produce varieties that will yield acceptable color potato chips after long-term storage at intermediate temperatures. Studies were conducted in 1989 and 1990 to examine the genetics of chip color in stored potatoes. Chip color became poorer with increasing storage time. Acceptable chip-processing ability, as determined by chip color, was correlated with lower glucose content and lower test tape values. Sucrose content and glucose-forming-potential were not acceptable indicators of chip-processing ability. Determination of test tape values is useful in the early stages of a potato breeding program when large numbers of progeny are being evaluated. Chip color evaluation is useful in the intermediate stages of a program. Glucose and sucrose content determination is best used later in a breeding program due to the high cost and labor requirement.

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INTRODUCTION

The potato is a major food crop worldwide and in the United States and is a valuable source of essential vitamins, minerals, and trace elements (28). Its protein content is comparable to other root crops. It is grown in more countries than any crop, excluding maize, as it adapts well to various climates and growing conditions. It 1983 potatoes ranked fourth, world wide, in acres grown and fifth in monetary crop value (28, 36). In the United States, over 18 million metric tons are raised annually.

Michigan ranks tenth in the US for potato production[1]. There are several regions of potato production in Michigan, with approximately half of the total acreage and production in the west central (Montcalm County) and east central thumb area of the lower peninsula. Michigan potatoes are used for fresh market, seed and processed products. Approximately 11-12% of the US crop is utilized by the chip-processing industry, while 30% of the Michigan crop is used for chip-processing[1].

Factors Affecting Chip Quality

Potatoes for chip processing must meet specific quality standards (11, 43, 53, 54, 61). Factors include consistent yields of mature (11, 16, 26, 43, 54), medium-sized (40-65 mm) tubers (26, 54) with a dependable production of light color chips throughout the processing season (26, 42, 63). A flat, round shape with shallow eyes minimizes waste during processing (54). Tubers free from external and internal defects (42, 54) are desired to produce visually appealing chips and to minimize waste. High specific

[1]Chase, R. Personal communication.

gravity (>1.080) (27, 42, 43, 54), low sucrose levels (<2.8 mg/g fresh weight) at harvest and during storage (61), or the ability to achieve low reducing sugar levels (<2.0 mg/g glucose fresh weight) through reconditioning (11, 13, 18, 24, 33, 35, 40, 57, 62, 63), are required for producing light color chips.

A specific gravity above 1.080 minimizes oil absorption during frying which increases the shelf life of the product, resulting in higher quality to the consumer and decreased processing costs (9, 20, 42, 43, 64). Immature tubers tend to have lower specific gravity than do mature tubers (27, 42, 43). Several researchers have noted a correlation between specific gravity and chip color (27, 43, 55, 56). As the specific gravity increases, often the chip color improves (27, 43, 55, 56).

In potato tubers, the primary reducing sugars are glucose and fructose (2, 3, 20, 33, 52). Reducing sugars are produced by the hydrolysis of sucrose (7, 15, 17, 21, 28, 49, 50). The reducing sugar level is generally considered to be the primary factor affecting chip color (3, 11, 13, 14, 15, 16, 18, 33, 55, 61). Hughes and Fuller (17) found that 90% of the variation in chip color could be related to the concentration of reducing sugars in tubers. High reducing sugar levels result in a dark chip color (9, 30, 60), an undesirable taste (9, 60), and often a poor texture (12, 13, 14, 20, 35). It is generally accepted that the most important factor to consumers in assessing potato chip quality is chip color (3, 9, 26, 27, 54, 63).

Role of Reducing Sugars in Potato Tubers

Chip browning is the result of the Maillard reaction, a nonenzymatic process where the carbonyl group of the monosaccharide reducing sugars (glucose and fructose) reacts with the amino group of free amino acids during exposure to heat during processing. This reaction produces brown melanoidin pigments (2, 14, 15, 16, 20, 39, 41, 44, 48, 50). Carbohydrate metabolism in potatoes is a complex set of events, mediated by numerous enzymes (12, 15, 21, 28). During the growing season, sucrose

is the dominant sugar produced and translocated from the leaves to the developing tuber tissue (12, 46, 49, 50). Sucrose is important for actively growing and stored tubers (28, 45) serving as an energy and carbon source for starch synthesis (12, 45, 47, 49). Starch is synthesized from sucrose during tuber growth resulting in a decreasing sucrose rating (mg sucrose/g fresh tuber) as tubers reach maturity (12). During storage, especially when tubers are held under such stress conditions as cold temperatures or poor ventilation, the starch may break down to sucrose via the enzymes phosphorylase and sucrose synthetase (12, 45, 55). This is a reversible reaction when the stress is removed (2, 12, 22, 23, 34, 45). Invertase is involved in the enzymatic degradation of sucrose to glucose and fructose (2, 3, 12, 15, 16, 33, 55). A protein inhibitor of invertase prevents the hydrolysis of sucrose during tuber growth. Invertase becomes active in storage (2, 33, 47, 49). Before cold storage, newly harvested mature tubers have low levels of reducing sugars and total invertase activity and high levels of the invertase inhibitor (33, 34, 55). Basal invertase activity is non-existent due to excess invertase inhibitor. During cold storage, starch is converted to reducing sugars (12, 46). Invertase production increases until it reaches a level above that of the inhibitor and basal invertase activity begins. As the maximum level of reducing sugars is reached, total invertase levels decrease and basal invertase activity decreases as inhibitor levels rise. This reaction is reversible at warmer temperatures (34). Senescent sweetening involves the breakdown of the amyloplast membrane after long-term storage and causes a rapid and irreversible increase in sucrose levels (12, 22, 49). Schwimmer (38) reported increased levels of phenols (especially chlorogenic acid) may result in increased reducing sugar levels due to the inhibition of the enzyme phosphorylase which is involved in starch synthesis.

Factors Affecting Reducing Sugar Levels in Potato Tubers

Numerous factors affect the level of reducing sugars in tubers (11, 20, 24, 40, 41, 42, 50, 63). Cultivar (11, 20, 24, 60), management practices (11, 24), environmental conditions/stresses during the growing season (11, 20, 39), maturity level of the tubers at harvest (20), air temperature at harvest (42, 43), handling of the tubers after harvest (20, 41, 48), storage conditions (20, 24, 40) and reconditioning ability are the factors most often considered (11, 20, 40, 63).

Cultivars vary in their accumulation of starch and total sugars during the growing season. The ability to reduce their sucrose pool as they reach maturity and to maintain low reducing sugar levels during storage is cultivar dependent. (20, 46, 49, 55, 63). Cultivars capable of reaching low sucrose levels before harvest generally process well from storage at intermediate temperatures of 8.8-11.7C (30, 46). Poor processors accumulate greater amounts of sucrose at maturity, than do good processors which appear more efficient at converting sucrose to starch (45, 46). Sucrose serves as a substrate for reducing sugar production via invertase but does not directly participate in the Maillard reaction (7, 16, 46, 50). In poor processors, the rate of reducing sugar production is greater than the rate of removal for cellular energy needs (46). This results in a rapid accumulation of reducing sugars in storage. Good processors seem to produce reducing sugars at a rate close to cellular use rates which results in only a slow accumulation of reducing sugars over time (46). Sucrose levels of 2.8 mg/g fresh tuber or less at harvest (12, 46), and a reducing sugar content of 2.0 mg/g fresh tuber or less at processing (30, 50) will generally produce chips with acceptable color from tubers stored at intermediate temperatures and in well ventilated conditions (30, 47, 50).

Management practices that encourage vine growth late in the season tend to delay tuber maturity which in turn results in elevated reducing sugar levels during storage (37, 42, 55). Early planting is the best means to ensure maturity at harvest (43). High levels of nitrogen and potassium, particularly late in the season, can delay maturity; while high

levels of phosphorous can result in early maturing of the crop (37, 42). Late season pest control can delay maturity by delaying vine death. Harvesting as late as feasible gives the crop time to mature and allows complete translocation of carbohydrates from leaves to tubers. To prevent cold injury to the tubers, harvest must be finished before air temperatures fall below 10C (42, 43). Drought conditions longer than three days and high temperatures during the growing season can also increase reducing sugar accumulation (33, 40, 42, 43, 57).

Mature tubers are best for chip production when the level of reducing sugars is generally at the lowest level as genetically determined for a given variety (45, 46, 50, 52). They also handle, store and recondition better than tubers harvested when immature (46, 55, 59). Physical factors such as tuber size, skin set and vine death have not been adequate predictors of maturity in relation to a tuber's ability to maintain low reducing sugar levels during storage (37). Chemical or physiological maturity is defined as when a tuber attains its maximum specific gravity and its minimum sucrose levels (20, 37, 46, 49). Tubers chipped directly from the field tend to produce acceptable color chips, regardless of maturity level or other factors (5, 11, 28). However, even with proper storage conditions, reducing sugars accumulate and chip color becomes darker faster in tubers harvested when immature than when mature (5, 28, 55).

Immature tubers have a higher level of sucrose, associated with the rate of sucrose translocation from the leaves exceeding the rate of conversion to starch in the tuber (49). This is not accompanied by a higher level of reducing sugars at harvest in immature versus mature tubers (7, 28, 30, 49). Immature tubers may produce acceptable chips out of the field due to the presence of the invertase inhibitor which inhibits the conversion of sucrose to glucose and fructose (33, 47, 50). However, after storage the chips produced are often dark and unacceptable (7, 55).

"Reversion" is the phenomenon where tubers that can produce acceptable chips immediately after harvest will not produce acceptable chips after even a short storage period (5). This often occurs in tubers harvested when immature (5, 55).

Tubers harvested at air temperatures of 10C or below often have elevated reducing sugar levels during storage. These tubers will not produce acceptable chips after storage (42, 43, 55).

Rough handling leads to bruising and an increase in tuber respiration rates with an increase in sucrose production which serves as a substrate for reducing sugar production and dark colored chips (41, 48).

Storage temperature of the tubers plays a major role in reducing sugar accumulation (2, 11, 13, 20, 26, 30, 33, 40, 43, 60, 63). An intermediate temperature of 8.9-12.8C results in minimal reducing sugar accumulation and generally permits the production of acceptable color chips after storage of 3-6 months. At this temperature, reducing sugar production is close to the rate of use by respiration, but it does result in sprouting and shrinkage (11, 46, 47). Therefore, the use of sprout inhibitors is required for long term storage at intermediate temperatures (43). Storage at temperatures of 4.4-6C results in reduced shrinkage due to slowed respiration (2, 8, 26, 51, 64) and decreased sprouting (2, 3, 26, 51, 64). There is decreased need for sprout inhibitors (8), decreased costs associated with maintaining storage facilities at higher temperatures (3), and decreased losses due to diseases transmitted while in storage (2, 14, 51). However, cold temperatures cause increased starch degradation, which leads to increased sucrose levels (21, 33, 46). This elevated sucrose level eventually results in an increase in reducing sugar levels (2, 11, 12, 13, 26, 30, 35, 40, 43, 55) and dark color chips when processed (2, 13, 26, 43, 60, 62).

The ability of a tuber to lower reducing sugar levels after storage via reconditioning is also important (11, 13, 20, 24, 35, 43, 55, 57, 62, 63). Reconditioning is accomplished by storing tubers at 15.5-21C for varying lengths of time. Varieties

differ in their ability to successfully lower their reducing sugar levels to an acceptable concentration (11, 20, 24, 57, 59, 63). Reconditioning seems most effective for tubers stored at 4.4-7C. (11). Tubers stressed during the growing season are difficult to successfully recondition, as are tubers harvested when immature (20, 59). Ideally, tubers would be stored at low temperatures (4-6C) and processed without reconditioning to save expenses and time associated with reconditioning (8, 61).

Determining Reducing Sugar Levels

Numerous methods are used to determine levels of reducing sugars in a tuber sample (1, 19, 25, 31, 49, 52, 58). Methods frequently reported include the use of glucose indicator tape, originally designed to test for glucose in the urine of diabetic patients (1, 19, 31), gas chromatography (58), calorimetric procedures (25) and the Yellow Springs Instrument (49, 52).

Test-tape is used as a rough guide for lines that would be obviously unacceptable for chipping (1, 19). A yellow color indicates negligible amounts of sugar. Increasing shades of green indicate increasing concentrations of sugar (1).

Chip color is determined by the use of an colorimeter instrument (Agtron) which measures light reflection from a sample of chips, or by the use of color cards (30).

Sowokinos developed a sucrose rating method (46, 47, 50) used to predict, at harvest, how long a given field of potatoes can be stored and still produce acceptable chips (46, 47, 50). This calculation can also be used to monitor the quality of tubers in storage and allow quick intervention if problems related to changes in sucrose levels are noted (46, 49). Tubers must be free of disease and defects, intermediate temperatures of 8.8-12.7C must be provided and the storage must be properly maintained (50). The sucrose rating does not correlate with chip quality when tubers are stored at cold temperatures (3.3-7.2C), because the sucrose pool increases above the initial harvest level due to cold induced starch degradation (46).

The sucrose rating is expressed as milligrams of sucrose per gram of tuber (46, 47, 50). Tubers with a sucrose rating of 1.0-2.8 at harvest should produce acceptable chips from long-term storage (7-11 mo). Tubers with a sucrose rating above 2.8 would produce acceptable chips after short-term storage (0.5-5.3 mo) (46, 47, 49, 50). According to Sowokinos (47, 49, 50), tubers for successful use in chip production should have a sucrose rating of less than 2.8 when physical maturity is reached at harvest (47, 49, 50). Theoretically, the higher the sucrose rating at harvest, the faster the reducing sugars will be produced in storage (47).

In the late 1980's, Sowokinos (52) proposed the Glucose-Forming-Potential (GFP) method to screen breeding clones for processing potential. GFP is expressed as μmoles of glucose per μmoles of sucrose. Tubers must be maintained at 9C during storage to reduce the clone's endogenous sucrose level to a minimum value between 1.0-4.0 μmoles of sucrose per gram of tuber. At the same time, glucose levels increase based upon the genetic tendency of the clone (50). Those clones that should be superior chippers maintain a GFP between 0.4-1.0 during long-term storage (8 months). Clones with low sucrose at harvest are not guaranteed to be good chippers after long-term, intermediate temperature storage. Clones with a low sucrose rating at harvest and a low GFP during storage seem to have superior germplasm for chip processing. A profile was developed that related the patterns of GFP and associated uses for the tubers. High GFP (4.0-13.0) indicates the tubers are best suited for fresh market use, moderate GFP (2.0-4.0) indicates tubers would be acceptable for the french fry market and a low GFP (0.2-2.0) indicates tubers acceptable for the chip market (51).

Genetic Evaluations

Work towards development of varieties that accumulate low reducing sugars during storage includes a cross by Hyde and Walkof in 1962 (18). One seedling, F5208, reportedly could be stored at 4.4C for 7 months and produce acceptable chips directly

from storage. The chip color was only slightly improved by reconditioning for ten days (18). Researchers have noted the most rapid accumulation of reducing sugars in the tubers occurs early during storage, and then slows (18, 33). There was only a slight worsening in chip color after four months of storage (18). In 1970, Lauer and Shaw (24) produced a single progeny from a cross of *S. phureja* x USW1 (a Kathadin haploid) that could be stored at 4.4C for 5 weeks and produce acceptable chips without reconditioning (24).

Cunningham and Stevenson (9) investigated the correlation between progeny chip color and the chipping ability of the parents, from a given environment, under storage conditions of 5.5C with reconditioning for four weeks at 21-26.6C. Crosses between good and poor chippers produced progeny that were darker than the best parents in a continuous range of color (termed "continuous variation of chip color"). Parents that produced light colored chips yielded a higher proportion of progeny that produced light colored chips (4, 9). Researchers believe that parental performance is a reliable predictor of the mean performance of the progeny and the ability to transmit chip color is heritable in a given population in a given environment (4, 9, 59). They also believe environment is as important as cultivar in determining expression of this trait (9, 54, 59, 61).

Johansen and Ehlenfeldt have investigated reducing sugar accumulation during cold storage (10). They used diallel crosses involving two advanced selections, ND860-2 and ND2221-6 and two standard varieties Norchip and Kennebec. ND860-2 and ND2221-6 are clones with *S. phureja* in their pedigree. They exhibit the ability to chip directly out of cold storage (3-4C), a trait termed "cold temperature processibility" ("CTP") (8, 64), which seems related to the ability to accumulate minimal reducing sugars during cold storage. These clones were able to transmit the "CTP" trait to their progeny (10).

Ehlenfeldt et al (10) found that after 100d of cold storage (3-4C), progeny families had reducing sugar levels that were more closely distributed toward the value of the parent with the higher reducing sugar values. Crosses between ND860-2 and ND2221-6 produced progeny with the lowest reducing sugar levels of all crosses, but above the levels of either parent. No definite genetic segregation patterns were noted (10).

ND860-2 was found to have the lowest total sugar levels during growth, at different stages of maturity and under various time and temperature storage treatments than other cultivars examined (8). The level of sugars increased during cold storage, but not enough to cause dark chips when processed. Coffin et al (8) believe the ability to chip from cold storage is associated with low initial sugar levels rather than a resistance to cold temperature sweetening. Possible theories are related to differences in enzyme systems responsible for starch biosynthesis and degradation, differences in the ultrastructure of the amyloplast membrane (which could affect the accessibility of the starch-degrading enzymes to the starch in storage) or differences in the starch composition of the amyloplast (64).

Accatino (4) investigated the inheritance of reversion resistance and reconditioning ability. In diploids, he found chip color was determined by two loci each for reversion resistance and reconditioning ability (or possibly common loci). At least one dominant allele must be present at each loci to produce good chips. In tetraploids he found the same results-two loci are involved for each trait and at least one dominant allele must be present at each loci to produce good chip color (4).

Loiselle et al. (26) separated the genetics of chip color into two components. Chipping stability represents the consistency of chip color produced by a genotype stored at different conditions. Overall chipping ability represents the average performance of a genotype over various treatments. The major source of variation seems to be due to the overall chipping ability component. The researchers determined that general and

specific combining ability were both significant in both component; thus, additive and dominant genetic interactions are involved in chipping ability (26).

Finding a line that could be stored at low temperatures and chip directly out of storage (without reconditioning) would save growers money in energy costs, in decreased need for sprout inhibitors and in allowing longer storage without loss of quality due to sprouting, shrinkage and chilling injury (8, 10). The task of improving tuber processibility can be addressed by the using cultivars known to meet processor requirements, manipulation of management factors, handling and storage conditions.

MATERIALS AND METHODS

Progeny

Crossing blocks were established in the greenhouse (January-March 1987 and 1988) with seven clones mated in a diallel design. The parental clones used are listed in Table 1, along with pertinent agronomic characteristics (6).

The field studies were conducted at the Michigan State University Montcalm Research Farm, Entrican, MI (MRF) and the MSU Clarksville Horticultural Experiment Station, Clarksville, MI (CHES). Tubers from 1987 crosses and seedlings from 1988 crosses were hand-planted at the Montcalm Research Farm on May 22 and June 3, 1989 respectively. Tubers and seedlings were also planted at the Clarksville Horticultural Experiment Station on May 23 and June 8, 1989, respectively. Tubers harvested in 1989 from the Clarksville station were stored at 4C and used for seed the following year. They were planted at the Montcalm Research Farm on May 9, 1990. Standard management and pest control practices were used throughout the growing season. A total of 20 tubers and seedlings were planted approximately 3' apart within rows and 34" between rows in 20' plots to insure adequate spacing and prevent mixing during harvest. Plants were sprayed with a desiccant, two weeks prior to harvest. Tubers were hand harvested to minimize the risk of mixing progeny and bruising during harvest. Harvest at the Montcalm Research Farm was on September 28, 1989 (98d and 88d after planting). The tubers were harvested on October 10, 1989 (110d and 93d after planting) at the Clarksville station. In 1990, the tubers were harvested at the Montcalm Research Farm on September 10 and 11 (92d after planting).

Table 1. Parental varieties and traits of interest

Variety	Tuber Type-Skin	Market Use
Atlantic	Round-White	Chip-Field-Some Storage
Saginaw Gold	Round-Yellow Flesh	Chip-Field
Superior	Round-White	Fresh Market
Onaway	Round-White	Fresh Market
Lemhi Russet	Long-Russet	French Fries
Spartan Pearl	Round-White	Chip-Field
ND860-2	Round-White	Chip-Cold Storage

Tubers (greater than 2" diameter) from each of the 20 individual hills within a family were harvested. They were held at 18.4C for two weeks. The tubers from the Montcalm Research Farm were stored at 10C for two month analysis. The tubers from the Clarksville Station were stored at 4C for use as 1990 seed material.

Analysis-1989

The extraction procedure was adapted from the work of Dr. J. Sowokinos of the University of Minnesota. Two months after harvest, two tubers from each progeny hill were sliced apical to basal end and the center core tissue removed. The tissue was diced and a random 20 g sample was weighed and mixed with 50 ml distilled water for 60 sec in a Sorvall blender. The final volume was brought to approximately 80 ml. The extract was sieved through a coarse sieve and was refrigerated for 1 hour to allow the sediment to settle. Two-20 ml aliquots of the supernatant were then removed and frozen (-20C) for later analysis (46, 52).

Five months after harvest, 2 tubers from each hill were sliced from apical to basal end and two-1/8" slices were removed from each tuber for frying and chip color determination. Test tape analysis was performed on the remaining tissue using the glucose strip test (18).

Analysis-1990

Two months after harvest and storage at 10C, five tubers per progeny hill were prepared for sugar analysis as in 1989. Fifty grams of tissue were blended with 80 ml distilled water. The final volume was approximately 100 ml.

At two and five months after harvest, five tubers from each hill were prepared for frying as in 1989. With the larger tuber size, four slices per tuber were fried and chip color determined.

Glucose and sucrose analysis were accomplished by the use of the Yellow Springs Instrument (Model 2000) (49, 52). Chip color determinations were made visually by the use of the Potato Chip Color Reference Standards developed by Proctor and Gamble (PG/SFA color cards) in 1989 and by the Agtron Model E-10 self-calibrating colorimeter, standardized at the factory, in 1990.

Parental Material

In 1989 seven varieties and advanced breeding lines were evaluated for changes in glucose and sucrose levels and chip color ratings over time. In 1990, four clones were evaluated.

Parental varieties were planted by hand. Plots were 20' long and spacing was 1' between each seed piece with 3' between varieties and 34" between rows. Planting dates were May 22, 1989 and May 5, 1990 at the Montcalm Research Farm and May 23, 1989 at the Clarksville Station. Standard cultural and pest management practices were maintained throughout the growing season.

Plots were hand harvested on Sept. 28, 1989 (97d after planting) and Sept. 10, 1990 (96d after planting) at the Montcalm station and on Oct. 10, 1989 (109d after planting) at the Clarksville Station. Each variety was bagged and stored at 18.4C for two weeks, then stored at 10C until analyzed.

From the 1989 harvests, varieties were analyzed monthly from 0-6 months after harvest and in 1990, at 2, 4 and 6 months after harvest.

Ten tubers were removed from storage and a center cut was made from apical to basal ends (49, 52). Two slices were removed for frying and chip color evaluation. The remaining central core tissue from all 10 tubers was diced and mixed for a 200 gram sample. The tissue was blended with 400 ml distilled water in an Acme Juicerator. The extract was refrigerated for 1 hr, two 20 ml aliquots were removed and frozen (-20C) for analysis at a later time (46, 52, 63).

Glucose and sucrose determinations were made by use of the Yellow Springs Instrument (Model 2000) (49, 52). Chip color determinations were made by the use of an Agtron E-10 colorimeter.

Statistical Design and Analysis

The studies were designed as randomized complete blocks. The parental material in 1989 consisted of 1 replication. In 1990, there were 3 replications. The progeny study in 1989 had 3 replications. In 1990, there were 2 replications.

In 1989, the diallel analysis for the progeny was based on 20 individual progeny per replication. In 1990, the diallel analysis was based on 10 individual progeny per replication.

Data was analyzed using the MSTAT data analysis program. It was transformed by taking the square root of Y+1/2 for glucose, sucrose rating and glucose-forming-potential (GFP) due to the presence of zero values in the data file (53). Analysis of variance was performed with the least significant differences (LSD) determined. Correlations were determined on the untransformed data. Glucose, sucrose rating, glucose-forming-potential and chip colors were correlated by individual clones or progeny and across all the clones or parents in a study. Diallel analysis in the MSTAT program was performed to determine General and Specific Combining Ability.

RESULTS

1989 Parental Clone Analysis

Seven clones were analyzed in 1989 for changes in glucose levels, sucrose levels, glucose-forming-potential (GFP), and chip colors (by the Agtron E10 machine) over 6 monthly extraction times. With the Agtron E10 machine, values 60 or above are acceptable. The clones examined were Atlantic, Superior, Saginaw Gold, Onaway, Lemhi Russet, and Spartan Pearl. The study was conducted at the Montcalm Research Farm and the Clarksville Horticultural Experiment Station. The data is discussed with locations combined as the results of the analysis indicated no differences due to location.

Tables 2-6 present correlation data for the study. Most of the correlations were very low (0.127-0.778). Habib and Brown (14) suggest a correlation above 0.80 has actual predictive value. In a breeding program such numbers are not expected, but a statistically significant correlation can be valuable in determining the usefulness of the data.

Table 2 presents correlations for the 1989 parental material. The glucose level was significantly negatively correlated with chip colors (by use of the Agtron E10 machine) in 3 of the clones examined (Superior, Saginaw Gold, and Onaway). Sucrose level was not correlated with glucose level in any clone. Glucose was positively correlated with GFP in Spartan Pearl, ND860-2, and Saginaw Gold. Sucrose level was negatively correlated with GFP Spartan Pearl, ND860-2, and Atlantic. Sucrose level did not correlate with chip colors. Glucose-forming-potential did not correlate well with chip colors.

Table 2. Correlations--1989 Parental Material

	Glucose	Sucrose	GFP	Chip Color
	Atlantic			
Glucose	--	NS	NS	NS
Sucrose		--	-0.649*	-0.606*
GFP			--	NS
	Superior			
Glucose	--	NS	NS	-0.870**
Sucrose		--	NS	NS
GFP			--	NS
	Saginaw Gold			
Glucose	--	NS	-0.671*	-0.693*
Sucrose		--	NS	NS
GFP			--	NS
	Onaway			
Glucose	--	NS	NS	-0.756**
Sucrose		--	NS	NS
GFP			--	NS
	Lemhi Russet			
Glucose	--	NS	NS	NS
Sucrose		--	NS	NS
GFP			--	NS
	ND860-2			
Glucose	--	NS	0.749**	NS
Sucrose		--	-0.703**	NS
GFP			--	NS
	Spartan Pearl			
Glucose	--	--	0.749**	NS
Sucrose		--	-0.627*	NS
GFP			--	NS
	Over All Parental Clones			
Glucose	--	-0.227*	0.462**	-0.778**
Sucrose		--	-0.298**	NS
GFP			--	-0.440**

*Significant at 0.05 level
**Significant at 0.01 level

Chip colors were darker in 1989 than would be expected at all storage times examined. Improper frying technique or improper oil temperature are possible explanations. The problem seemed to affect all clones equally so general trends can still be observed from the data presented.

In looking at chip color, ND860-2 provided the best chip colors across all storage periods, whereas Onaway had consistently the poorest chip colors (Fig. 1). Atlantic readings were generally high, while Saginaw Gold, Lemhi Russet, and Spartan Pearl were intermediate. There was a slight darkening of chip color observed over storage periods.

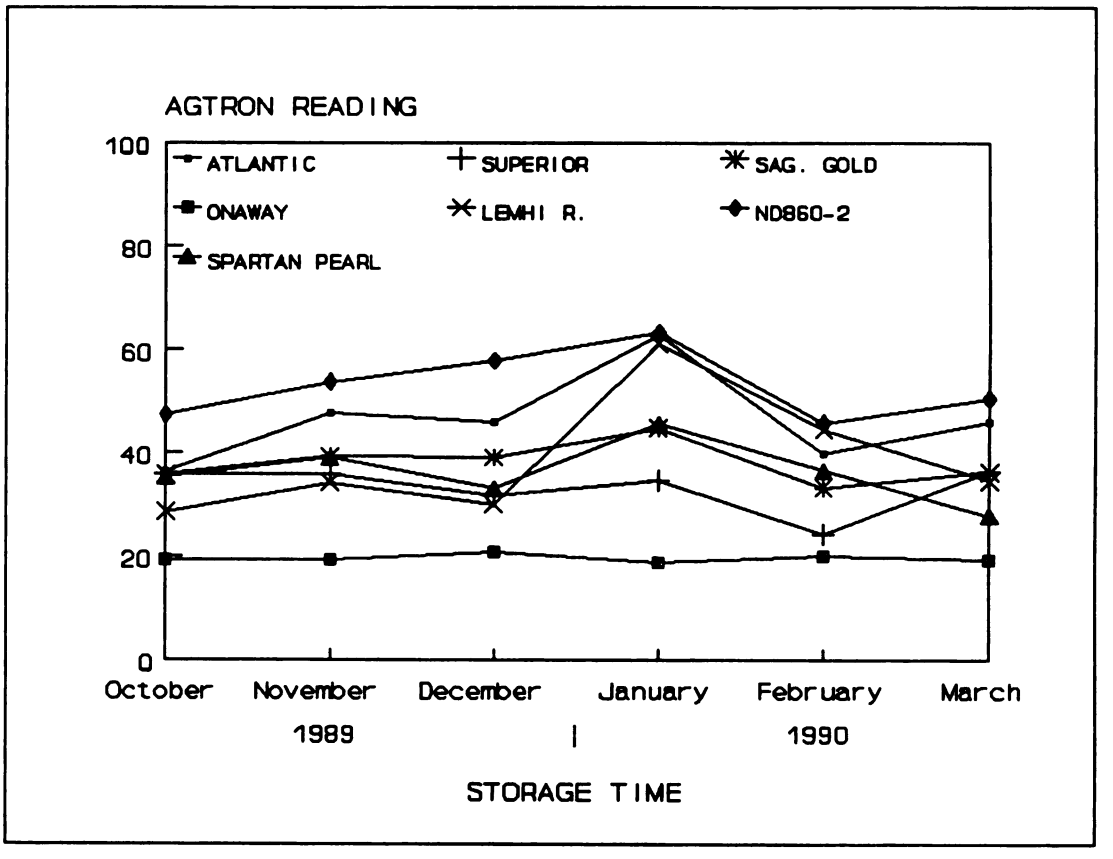

Figure 1. Chip color of 1989 parental material stored at 10C

Onaway had the highest glucose levels across all storage periods (Fig. 2), while ND860-2 and Atlantic had the lowest levels. Spartan Pearl, Lemhi Russet, and Saginaw Gold again fall between extremes. Superior, Saginaw Gold, and Onaway exhibited a gradual increase in glucose levels over storage periods, while ND860-2 and Atlantic and Spartan Pearl stayed fairly constant over time.

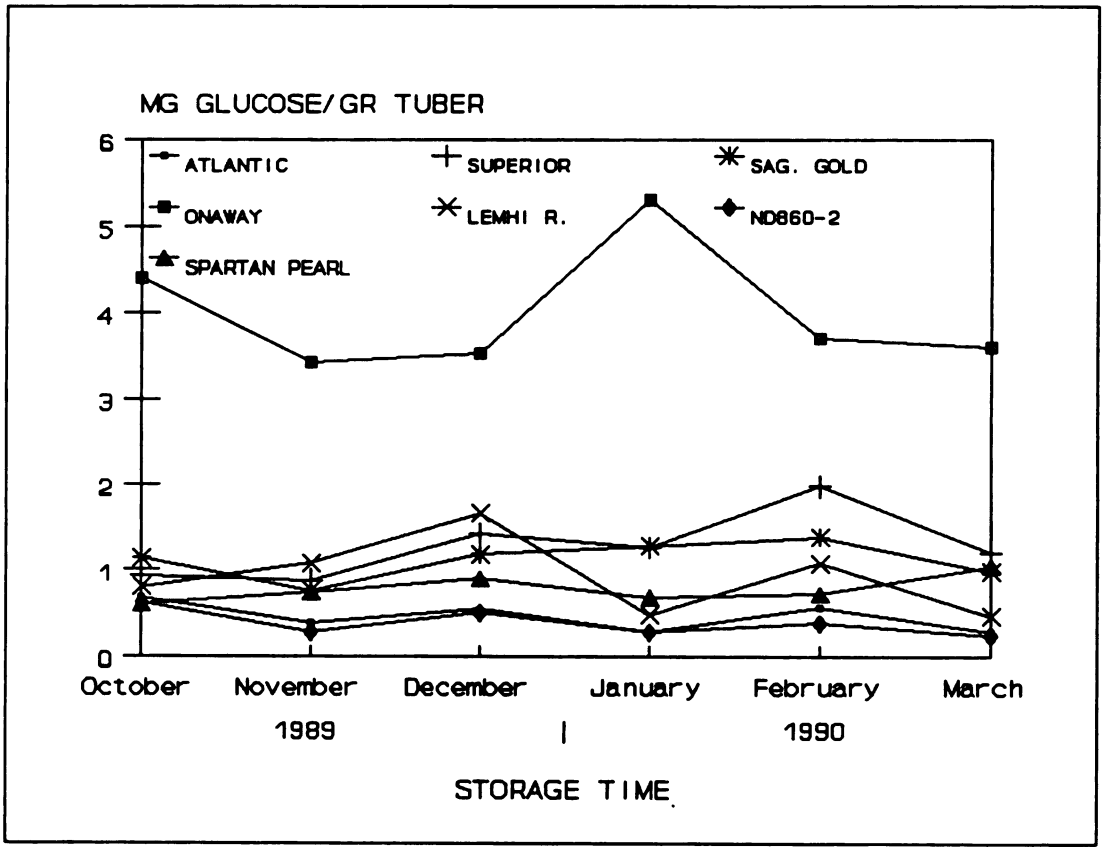

Figure 2. Glucose level of 1989 parental material stored at 10C

The sucrose level (Fig. 3) showed a trend towards a gradual decrease over time. There were no strong varietal trends noted.

The GFP (Fig. 4) showed no strong trends. Atlantic and ND860-2 were stable over time.

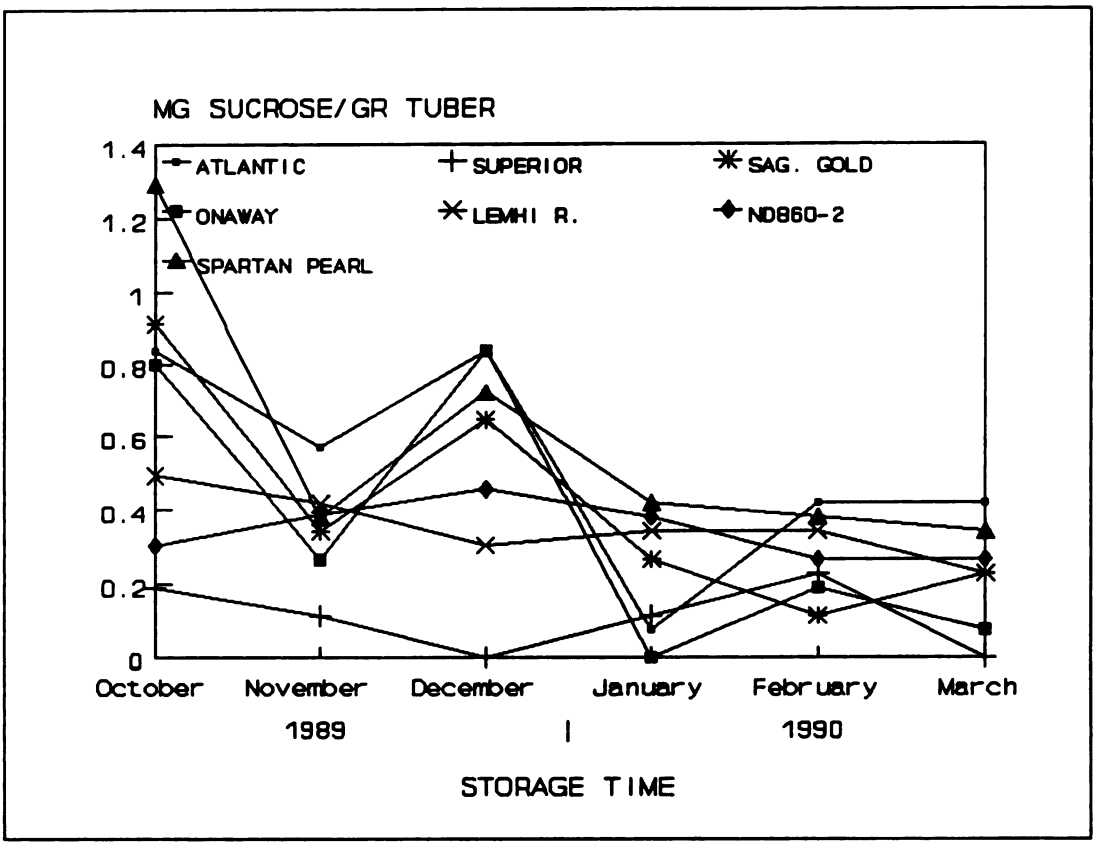

Figure 3. Sucrose level of 1989 parental material stored at 10C

1990 Clone Analysis

Atlantic, Superior, Saginaw Gold, and ND860-2 were evaluated for changes in glucose content, sucrose level, GFP, and chip color (by the use of PG/SFA color cards) over time. Values 4 or below are acceptable when using the color cards to evaluate chip color. The study was conducted at the Montcalm Research Farm.

Table 3 presents correlation data for the study. Atlantic and Saginaw Gold did not have any significant correlations for any variables examined. In ND860-2, a negative correlation was found between sucrose and glucose levels. Superior produced a significantly positive correlation between chip color and glucose. Across all clones, chip color was significantly correlated to glucose levels.

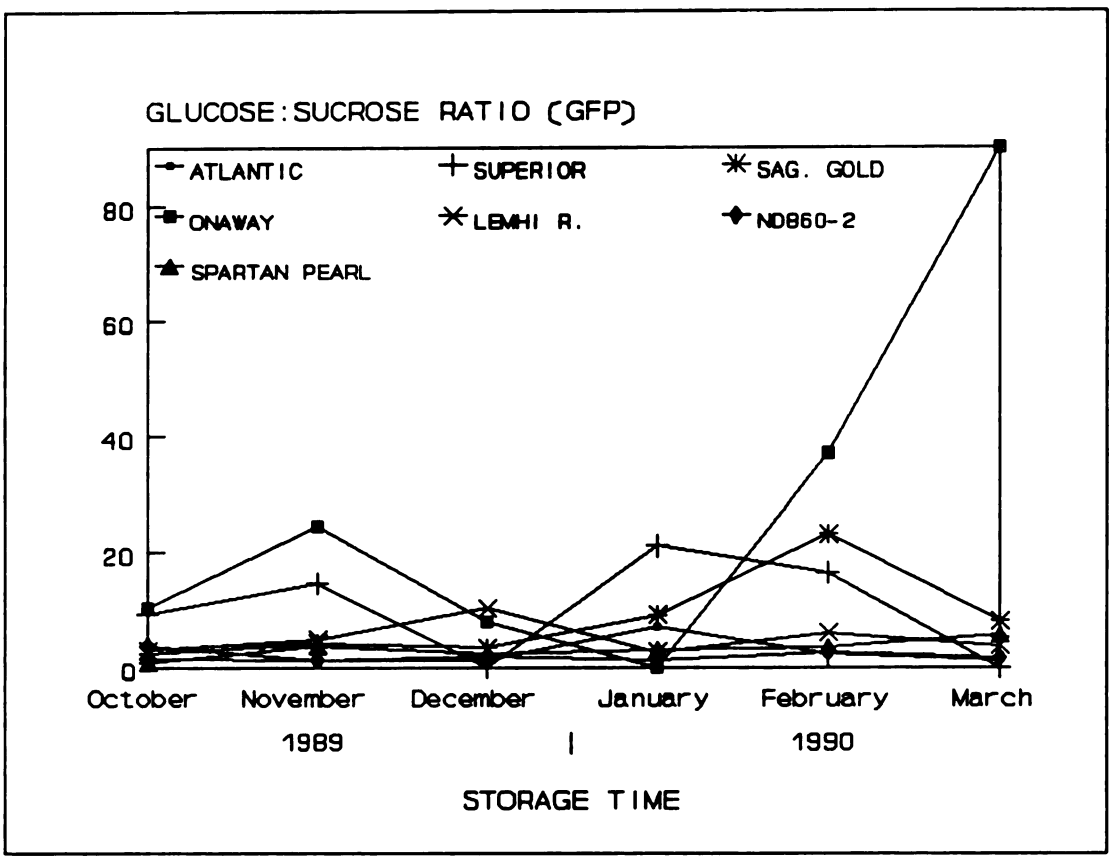

Figure 4. Glucose-forming-potential of 1989 parental material stored at 10C

In looking at general trends, ND860-2 provided the best chip colors over time, using the PG/SFA color cards. The Atlantic sample in January was poor, but improved in March. Saginaw Gold and Superior had the poorest overall chip colors (Fig. 5). The glucose level increased gradually over time. ND860-2 was consistently lowest, while Superior was consistently the highest (Fig. 6). The sucrose level showed a general increase over storage period for all varieties except Saginaw Gold which decreased in March. ND860-2 had the highest sucrose level followed by Atlantic and Superior (Fig. 7). The GFP did not exhibit obvious trends over storage time (Fig. 8).

Analysis of variance was performed for chip color (by Agtron E10 and PG/SFA color cards), glucose levels, sucrose levels, and GFP. The means were separated by LSDs as indicated (Fig. 9-13).

Table 3. Correlations--1990 Parental Material

	Glucose	Sucrose	GFP	Chip Color
	Atlantic			
Glucose	--	NS	NS	NS
Sucrose		--	NS	NS
GFP			--	NS
	Saginaw Gold			
Glucose	--	NS	NS	NS
Sucrose		--	NS	NS
GFP			--	NS
	Superior			
Glucose	--	NS	NS	0.747*
Sucrose		--	NS	NS
GFP			--	NS
	ND860-2			
Glucose	--	NS	NS	NS
Sucrose		--	-0.718*	NS
GFP			--	NS
	Over All Parental Clones			
Glucose	--	NS	NS	0.468**
Sucrose		--	NS	NS
GFP			--	NS

*Significant at 0.05 level
**Significant at 0.01 level

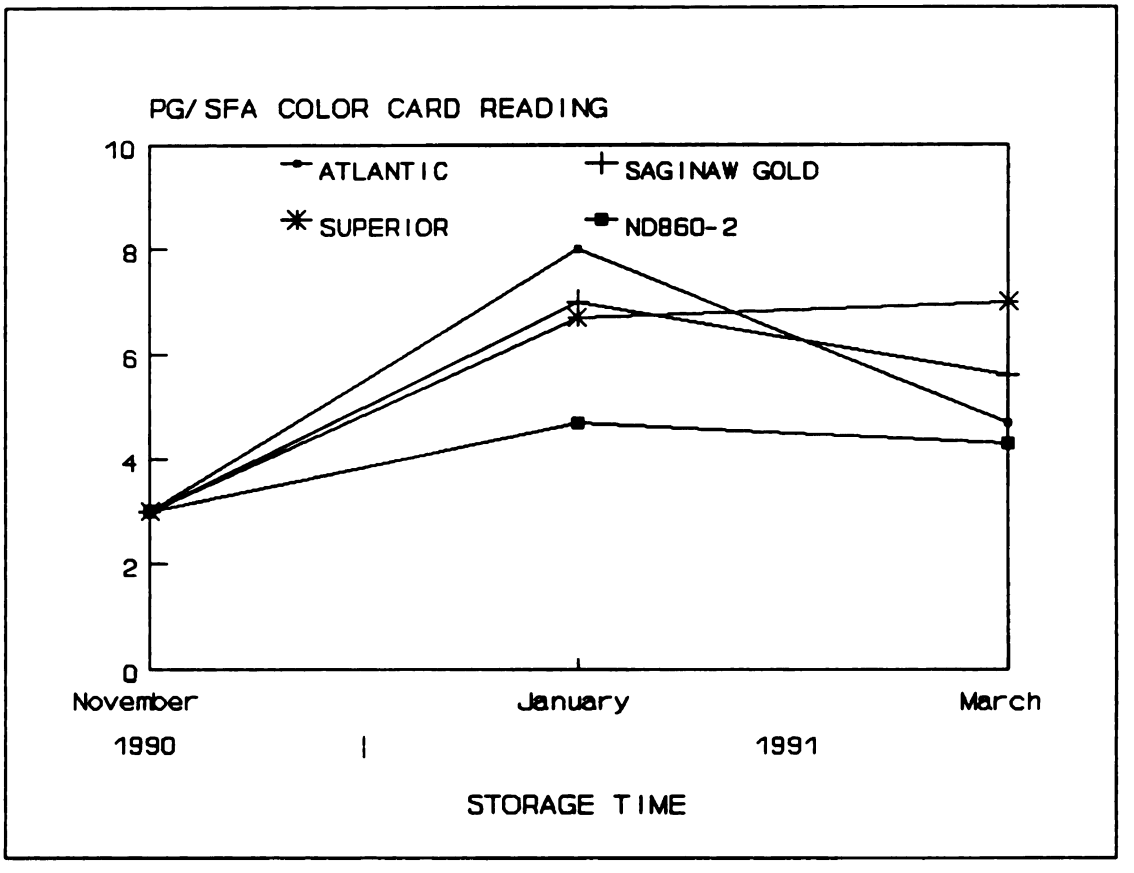

Figure 5. Chip color of 1990 parental material stored at 10C

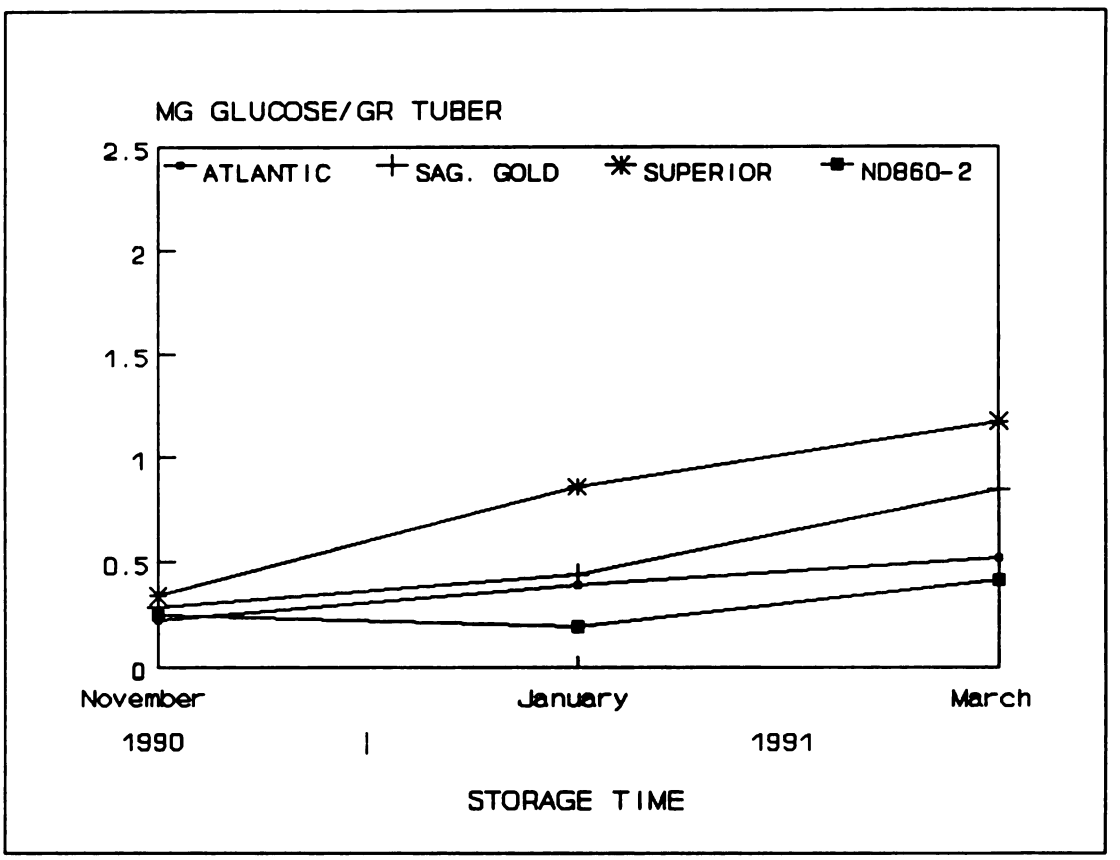

Figure 6. Glucose content of 1990 parental material stored at 10C

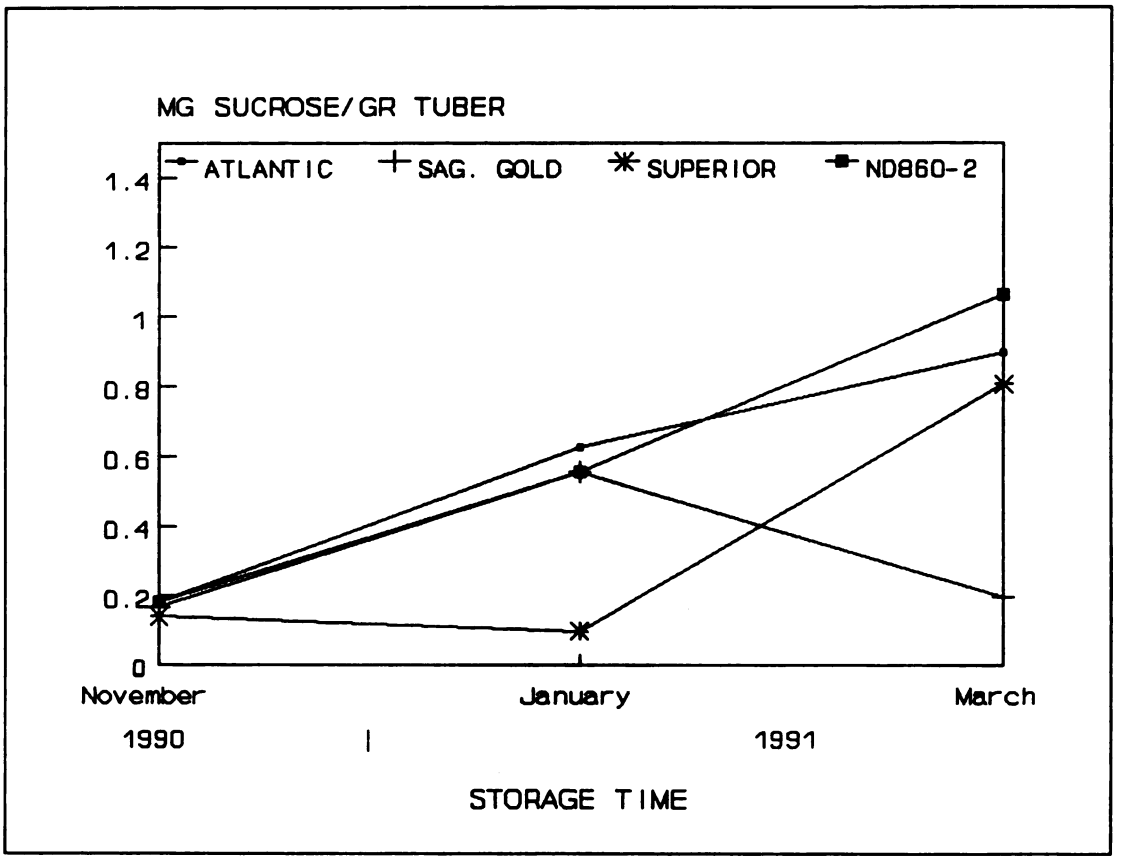

Figure 7. Sucrose content of 1990 parental material stored at 10C

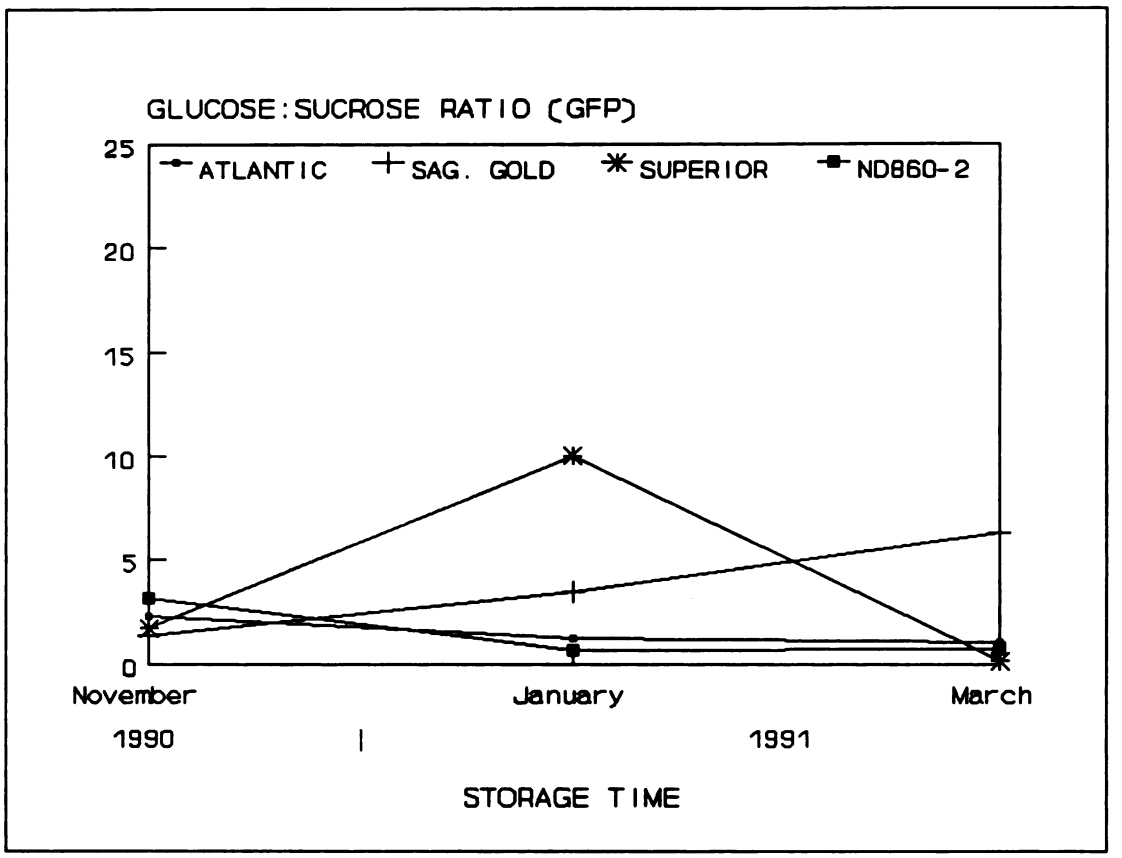

Figure 8. GFP of 1990 parental material stored at 10C

The chip color ratings (based on the use of the Agtron E10 machine) showed no significant differences at the November storage time; however, in January, ND860-2 was significantly better than all other clones (Fig. 9). The chip color, as determined by the PG/SFA color cards was not significantly different in November (Fig. 10). In January, ND860-2 chip colors were significantly better than all others. In March, Atlantic and ND860-2 chip colors were significantly better than Superior. Saginaw Gold was not significantly different than the other clones.

The glucose content of the parents was not significantly different in November (Fig. 11). In January, Superior had significantly higher glucose levels than ND860-2; however, Atlantic and Saginaw Gold levels were intermediate, but not significantly different from either ND860-2 or Superior. In March, Superior still contained the highest glucose level, ND860-2 and Atlantic had the lowest levels while the Saginaw Gold level was intermediate. The sucrose levels were not significantly different in November or March (Fig. 12). In January, Atlantic and ND860-2 had significantly higher levels than Superior, but not Saginaw Gold. The GFP showed no significant differences at any storage period (Fig. 13).

1989 Progeny

A half diallel mating design was produced using Atlantic, Superior, Saginaw Gold, Onaway, and ND860-2 as parents. The resulting progeny were analyzed for glucose level, sucrose level, GFP, and 5-month chip color determination (by use of the PG/SFA color cards) and test-tape analysis.

Table 4 presents correlations for the study. Test-tape, chip color ratings, and glucose levels were all significantly correlated for all the progeny regardless of the parent and when all the progeny were analyzed together.

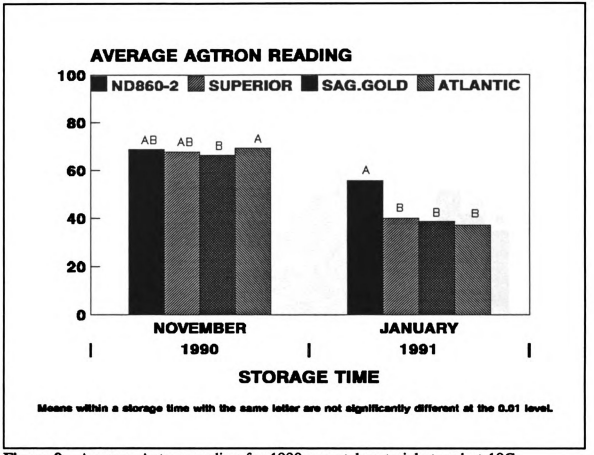

Figure 9. Average Agtron reading for 1990 parental material stored at 10C

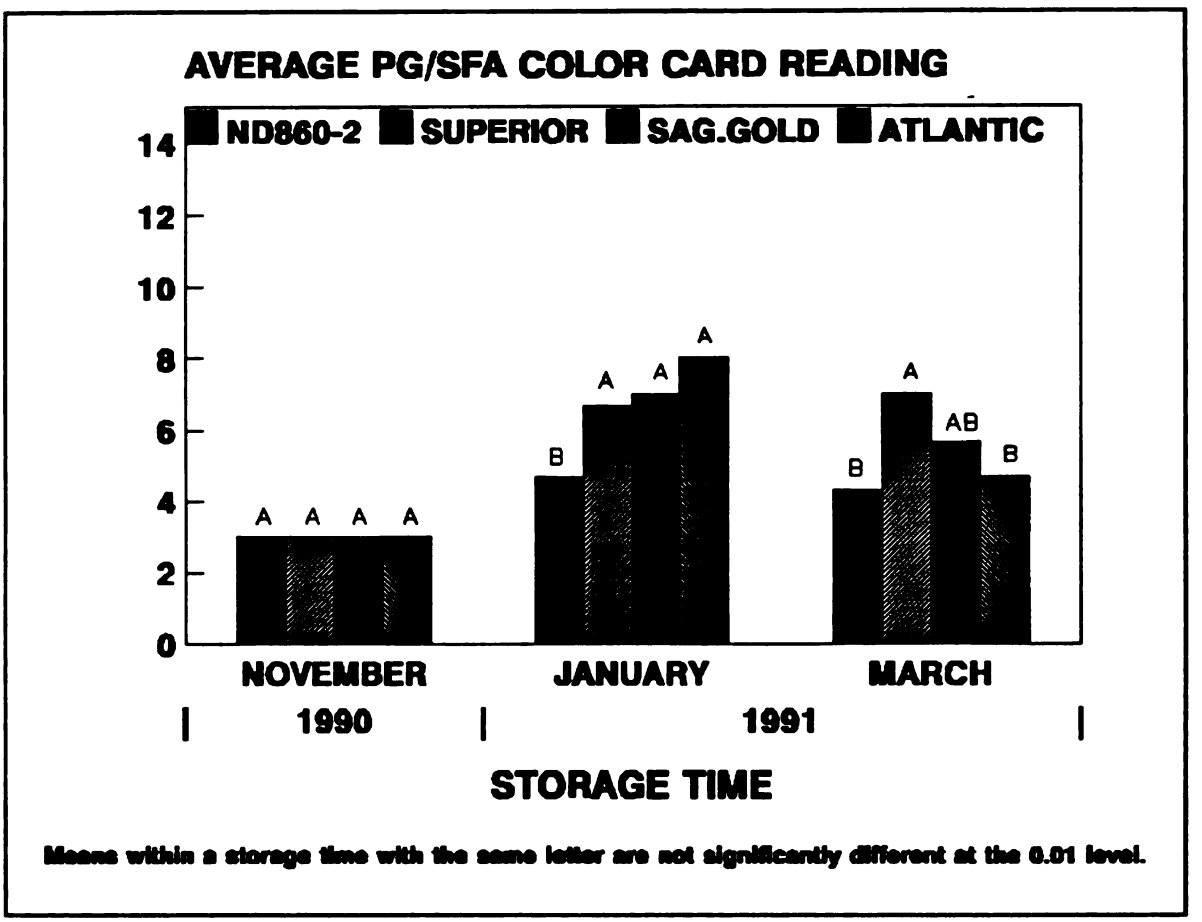

Figure 10. Average color card reading for 1990 parental material stored at 10C

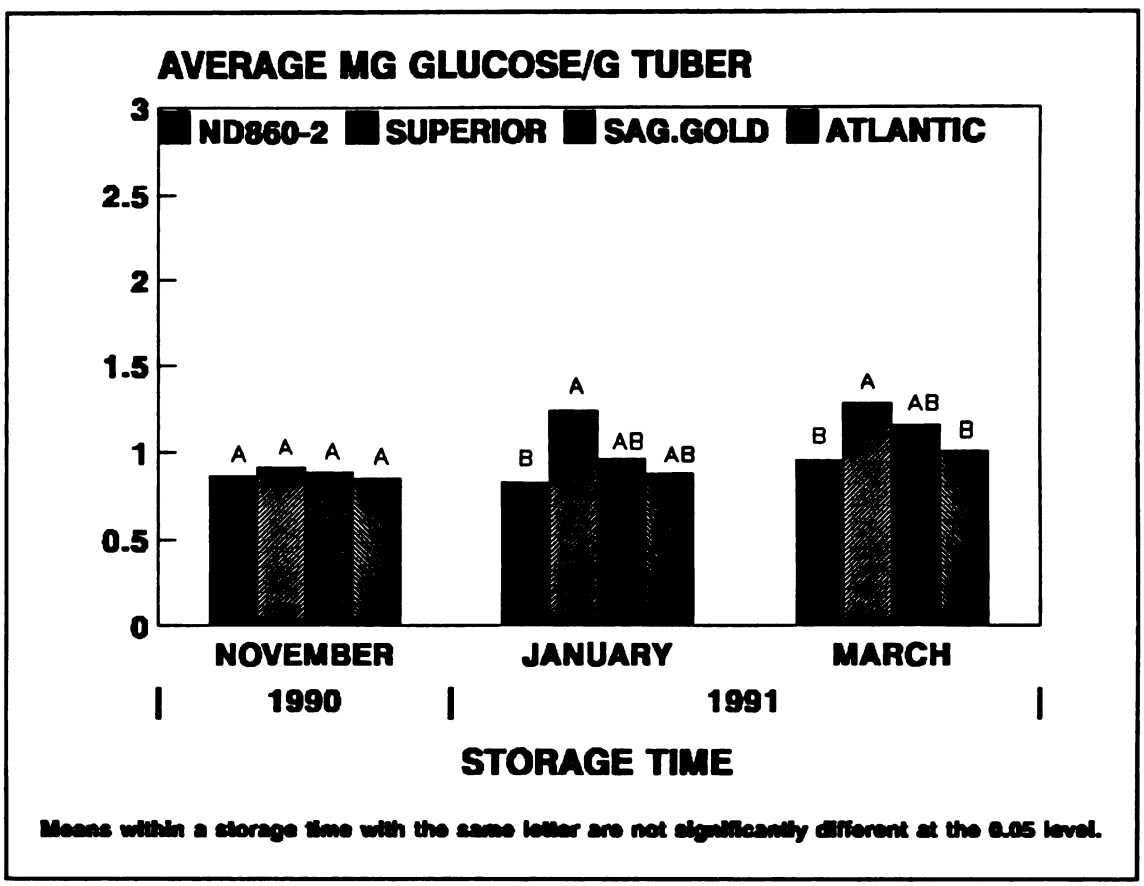

Figure 11. Average glucose content for 1990 parental material stored at 10C

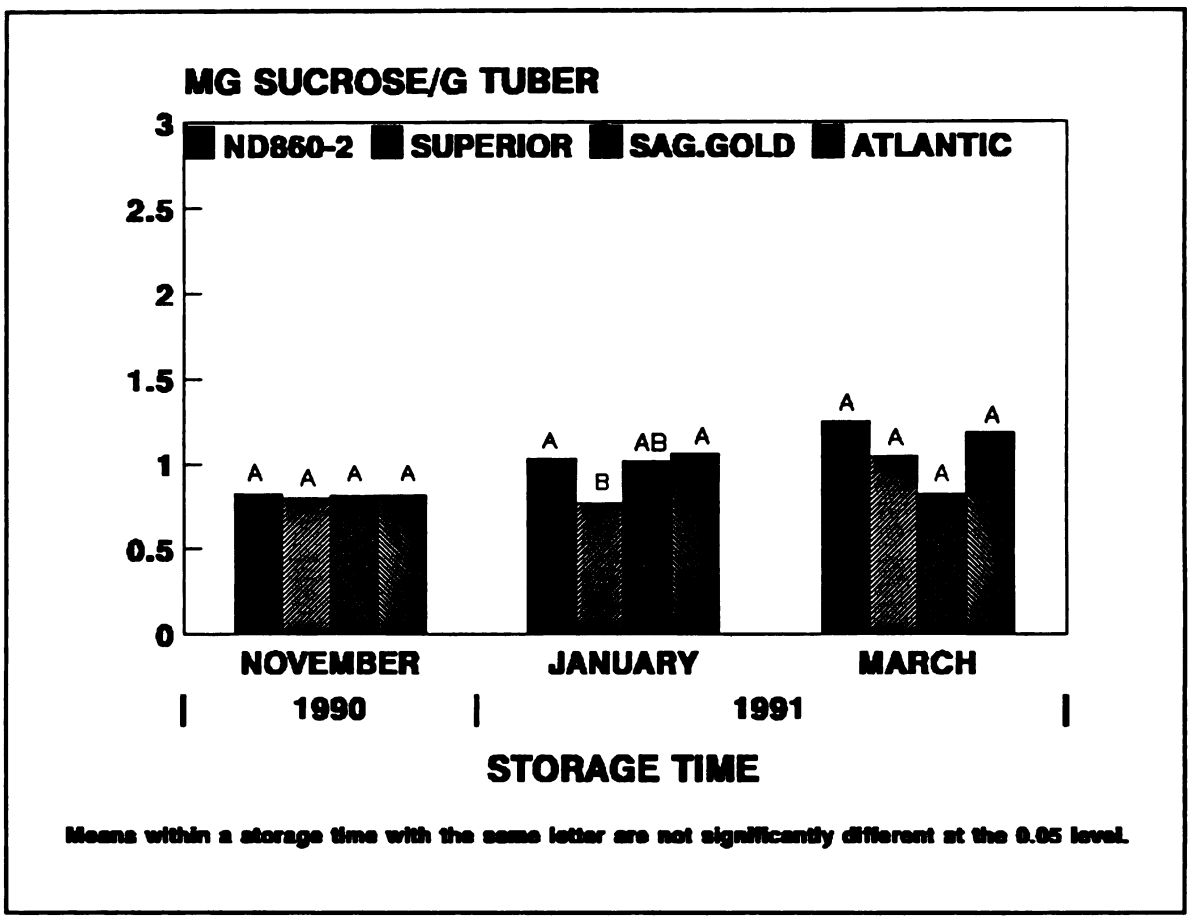

Figure 12. Average sucrose content for 1990 parental material stored at 10C

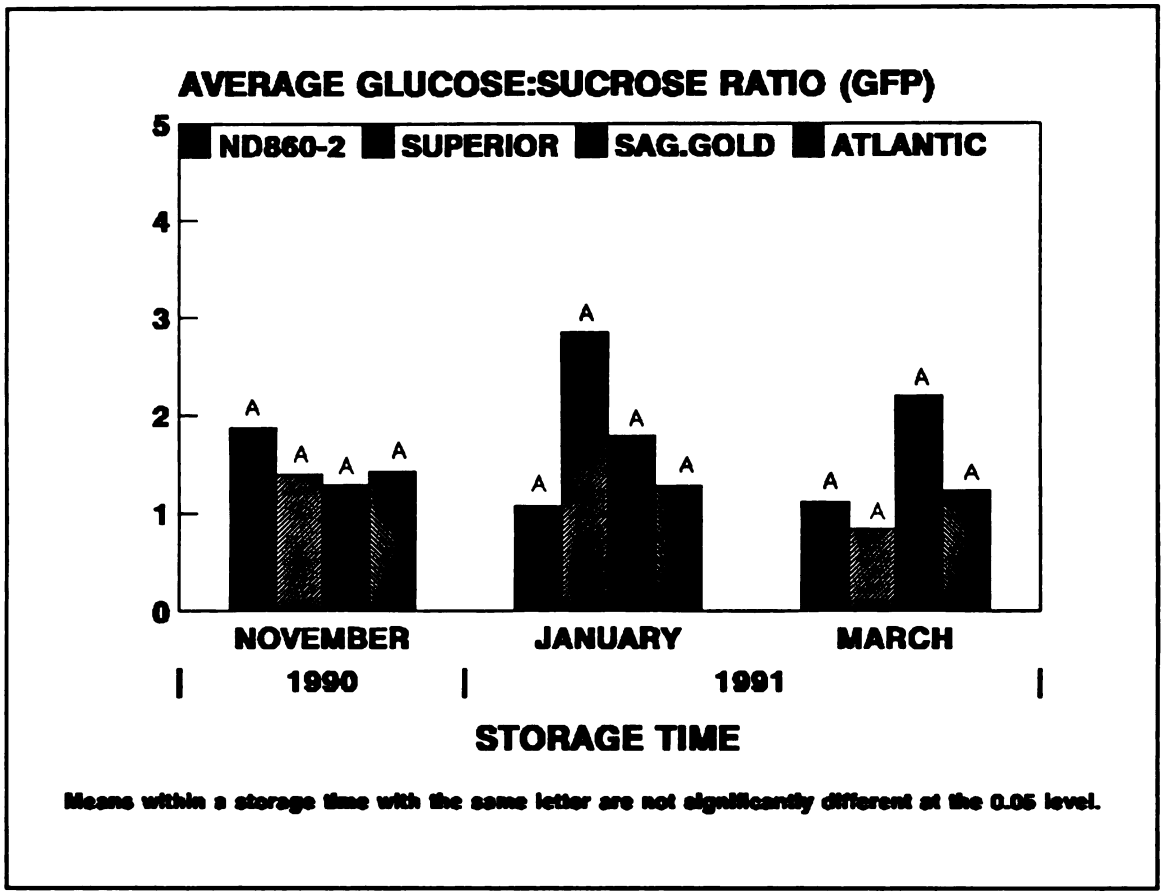

Figure 13. Average GFP for 1990 parental material stored at 10C

Table 4. Correlations--1989 Progeny

	Glucose	Sucrose	GFP	Test Tape	Jan. chip color (PC/SFA)
	Atlantic				
Glucose	--	NS	0.419**	0.312**	0.274**
Sucrose		--	-0.379**	NS	NS
GFP			--	NS	0.276**
Test Tape				--	0.492**
	Saginaw Gold				
Glucose	--	-0.279**	NS	0.554**	0.494**
Sucrose		--	-0.194*	-0.196*	-0.240**
GFP			--	0.249**	0.287**
Test Tape				--	0.710**
	Superior				
Glucose	--	-0.226**	0.216**	0.386**	0.402**
Sucrose		--	NS	NS	NS
GFP			--	NS	NS
Test Tape				--	0.612**
	ND860-2				
Glucose	--	NS	0.386**	0.361**	0.355**
Sucrose		--	-0.280**	NS	NS
GFP			--	NS	0.251**
Test Tape				--	0.608**
	Onaway				
Glucose	--	-0.322**	0.166*	0.310**	0.308**
Sucrose		--	NS	NS	NS
GFP			--	NS	NS
Test Tape				--	0.529**
	All Progeny Combined				
Glucose	--	-0.266**	0.268**	0.501**	0.452**
Sucrose		--	-0.186**	-0.127**	-0.154**
GFP			--	0.161**	0.218**
Test Tape				--	0.664**

*Significant at the 0.05 level
**Significant at the 0.01 level

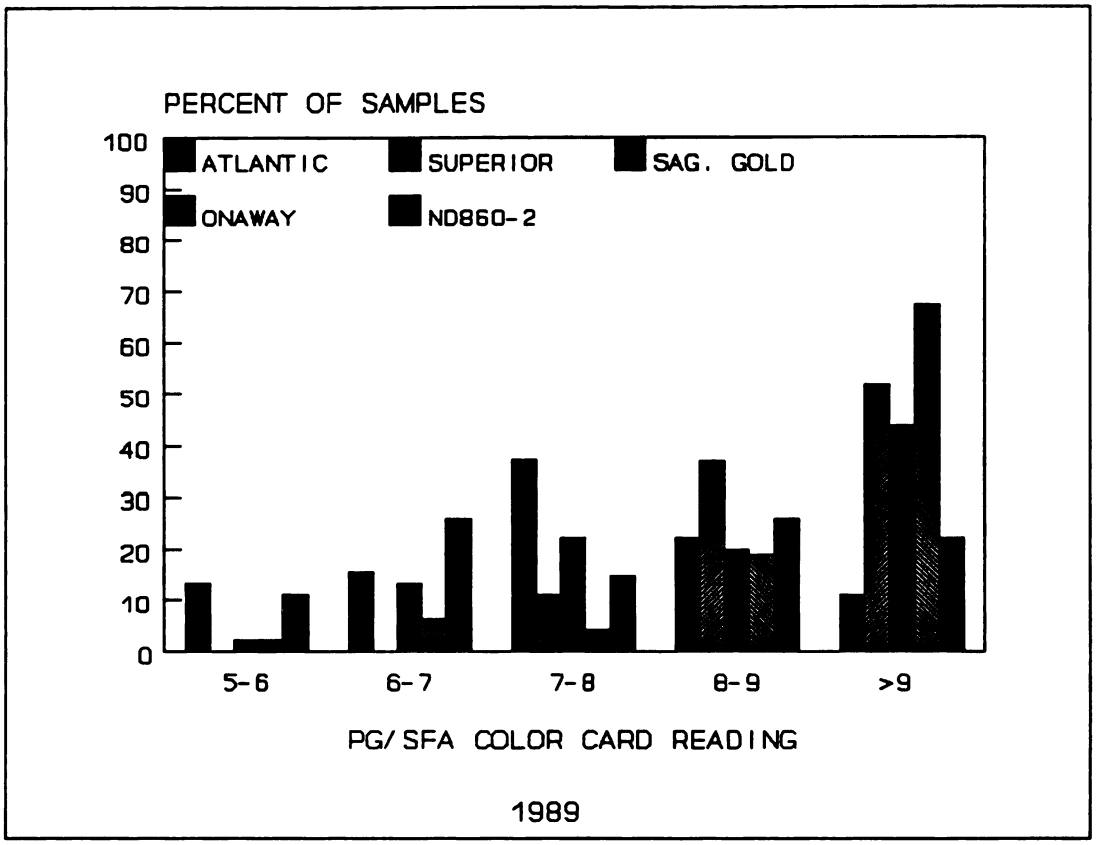

Figure 14. Distribution of visually scored chip color for 1989 progeny from ND860-2 crosses stored 5 months at 10C.

Analysis of variance was performed for test-tape and glucose level and means separated by LSDs as indicated. The test-tape value and glucose level had significant differences as presented in Tables 6 and 7.

A closer look at chip colors (by use of PG/SFA color cards) after 5 months of storage shows the following. Crosses involving ND860-2 produced progeny with a wide range of chip colors (Fig. 14). Progeny from ND860-2 self-pollinated (ND860-2 "selfed") were evenly distributed over the range of chip colors (5-9). ND860-2 x Atlantic progeny demonstrated slightly improved chip color distribution over ND860-2 "selfed". ND860-2 x Onaway had the poorest distribution of chip colors (primarily >9.0).

Most of the progeny resulting from Onaway crosses produced very poor chip color (Fig. 15). Onaway "selfed" progeny were the poorest of all the Onaway crosses. Slight improvements in chip colors were found in crosses with Atlantic, ND860-2, and Saginaw Gold. Most progeny were consistently very poor (9.0 or above). Saginaw Gold progeny provided a range of chip colors; however, a majority of the progeny were poor (Fig. 16). The poorest chip colors were a result of the crosses Saginaw Gold x Superior and Saginaw Gold x Onaway. Some improvement in chip colors was seen in progeny from Saginaw Gold x Atlantic and Saginaw Gold x ND860-2.

Superior progeny provided a range of chip colors, some of which were more acceptable than was found when other varieties were used as parents, but large numbers of progeny were associated with poor chip colors (Fig. 17). Superior x Onaway and Superior x Saginaw Gold progeny were generally 9.0 or above. An improvement in chip color was seen in progeny from Superior x Atlantic and Superior "selfed".

Atlantic progeny were evenly distributed across the range of chip colors (Fig. 18). Atlantic "selfed" progeny produced an even range of chip colors from poor to acceptable. Atlantic x Onaway progeny had the poorest chip colors. Progeny from Atlantic x ND860-2 provided some good chip colors.

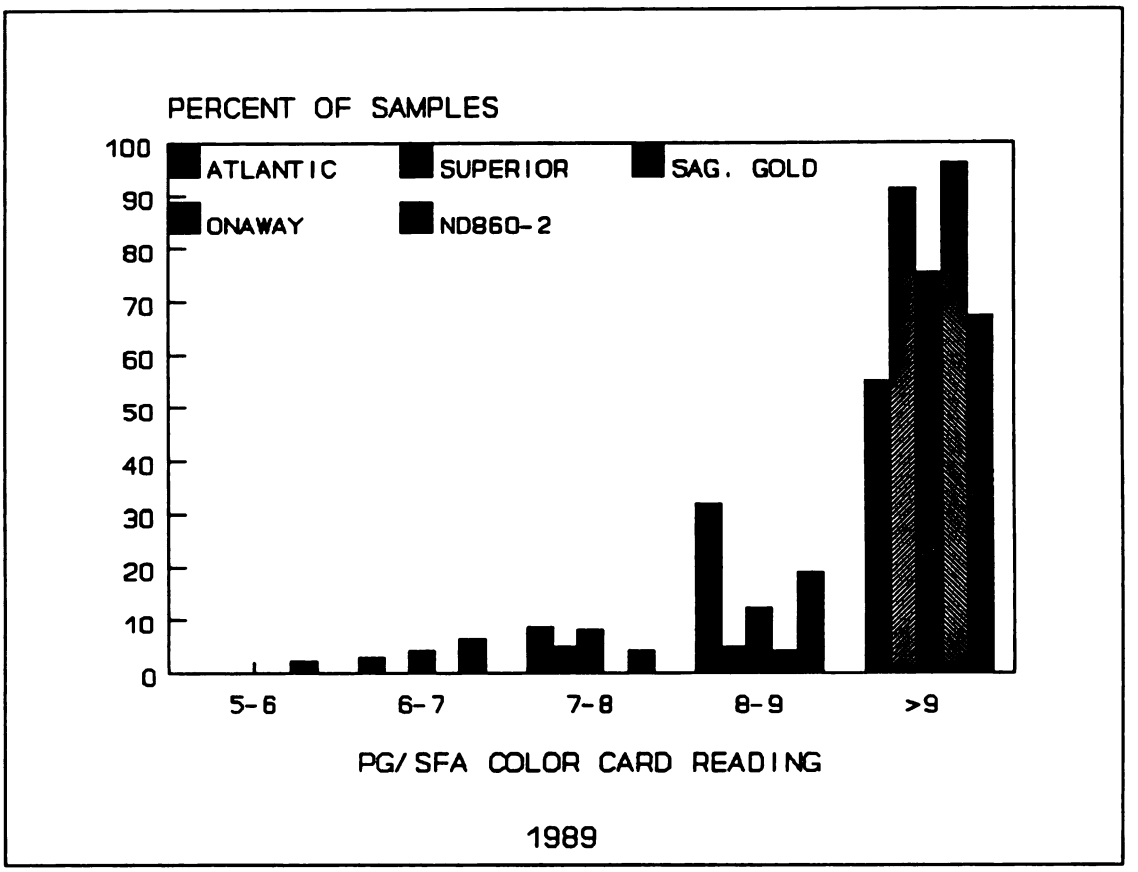

Figure 15. Distribution of visually scored chip color for 1989 progeny from Onaway crosses stored 5 months at 10C.

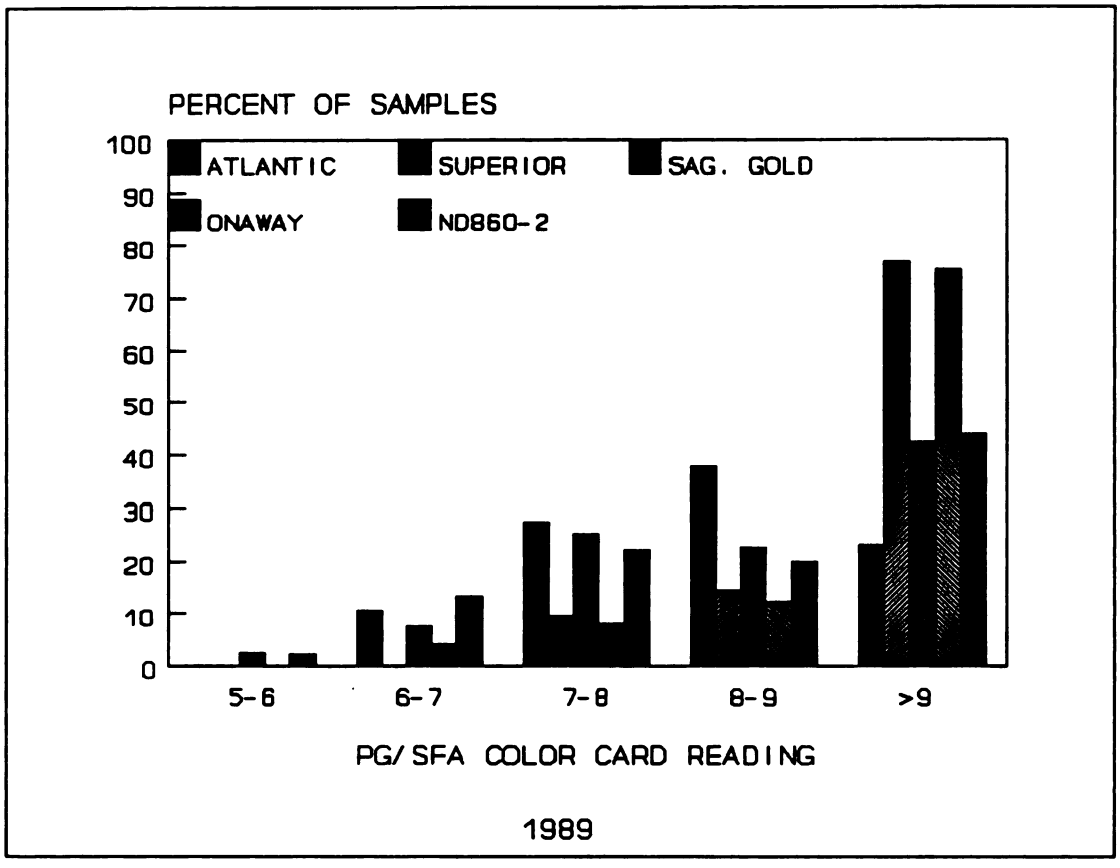

Figure 16. Distribution of visually scored chip color for 1989 progeny from Saginaw Gold crosses stored 5 months at 10C.

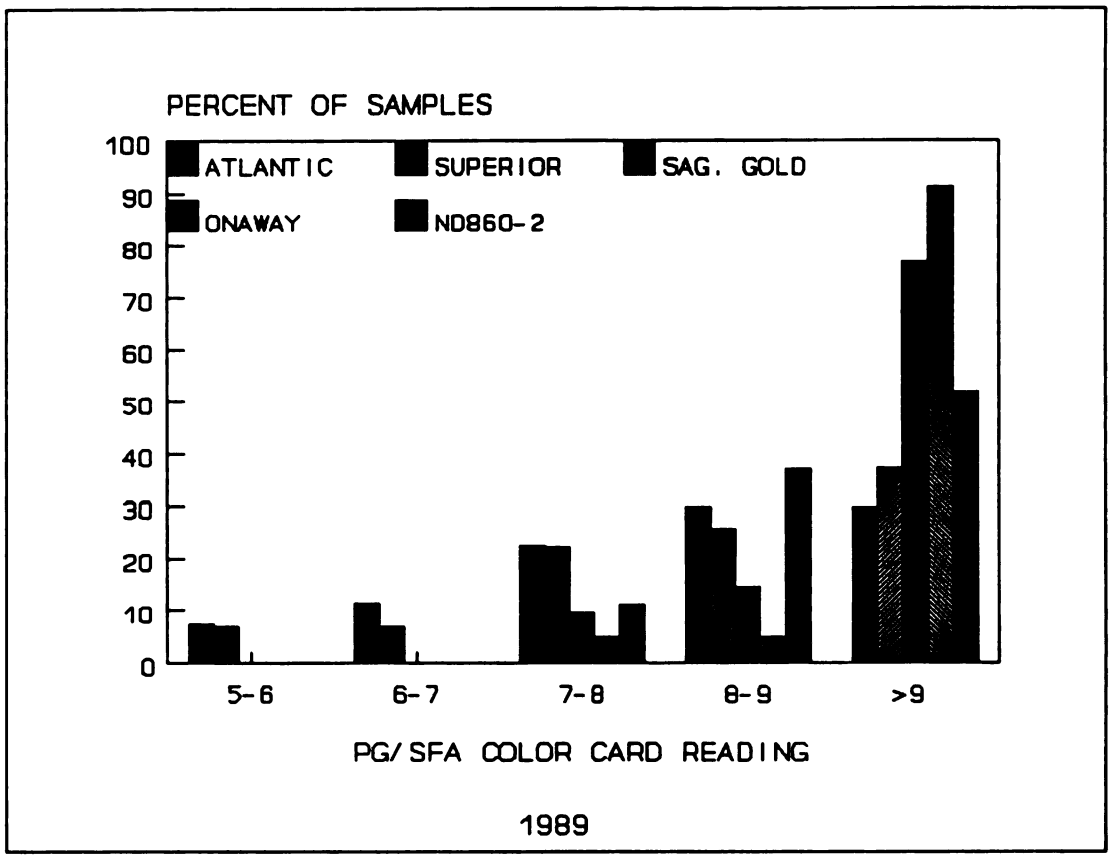

Figure 17. Distribution of visually scored chip color for 1989 progeny from Superior crosses stored 5 months at 10C.

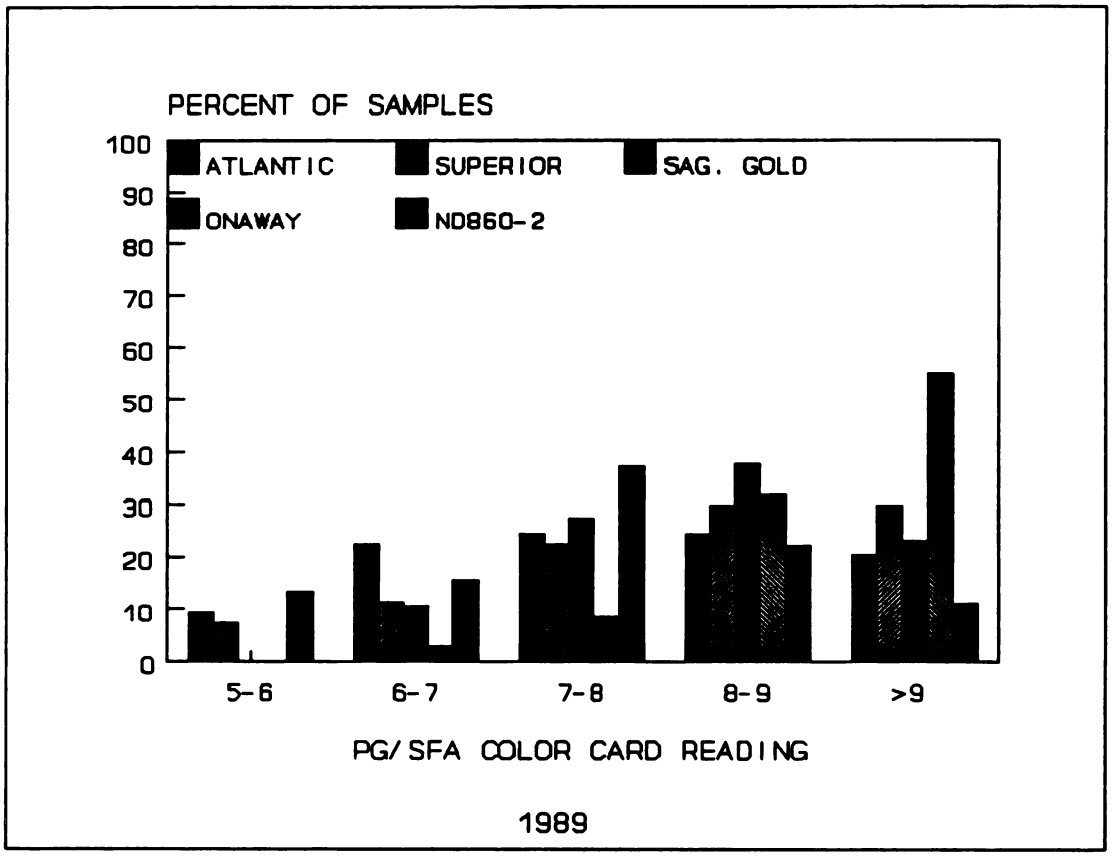

Figure 18. Distribution of visually scored chip color for 1989 progeny from Atlantic crosses stored 5 months at 10C.

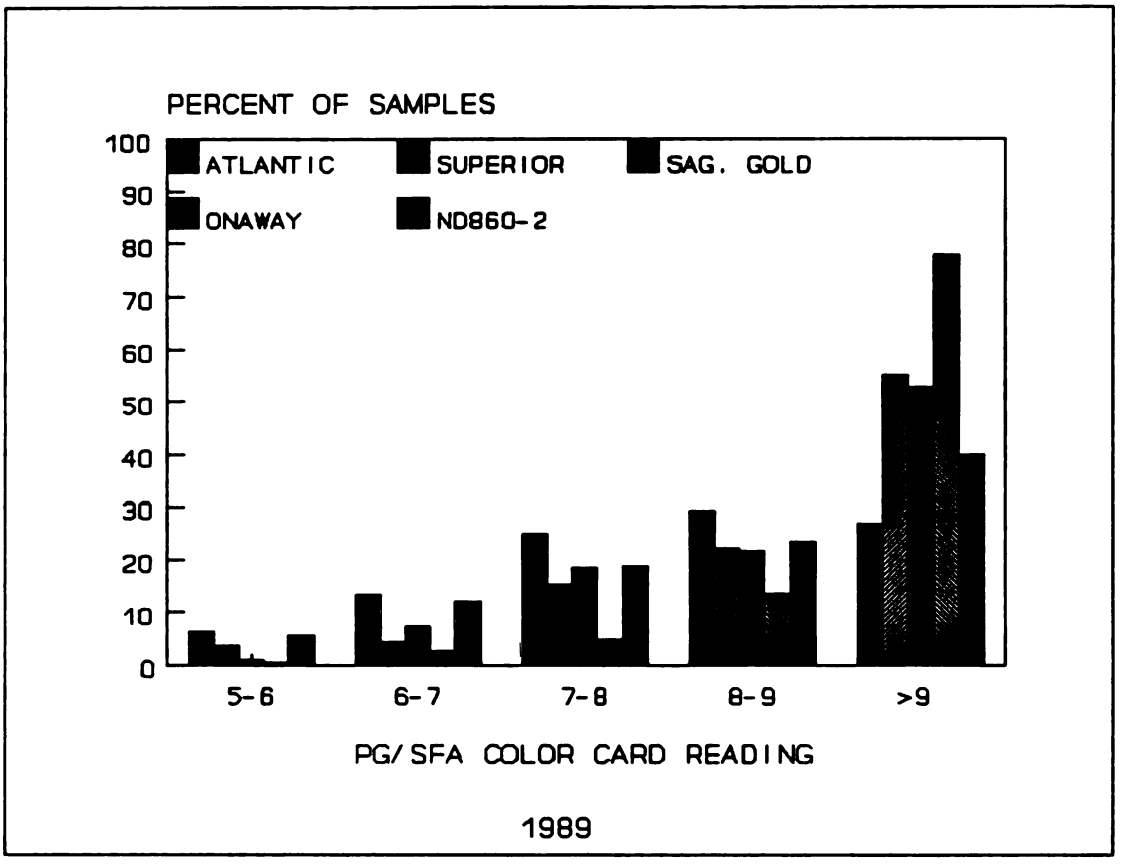

Figure 19. Distribution of visually scored chip color for 1989 progeny from each parent averaged over all crosses stored 5 months at 10C.

When all crosses were analyzed together (Fig. 19), Atlantic produced the highest proportion of acceptable progeny chip color, followed by ND860-2. Onaway progeny produced the highest proportion of poor chip colors.

1990 Progeny Analysis

In 1990, a half diallel mating design was produced using Saginaw Gold, Superior, and ND860-2. The resulting progeny were analyzed for glucose content, sucrose level, GFP, and at 2 and 5 months after harvest, chip color was evaluated by use of the Agtron E10 machine and PG/SFA color cards.

Table 5 presents correlation data for the study. January chip color evaluation methods were significantly correlated for PG/SFA color card numbers and Agtron E10 values. There was a great deal of variability in the other correlations. Generally, glucose levels were significantly correlated with chip color, regardless of the method used or when evaluated.

An analysis of variance was performed on glucose content, sucrose level, GFP, and chip color. No significant treatment effects were noted for any of the variables.

General trends for chip colors (by Agtron E-10 reading) at 2 months after harvest indicated that most crosses produced acceptable progeny at this time. Saginaw Gold crosses gave progeny with mostly acceptable chip colors, Saginaw Gold X Superior gave the highest proportion of Agtron readings below 60 (unacceptable) (Fig. 20). Progeny from Superior crosses also produced mostly acceptable chip colors (Fig. 21). Poor Agtron readings were found in progeny from all crosses with Superior. Superior "selfed" progeny produced the highest percentage of Agtron readings above 60. ND860-2 crosses produced progeny with mostly acceptable chip colors (Fig. 22). The poorest chip colors for ND860-2 progeny were from ND860-2 x Superior. An analysis across all the progeny showed most of the crosses produced progeny that yielded acceptable chip colors after 2 months of storage (Fig. 23).

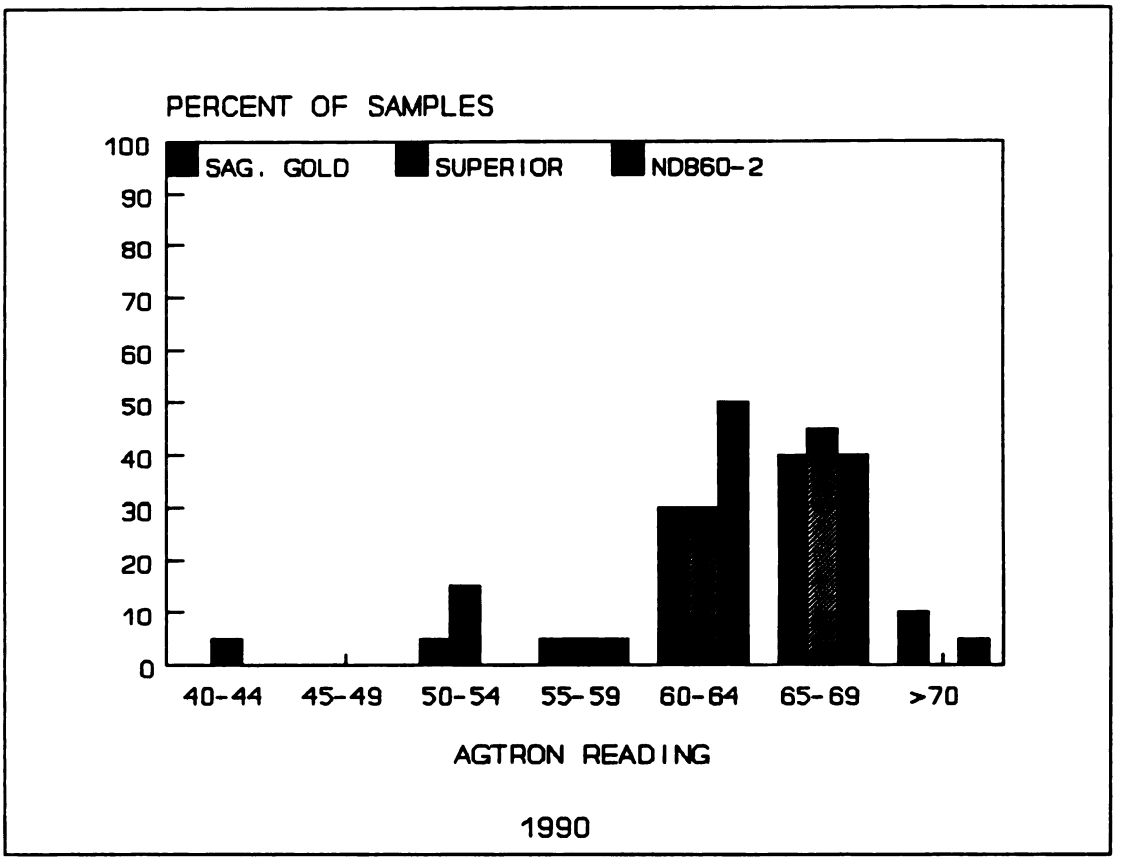

Figure 20. Distribution of Agtron chip color for 1990 progeny from Saginaw Gold stored 2 months at 10C

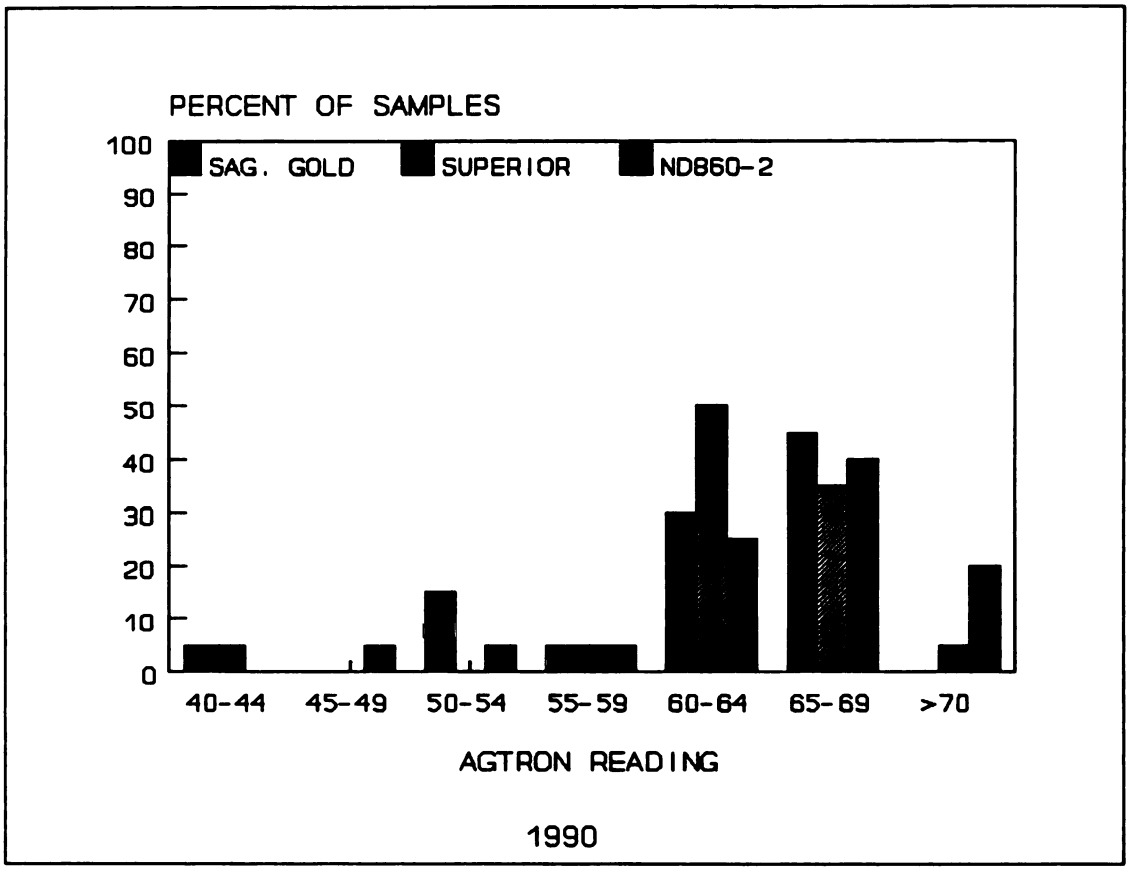

Figure 21. Distribution of Agtron chip color for 1990 progeny from Superior stored 2 months at 10C

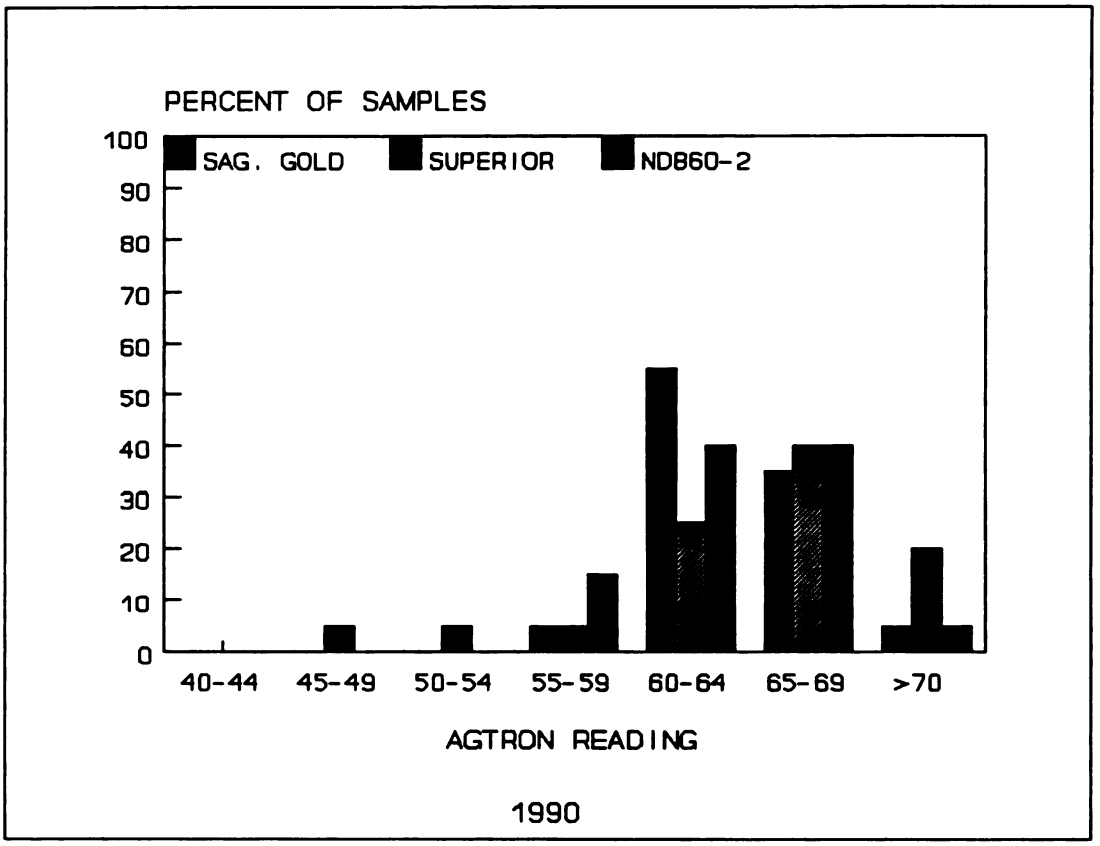

Figure 22. Distribution of Agtron chip color for 1990 progeny from ND860-2 stored 2 months at 10C

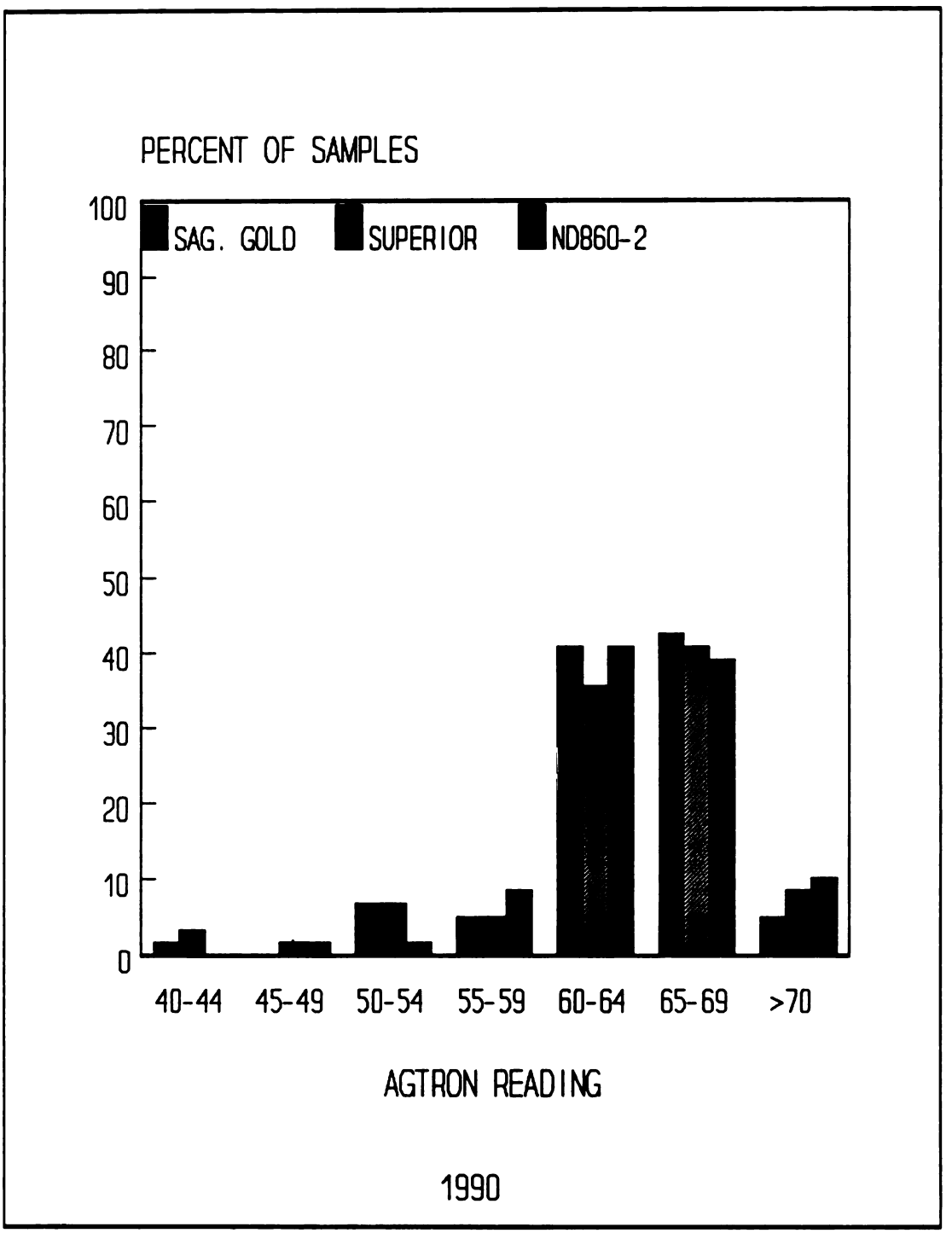

Figure 23. Distribution of Agtron chip color for 1990 progeny from each parent averaged over all crosses stored 2 months at 10C

Table 5. Correlations--1990 Progeny

	Glucose	Sucrose	GFP	Nov. chip color (Agtron E10)	Jan. chip color (Agtron E10)	Jan. chip color (PC/SFA)
Saginaw Gold						
Glucose	--	NS	0.404**	-0.265*	-0.313*	0.364**
Sucrose		--	NS	NS	NS	NS
GFP			--	NS	NS	NS
Nov Chip Color Agtron E10				--	NS	NS
Jan Chip Color Agtron E10					--	-0.454**
Superior						
Glucose	--	-0.290*	NS	-0.333**	-0.545**	0.259*
Sucrose		--	NS	0.261*	0.306*	NS
GFP			--	NS	NS	NS
Nov Chip Color Agtron E10				--	NS	NS
Jan Chip Color Agtron E10					--	-0.343**

Table 5 (con'd).

ND860-2						
Glucose	NS	NS	NS	NS	NS	0.307*
Sucrose		--	NS	NS	-0.362**	0.313*
GFP			--	NS	NS	NS
Nov Chip Color Agtron E10				--	NS	NS
Jan Chip Color Agtron E10					--	-0.314*
All progeny combined						
Glucose	--	NS	NS	-0.293**	-0.370**	0.298**
Sucrose		--	NS	NS	NS	NS
GFP			--	NS	NS	NS
Nov Chip Color Agtron E10				--	NS	NS
Jan Chip Color Agtron E10					--	-0.364**

*Significant at the 0.05 level
**Significant at the 0.01 level

Table 6. Mean separations for 1989 progeny glucose content determined 2 months after harvest.

ND860-2 x Onaway	A
Atlantic x Saginaw Gold	AB
Saginaw Gold x Onaway	AB
Atlantic X	AB
ND860-2 X	AB
Onaway X	AB
Atlantic x Onaway	AB
Atlantic x ND860-2	AB
Saginaw Gold X	AB
Atlantic x Superior	AB
Saginaw Gold x Superior	B
Superior X	B
Saginaw Gold x ND860-2	B
Superior x Onaway	B
Superior x ND860-2	B

Varieties followed by the same letter are not significantly different according to Fisher's protected LSD at the 0.01 level.

Table 7. Mean separations for 1989 progeny test tape readings evaluated 5 months after harvest.

Atlantic x Saginaw Gold	A
ND860-2 x Onaway	A
Saginaw Gold x Onaway	AB
Atlantic X	ABC
Onaway X	ABC
ND860-2 X	ABC
Atlantic x ND860-2	ABC
Atlantic x Onaway	ABC
Atlantic x Superior	ABC
Saginaw Gold X	ABC
Superior X	ABC
Saginaw Gold x ND860-2	BC
Saginaw Gold x Superior	BC
Superior x Onaway	BC
Superior x ND860-2	C

Varieties followed by the same letter are not significantly different according to Fisher's protected LSD at the 0.01 level.

General trends for chip colors (by Agtron E-10 reading) 5 months after harvest showed that the progeny range produced a general worsening of chip colors and a greater percentage of unacceptable chip colors. Saginaw Gold crosses produced a wide range of chip colors (Fig. 24). The poorest results were from Saginaw Gold x Superior and Saginaw Gold x ND860-2 crosses. The best progeny were associated with Saginaw Gold "selfed" crosses. Progeny from Superior crosses had a wide range of chip colors (Fig. 25). The poorest chip colors resulted from crosses with Saginaw Gold. The best results were from crosses with ND860-2. Crosses with ND860-2 gave progeny that covered a wide range of chip colors (Fig. 26). The poorest chip colors were associated with the progeny from ND860-2 x Saginaw Gold. The best progeny colors were evenly distributed between ND860-2 x Superior and ND860-2 "selfed". The progeny from each parent analyzed together, showed a general decrease in chip colors with a greater range of chip colors produced, as compared to the results at 2 months (Fig. 27).

General trends for chip color (measured visually by PG/SFA color cards) 5 months after harvest showed the progeny results as follows. Saginaw Gold "selfed" crosses produced the highest percentage of good chip colors, as well as the some of the poorest (Fig. 28). Superior crosses provided progeny with a wide range of chip colors, Superior x ND860-2 crosses produced the highest percentage of good chip colors (Fig. 29). ND860-2 crosses produced progeny with a wide range of chip colors (Fig. 30). All ND860-2 crosses produced a high percentage of acceptable progeny. When the progeny from each parent was analyzed together, there was a fairly comparable distribution of chip colors regardless of the parent, most of the chip colors in the 3-5 range (Fig. 31).

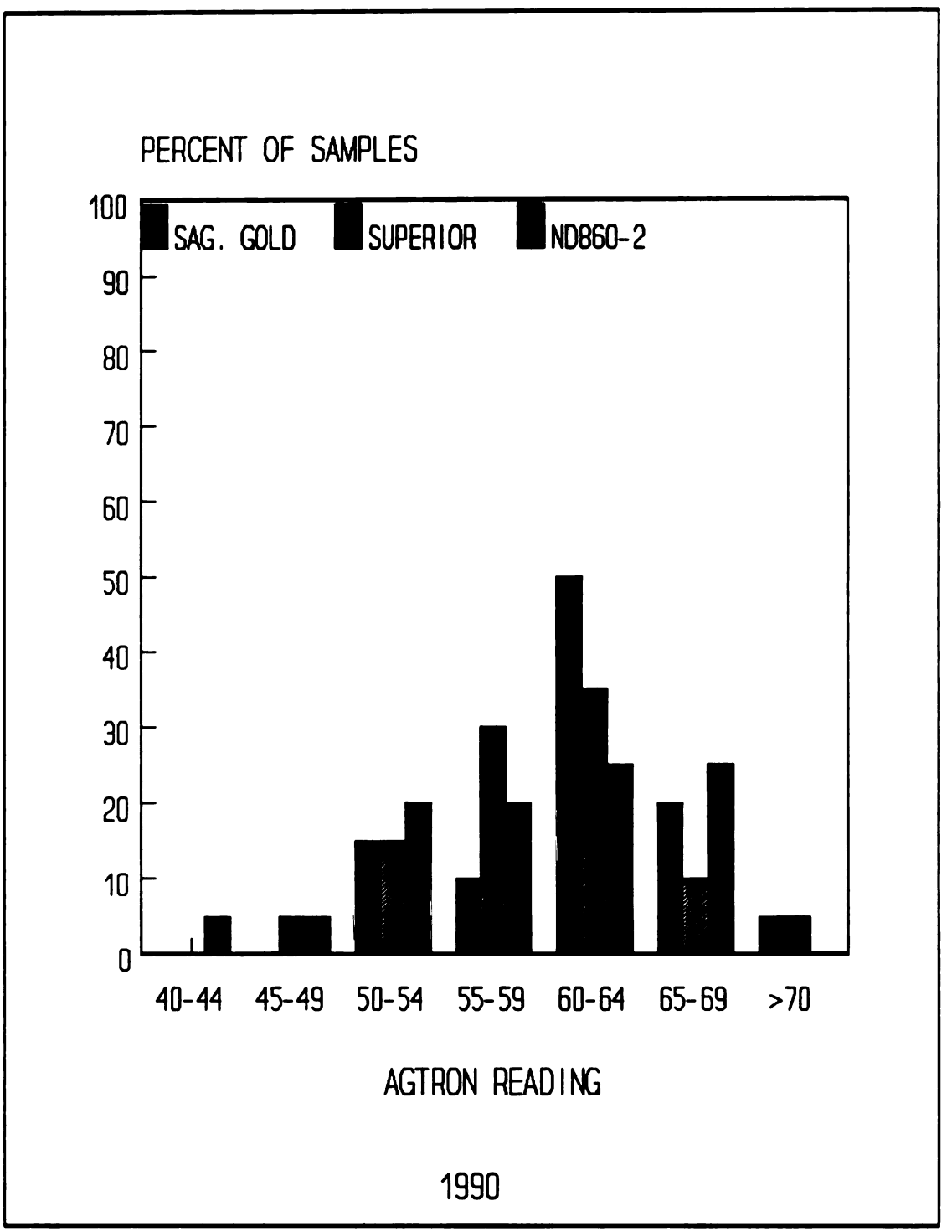

Figure 24. Distribution of Agtron chip color for 1990 progeny from Saginaw Gold stored 5 months at 10C.

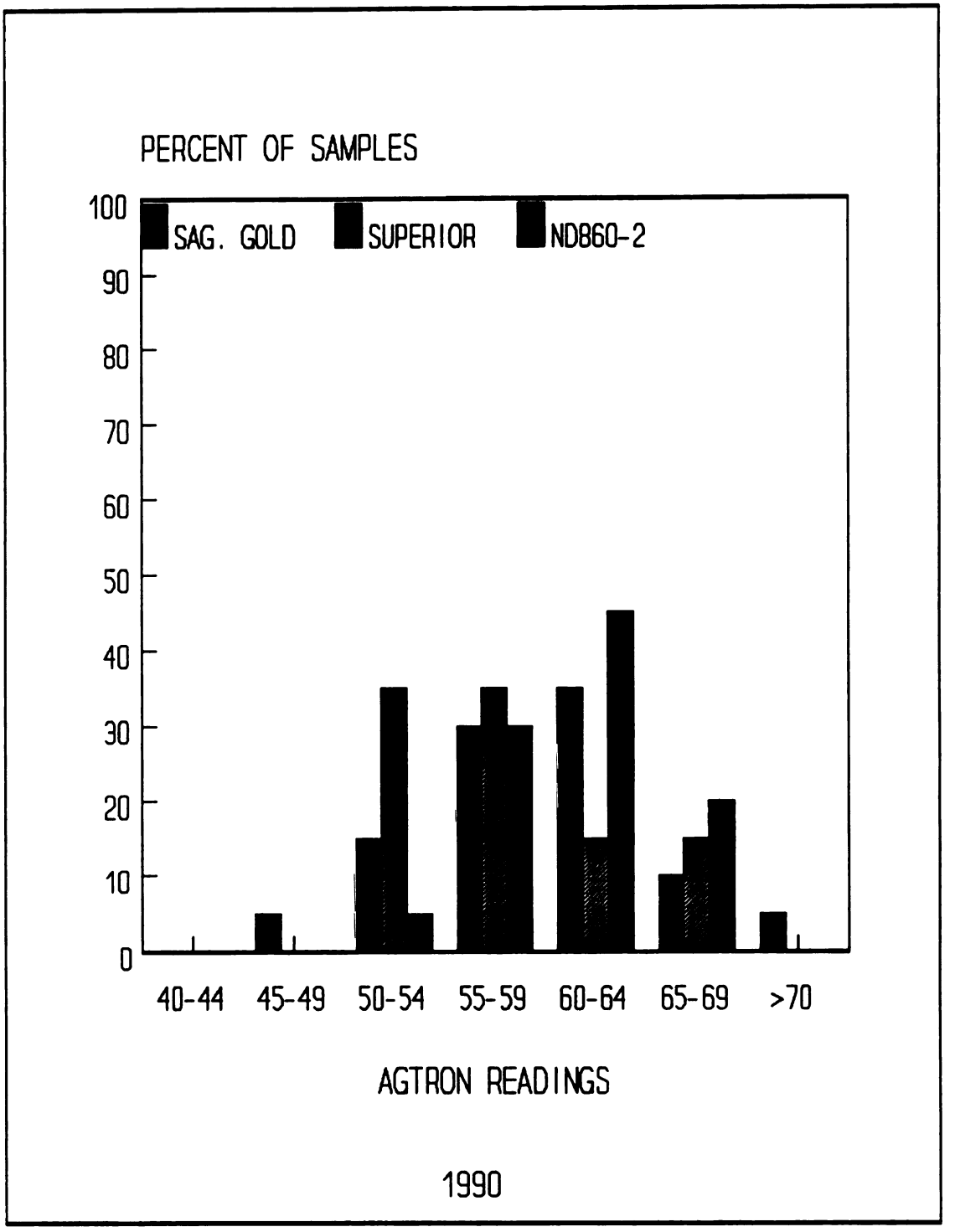

Figure 25. Distribution of Agtron chip color for 1990 progeny from Superior stored 5 months at 10C.

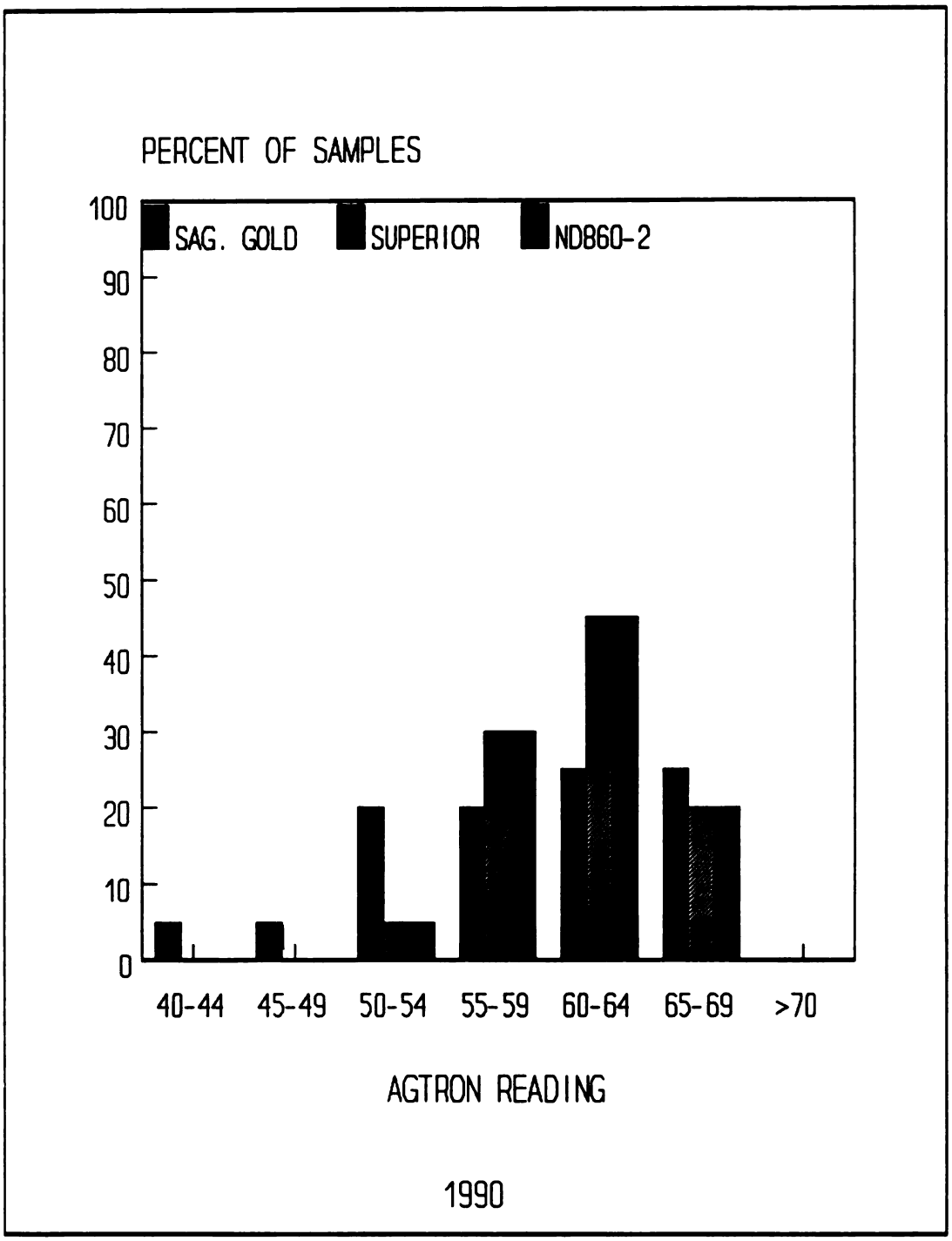

Figure 26. Distribution of Agtron chip color for 1990 progeny from ND860-2 stored 5 months at 10C.

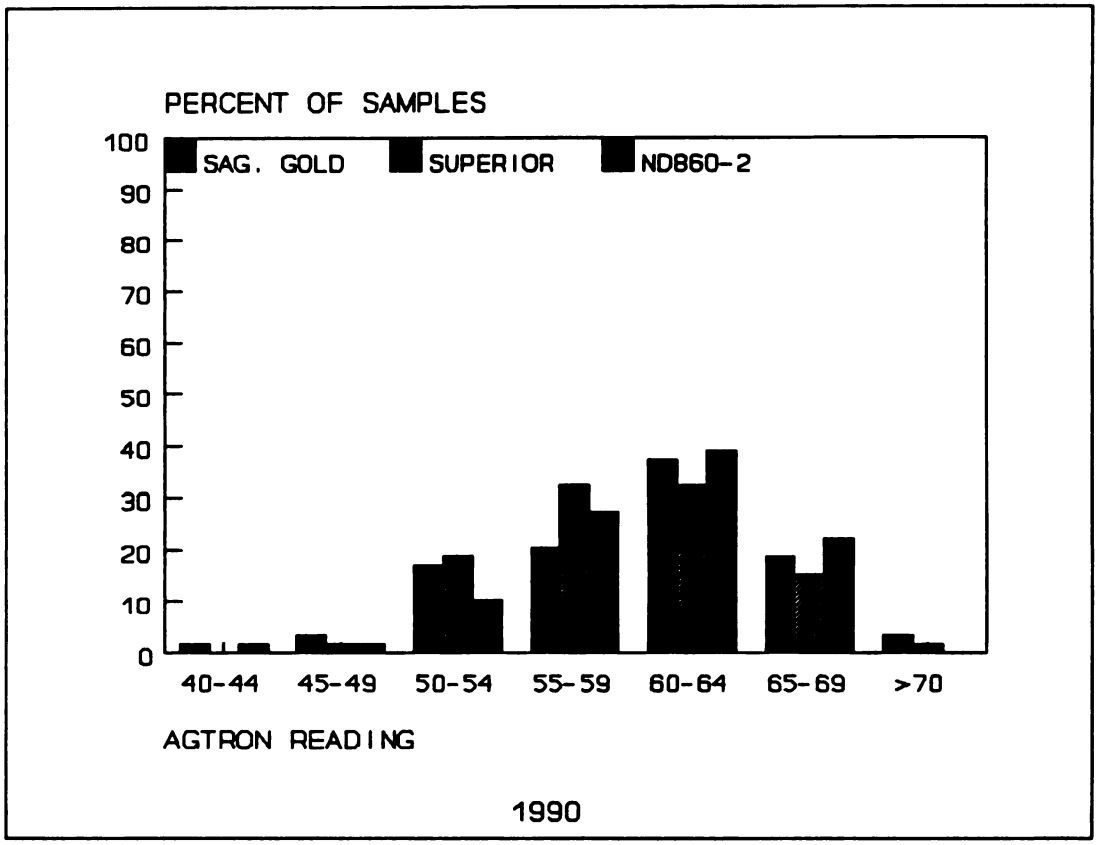

Figure 27. Distribution of Agtron chip color for 1990 progeny from each parent averaged over all crosses stored 5 months at 10C

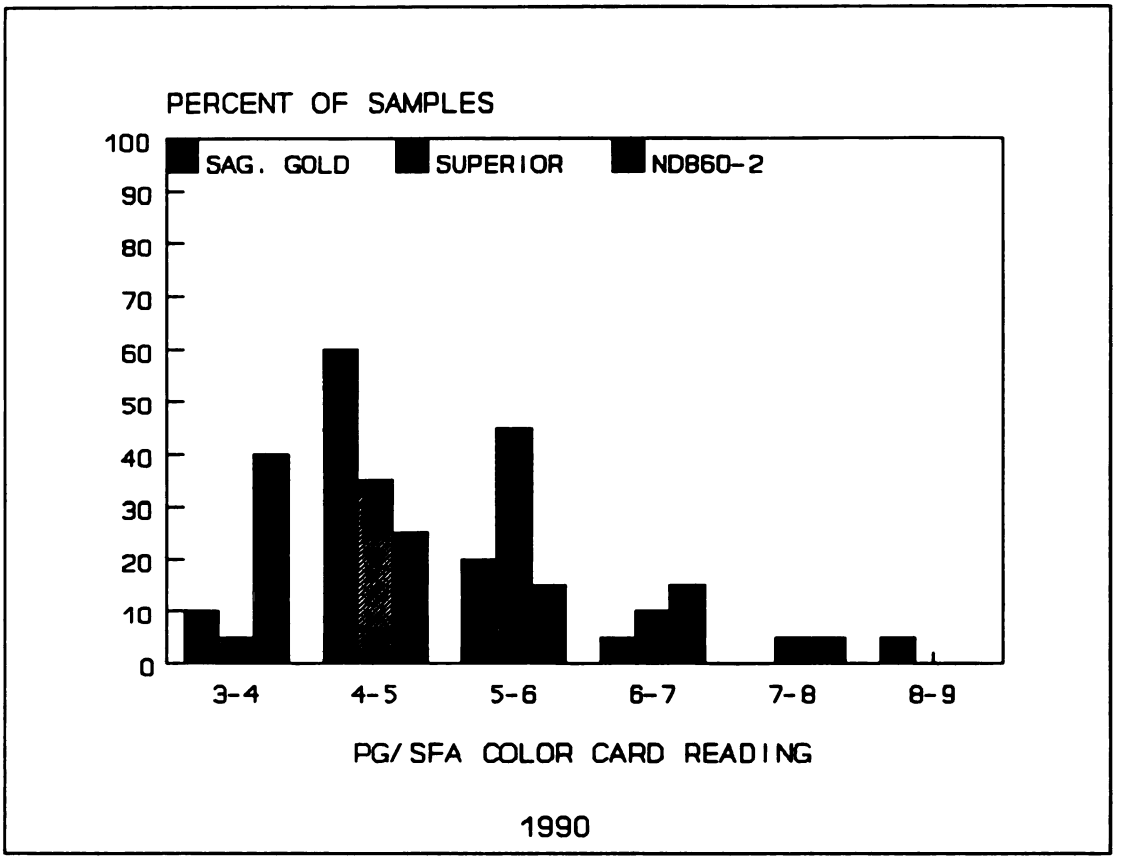

Figure 28. Distribution of visually scored chip color for 1990 progeny from Saginaw Gold crosses stored 5 months at 10C

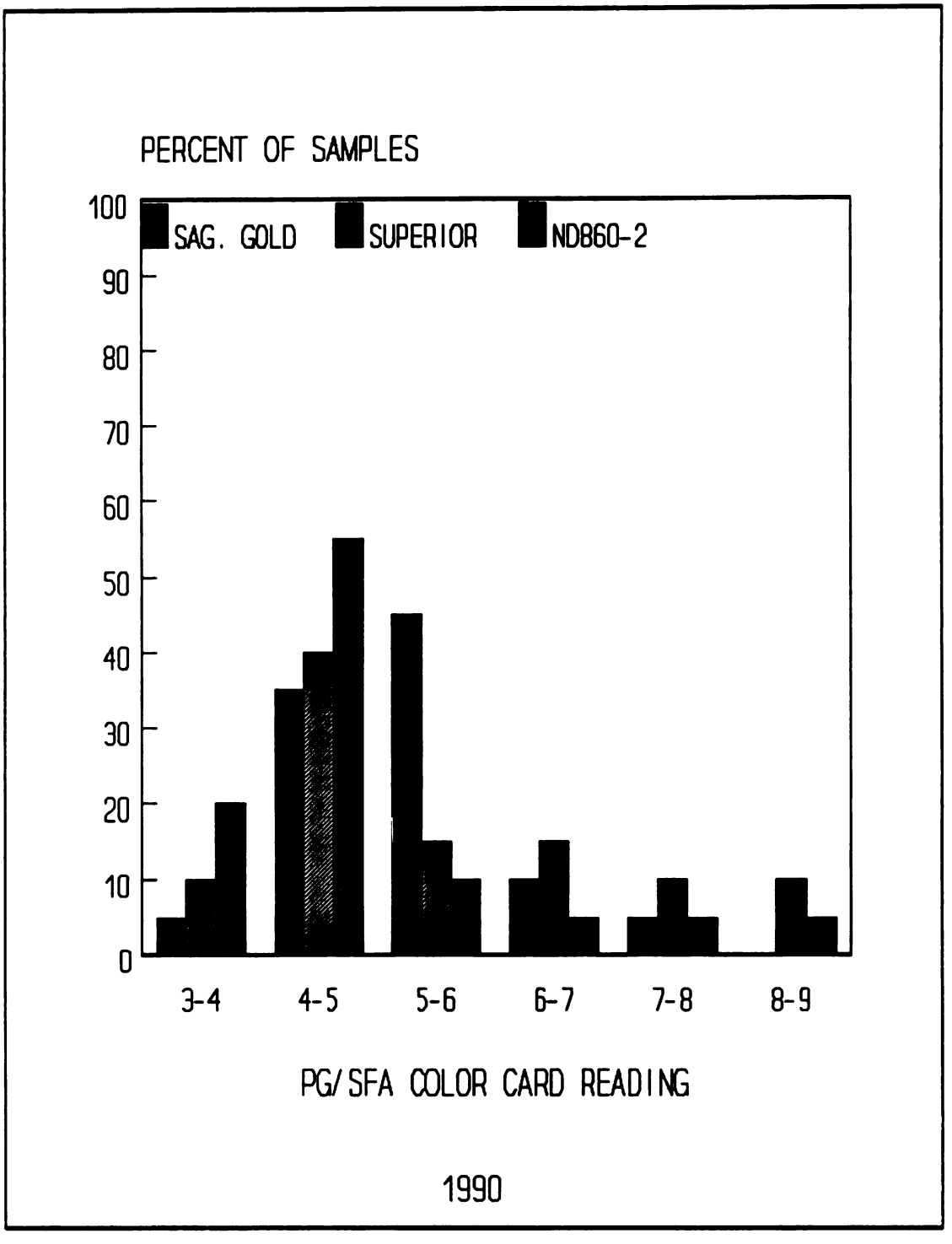

Figure 29. Distribution of visually scored chip color for 1990 progeny from Superior crosses stored 5 months at 10C

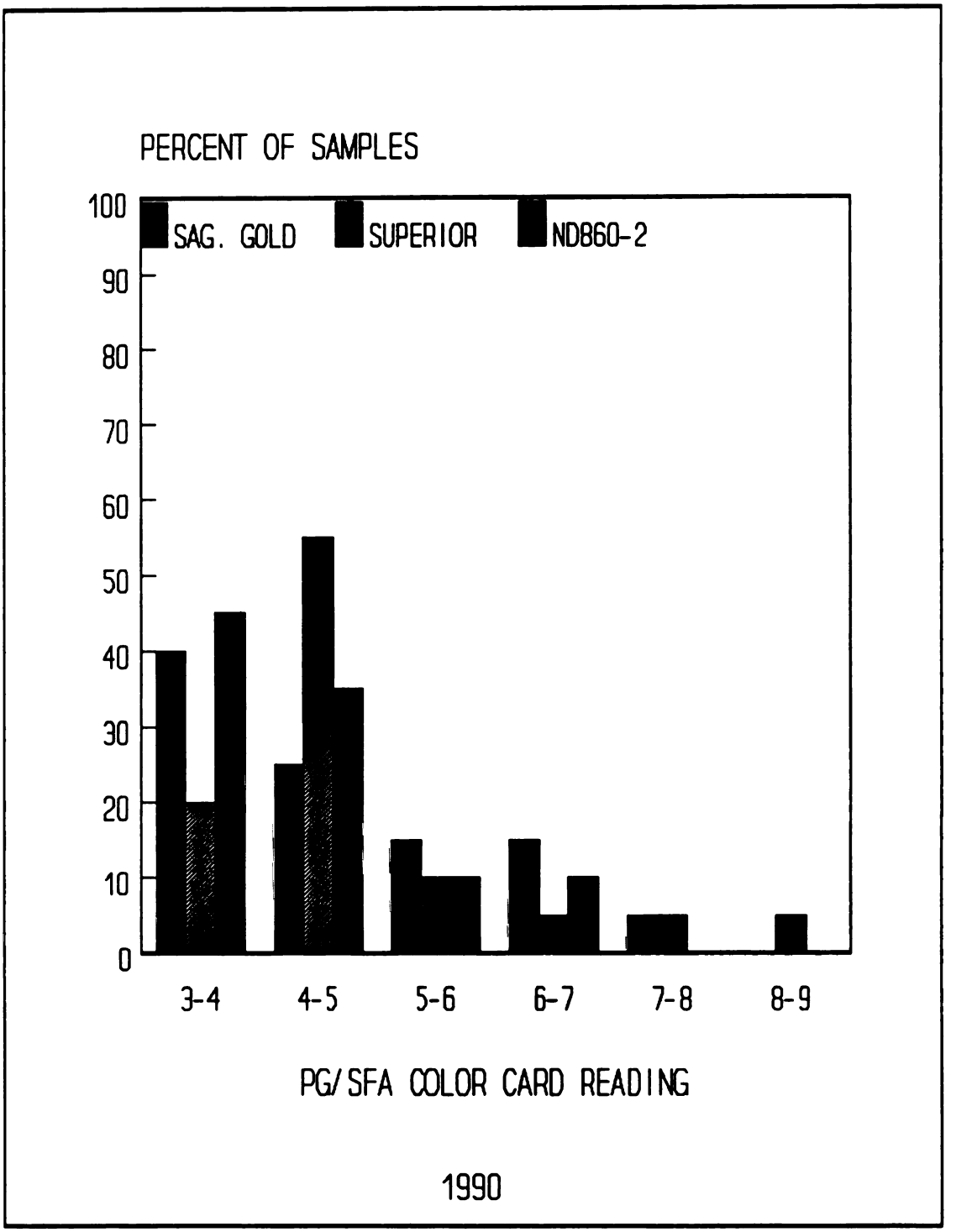

Figure 30. Distribution of visually scored chip color for 1990 progeny from ND860-2 crosses stored 5 months at 10C

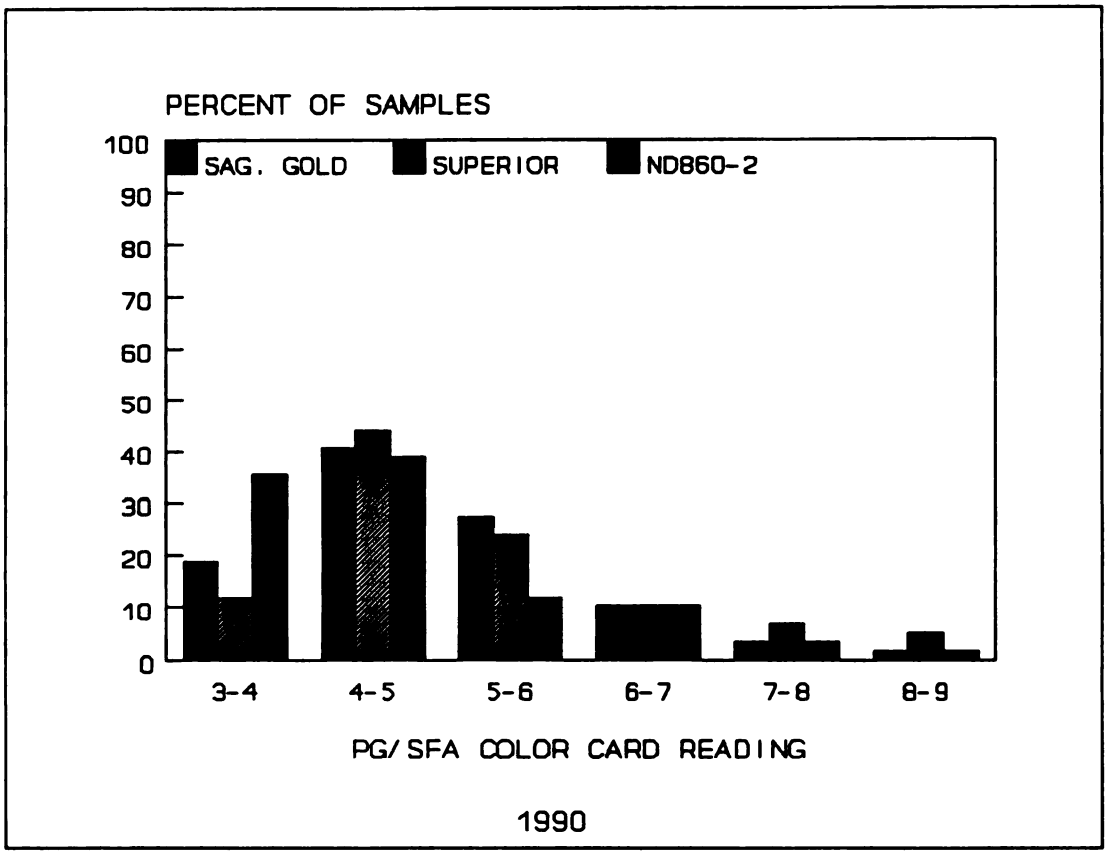

Figure 31. Distribution of visually scored chip color for 1990 progeny from each parent averaged over all crosses stored 5 months at 10C

Discussion

Sugar content and thus chip color is highly subject to environmental factors and varies from year to year and by location; however, those that are the best processors overall are generally a good processor in any given year (50). This could account for some of the variability of our data as compared to what would be expected from work done by others.

Results seem to indicate that Atlantic and ND860-2 possess the ability to improve the chipping potential of most crosses. These clones are used as chip-processors and are able to attain chemical maturity at physical maturity (6). Onaway has the greatest potential to result in poor chip processing ability. Onaway is strictly a fresh market potato and is not used for the chip processing market due to excess levels of sucrose at physical maturity (6).

ND860-2 is reported to be tolerate cold temperature storage (4C) for as long as 5 months and still produce acceptable color chips without reconditioning (8, 10, 64). From 10C storage, Atlantic and its progeny produced chip color as good or better than ND860-2 and its progeny. Cold storage may have provided the ability to better discriminate for improved chip color from ND860-2 than the others.

General combining ability was significant at the 0.05 level for all progeny for all traits examined, except the November and January agtron readings for the 1990 progeny (Table 8). This suggests that additive gene action is the primary factor influencing chip color (32). Therefore, breeding progress can be made through simple recurrent selection.

Specific combining ability was not significant for any traits of any progeny. This suggests no one cross was unusually good or poor and is an indicator of the lack of dominance and epistasis in chip color development (32).

The test-tape method for chip color evaluation is a quick test based on glucose levels in tuber tissue (1, 19). As the test-tape value increases, the level of glucose

Table 8. General (GCA) and specific combining ability (SCA) for potato chipping quality characteristics.

		Level of Significance	
Year	Measurement	SCA	GCA
1989	Test-tape	NS	**
	Chip color (PG/SFA)	NS	**
	Glucose content	NS	**
	Sucrose content	NS	**
	GFP	NS	**
1990	Nov. chip color (Agtron E-10)	NS	NS
	Jan. chip color (Agtron E-10)	NS	NS
	Jan. chip color (PG/SFA)	NS	NS
	Glucose content	NS	**
	Sucrose content	NS	**
	GFP	NS	**

NS--Not significant at the 0.05 level
*--Significant at the 0.05 level
**--Significant at the 0.01 level

increases in the tissue. A positive correlation would be expected between test-tape and glucose, and our results confirm that correlation.

Chip color is largely determined by glucose levels in the tissue being fried (13, 14, 39, 50). As glucose levels increase, the resulting chip color becomes darker (13, 14, 39). A significant correlation between chip color and glucose levels would be expected. Generally, our data produced those same results. A negative correlation resulted when using the Agtron E10 machine (as glucose levels increased, the Agtron readings decreased). A positive correlation resulted when using the PG/SFA color cards (as glucose levels increased, the color card readings increased). A correlation between chip color and test-tape values would also be expected. Our data indicated that as chip colors worsened, the test tape values increased.

Chip color evaluations taken at different storage periods may not be expected to correlate well with one another. Our data did not indicate any correlation between the November and January progeny chip color results. The chip colors are an indication of glucose levels at a given time in storage and not necessarily related to glucose levels at a later time in storage.

Different chip color evaluation methods (i.e., Agtron E10 and the color cards) performed at the same storage period would be expected to correlate well as they are both measuring the glucose levels found in tuber tissue at a fixed storage period. A negative correlation was found for the January progeny chip color results determined by the use of the color cards as compared to the results from Agtron E10 machine. This is as expected, higher Agtron numbers and lower PG/SFA color card numbers are both indicative of improving chip color.

Sucrose does not directly participate in the reaction that results in the production of dark color chips during frying (7, 16, 46, 50). It would not be expected to see a correlation between sucrose levels and chip colors or other factors at a given storage period (6, 39). Our data found no significant correlation for the sucrose levels as

compared to the chip colors when the parental material was analyzed. Sucrose levels at harvest should correlate with chip colors later in storage (46, 47, 50). Our sucrose analysis was done two months after harvest and the results may not be expected to be useful for determining later chip color. This could account for the lack of correlation between sucrose levels and later chip color ratings.

The combination of low sucrose and low glucose levels is termed "chemical maturity" (49). A variety that does not reach chemical maturity, such as Onaway or Lemhi Russet, before it reaches physical maturity is not suited for storage and use as a chip-processing variety (47, 49, 50, 52). These varieties may produce acceptable color chips from the field as our data indicate.

Clones with high GFP (>4), such as Onaway, are best suited for fresh market uses, moderate GFP levels (2-4), such as Lemhi Russet, are often used for the french fry market, while those with the best chipping potential have a GFP level less than 2, such as Atlantic and ND860-2 (53). Our results regarding the GFP were inconclusive.

The analyses performed for these studies demonstrated the value of different methods for determining chip-processability. Not all methods would be appropriate for all stages of a breeding program, such as at Michigan State University.

The test tape analysis would be very useful early in a breeding program, for example at the single-hill evaluation stage. It can be done quickly and requires only one tuber for analysis. These factors are both important early in a breeding program when large numbers of progeny are being evaluated and the number of tubers is relatively limited.

Frying, with chip color determinations, is useful as it gives the most obvious answer regarding a progeny's chip-processing ability at a given time. Due to the increased time, labor, and tuber numbers required to do an adequate evaluation, this method is best used when the number of lines being evaluated in a breeding program is

significantly decreased. In the MSU program, this would occur at the 8-hill stage, about 3 years into the cycle and at the single-hill stage if numbers are not too large (> 1000).

The Yellow Springs Instrument (YSI) requires the greatest investment in time, labor, and expense. This method may be best used when a given progeny has been shown to be a good chip-processor when grown over years and locations. This method is useful in determining chip-processing ability after long-term storage. It is also useful for a grower to evaluate the chip-processing status of a given lot of potatoes.

Future Research

Follow-up research to this project could investigate variety comparisons of test tape values and chip-processing ability after various storage periods at 4.4 C/7.2 C/10 C with and without re-conditioning.

Standard chip-processing varieties, non-chip-processing varieties, and those known to possess cold-temperature-processability should be considered as parental material to provide a wide genetic base. The construction of a half-diallel mating pattern, using the same parents would provide valuable information on the segregation of traits associated with chip-processability.

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