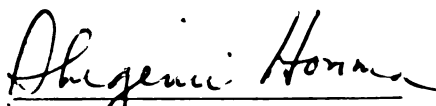


GENETIC RELATIONSHIPS BETWEEN ABOVE-GROUND
PLANT PARTS IN CABBAGE,
(Brassica oleracea var. capitata Linn.)

Dissertation for the Degree of Ph. D.
MICHIGAN STATE UNIVERSITY
WILLIAM LYNN SUMMERS
1977

This is to certify that the
thesis entitled
GENETIC RELATIONSHIPS BETWEEN ABOVE-GROUND
PLANT PARTS IN CABBAGE,
(Brassica oleracea var. capitata Linn.)
presented by
WILLIAM LYNN SUMMERS

has been accepted towards fulfillment
of the requirements for
Ph.D. degree in Horticulture


Major professor

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ABSTRACT

GENETIC RELATIONSHIPS BETWEEN ABOVE-GROUND PLANT PARTS IN CABBAGE, (*Brassica oleracea* var. *capitata* Linn.)

By

William L. Summers

Thirty open-pollinated cabbage cultivars were screened for quantitative traits during 1973. Using an efficiency index, (total non-wrapper leaf weight + stalk size (weight))/(head weight), 2 efficient cultivars, 'Baby Head' and 'Badger Ballhead', and 3 less efficient cultivars, 'Red Danish', 'Chieftain Savoy' and P.I. 215514, were hybridized to obtain F_1 and F_2 populations using a NC II design. For the selected cultivars, data were collected on the effects of 1 generation of inbreeding. Three plantings of the F_1 population and 2 plantings of the F_2 population were made for this study. Narrow sense heritability, genetic correlation and direction of dominance determinations were made. F_2 segregation ratios for 7 traits including maturity, head weight, total non-wrapper leaf weight, stalk size, non-wrapper leaf number, efficiency index and non-wrapper leaf size were compared to weighted ratios produced by postulated models.

Crosses involving the cv. Red Danish generally exhibited dominance patterns which were opposite to patterns observed in crosses involving only green cabbage cultivars. A digenic model with 5 alleles per loci

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is proposed for each trait. Higher heritability estimates were observed for green cabbage crosses than for red x green cabbage crosses. Heritability estimates suggest that progress could be made in selecting for better plant efficiency, since most of the desirable traits, i.e., increased head weight, reduced days to maturity, and reduced total non-wrapper leaf weight and number were dominant in this study. Genetic correlations suggest progress can be made with 2 or 3 traits by selecting for a trait that is highly correlated with these traits. Added inbreeding of open pollinated cabbage cultivars may be desirable for studies of head weight, total non-wrapper leaf weight, non-wrapper leaf number and efficiency index. Studies of maturity, stalk size and non-wrapper leaf size did not require inbreeding in this study.

**GENETIC RELATIONSHIPS BETWEEN ABOVE-GROUND PLANT PARTS
IN CABBAGE, (*Brassica oleracea* var. *capitata* Linn.)**

**By
William Lynn Summers**

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

DOCTOR OF PHILOSOPHY

Department of Horticulture

1977

To Kent L. Phillips
without whose help and motivation the data
collection phase of this study would not have been possible.

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I would like to thank Dr. Shigemi Honma for his guidance and encouragement throughout this study. The writer also wishes to express his appreciation to Drs. L. R. Baker, J. L. Gill, J. W. Hanover, B. B. Dean, and H. C. Price for their interest and suggestions. Special thanks is due to those people without whose help this study could never have been completed including: Amos Lockwood, for his field assistance and council, Kent Phillips, for his help in harvest and data collection, vegetable breeding graduate students who provided suggestions and encouragement, and my wife, Sylvia for her continued understanding and patience.

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INTRODUCTION

Energy and food shortages have placed increased emphasis on the efficient use of existing resources to produce greater amounts of food. Vegetable cultivars grown during a time of abundant energy and low cost fertilizer may no longer provide the yield per acre or profit needed to provide income. In an attempt to evaluate existing vegetable cultivars and to breed new lines with greater efficiency and less waste i.e., (unsalable above ground portion - kg / salable above ground portion - kg) open-pollinated cabbage was selected as a crop system for such a study.

Presently, the breeding of cabbage for yield is based on information derived from crosses made between green non-savoyed lines. Development of red and savoy cabbage cultivars is also dependent on the same information. If previous studies represent an adequate sample of genes and gene action for all cabbage cultivars, then, inbreeding of cabbage would be ideally suited to create efficient lines for hybrids since large head weight, few non-wrapper leaves and small non-wrapper leaf size are transferred as dominant traits. Experiments to increase cabbage efficiency by reducing plant parts such as stalk size and total non-wrapper leaf weight and to maximize other plant parts such as head weight have not been undertaken in cabbage.

The objectives of this study were:

1. Collect data on above-ground plant parts in cabbage to provide information for future breeding programs.

2. Test whether inbreeding is necessary prior to using open-pollinated cabbage varieties in an inheritance study.
3. Determine whether inheritance patterns of above-ground plant parts are similar for red and green cabbage with either a smooth or savoy leaf.
4. Provide paternal half sib heritability estimates for individual above-ground plant traits and genetic correlation estimates for pairs of these traits.
5. Simulate a breeding program using the heritability and genetic correlation estimates to provide estimates of expected genetic gain.

REVIEW OF LITERATURE

Although cabbage is widely planted and consumed in many areas of the world, genetic investigations have been limited to studies of maturity, head weight, non-wrapper leaf number and various head dimensions. These studies were further limited to smooth-leaf types of green cabbage.

Detjen and McCue (5) found that open-pollinated lines possessed variation for horticultural characters even when released for commercial use and that selection for plant type and color could be practiced in these lines. These authors also noted large phenotypic differences in quantitative characters between years and concluded that environment played a large role in the phenotypic expression of cabbage. They also found that non-wrapper leaf size was directly related to head and stalk size and realized that selection for one of these traits may predetermine the other two. Pearson (20) found environment played a large role in head formation and non-wrapper leaf production. Hot weather promoted greater non-wrapper leaf number at the expense of early head maturity. He also found a low number of non-wrapper leaves to be dominant to a large number of non-wrapper leaves and noted a direct correlation between days to maturity and head weight. In 1956 Yarnell (37) found small numbers of non-wrapper leaves were completely dominant. He also noted that head weight was only mildly affected by inbreeding depression. He also reported that earliness was dominant to later maturing cultivars. In a study of growing media on transplant

performance, Honma (9) reported that certain cultivars were more efficient at producing heads than others. Using a half diallel with 6 open-pollinated commercial cultivars, inbred 2 additional generations, Swarup *et al.* (33) found early maturity and large head weight were both dominant to late maturity and small head weight. Research in India and Canada by Swarup *et al.* (32) and Chiang (3) showed close agreement in spite of widely different environments. Swarup *et al.* (32) found heritabilities for maturity, head weight and non-wrapper leaf number were 0.80, 0.37, and 0.52 respectively while Chiang (3) using a full 5 parent diallel in Canada found heritabilities for these traits to be 0.83, 0.04, and 0.35. Dickson and Stamer (7) found heritability for percent dry matter in cabbage to be between 0.5 and 0.6. Their research also noted a direct correlation between high dry matter content and resistance to frost damage.

At present, genetic information for red and savoy cabbage consists of genetic models for red leaf color inheritance proposed by Sutton (31), Kristofferson (13), and Pease (21) and for savoy leaf inheritance by Swan (14), Rasmusson (24), and Tschermak (35). Currently, genetic improvement in red and savoy cabbage lines is based on research done only on green cabbage cultivars with smooth leaves.

A better understanding of inheritance patterns for total basal leaf weight and leaf number could possibly lead to solutions for other cabbage problems. Maynard (18) attributes tipburn in cabbage to an accumulation of Ca, Mg and K in basal leaves. The absence of a rapid transfer path for these ions from older basal leaves to younger head leaves is thought to increase tipburn incidence. Wiebe *et al.* (36) have shown that the high transpiration of basal leaves depletes meristem water

supply causing a reduction in both plant volume and plant growth during the day. Night time reductions in transpiration allow a more favorable plant water balance and resumption of plant growth. Ion mobility studies by Plazkill *et al.* (19) using ^{45}Ca , lend support for a link between basal leaf transpiration rate and increased tipburn in cabbage. Cabbage trait correlation studies by Sharma *et al.* (28), suggest that selection for a reduced number of non-wrapper leaves may produce an appreciable increase in head weight. With new knowledge of inheritance patterns for leaves it may be possible to reduce both the number and size of basal leaves and minimize tipburn in cabbage without sacrificing total head production.

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MATERIALS AND METHODS

Screening Studies

During the summer of 1973, 1 Plant Introduction (P.I.) and 29 open-pollinated cultivars of cabbage, a random sample of open-pollinated cultivars, were screened for parental material. The varieties were seeded in peat pots filled with soil in a greenhouse. The seedlings were watered and fertilized as needed. When the stems reached a diameter of 4-5 mm the plants were moved out-of-doors for hardening. One month after seeding the plants were transplanted in the field in a randomized complete block design with 5 replications and 5 plants per plot. The plants were transplanted 0.46 m apart in the row and 1.07 m between rows. As the plants approached maturity, the lines were tested by thumb pressure to determine maturity. Head formation began in late August and by mid-September the wrapper leaves of some lines began to slip. The heads of these lines were firm and were harvested by cutting the plant at ground level. Plants were harvested daily after mid-September.

Recorded data included harvest date, individual weights for the head, stalk, and non-wrapper leaves and the number of non-wrapper leaves.

Parental selection was based on a cabbage plant efficiency index, $(\text{total non-wrapper leaf weight} + \text{stalk size (weight)})/(\text{head weight})$. This measurement provided the number of kg of non-wrapper leaves and stalk required to produce a kg of head. Using this method the 30 cultivars were ranked from efficient (Figure 1) to least efficient (Figures

**Figure 1. The efficient cultivar Baby Head: A - cabbage head;
B - non-wrapper leaves; C - stalk.**



**Figure 2. The inefficient cultivar P.I. 215514: A - cabbage head;
B - non-wrapper leaves; C - stalk.**



**Figure 3. The inefficient cultivar Chieftain Savoy: A - cabbage head;
B - non-wrapper leaves; C - stalk.**



2-3). The 2 most efficient cultivars and the 3 least efficient cultivars were selected as parents (Table 1). Single plant selections of each of these cultivars were vernalized for 13 weeks at 4°C to induce flowering.

Crossing Scheme

The crossing scheme used in this study was the North Carolina "Factorial" Design II (NCII) proposed by Comstock and Robinson (4). This design was chosen because it produced the maximum amount of genetic information per family group evaluated (10, 22). The design required division of the parents into 2 groups: lines to be used as males and lines to be used as females. In this study single plant selections of 'Badger Ballhead', P.I. 215515, and 'Chieftain Savoy' were used as males while single plant selections of 'Baby Head', and 'Red Danish' were used as females. Each female line was reciprocally crossed to each male line. These 6 reciprocal combinations constituted the F_1 population. Four F_1 seedlings of each cross were randomly selected, grown, vernalized and selfed to provide the F_2 population. Each of the cultivars were vegetatively propagated to facilitate reciprocal backcrosses.

Incompatibility was encountered and resulted in a limited backcross (BC_1 & BC_2) population. Original seedlots of each of the cultivars were also grown in each test and were designated the P_1 population. Each parental plant was selfed once (S_1 population) and was planted in each test (Table 2). The parental populations P_1 and S_1 were analyzed to determine the effect of 1 generation of inbreeding. Estimates of genetic variance components, heritabilities within traits and estimates of genetic correlation between traits for each of the 3 F_1 plantings were made using the NCII analysis and covariance, correlation techniques described by Kempthorne (11). Frequency distributions of the 12 F_2

Table 1. Efficiency index for 30 cabbage cultivars grown in 1973.

Cultivar	Mean* Efficiency Index		
Baby Head	0.3569	a	**
Badger Ballhead	0.4795	ab	**
Early Jersey Wakefield	0.4885	ab	
Badger Market	0.5020	ab	
Greenback	0.5216	abc	
Early Marvel	0.5305	abc	
Metor	0.5313	abc	
Copenhagen Market Early	0.5376	abc	
Stokes Wisconsin Ballhead	0.5496	abc	
Emerald Acre	0.5664	abc	
Early Round Dutch	0.5725	abc	
Bonanza	0.6043	abc	
Early Greenball	0.6248	abc	
Copenhagen Market Late	0.6570	abcd	
Red Acre	0.6570	abcd	
Savoy Cabbage	0.6635	abcd	
Stokes Super Acre	0.6787	abcd	
Stokes Viking Golden Acre	0.6817	abcd	
Green Acre	0.6902	abcd	
Jumbo	0.6922	abcd	
Viking Extra Early Strain	0.7268	abcd	
Autumn Marvel	0.7657	abcd	
Penn. State Ballhead	0.7869	abcd	
Danish Ballhead	0.8600	bcd	
Golden Acre 84	0.9970	cde	
Wisconsin Hallander No. 8	1.1080	de	
Eastern Ballhead	1.1157	de	
Red Danish	1.3316	e	**
Chieftain Savoy	1.3714	e	**
P. I. 215514	2.0312	f	**

* Means followed by the same letter are not significantly different at the 5% level by Duncan's Multiple Range Test.

** Selected as parents.

Table 2. Plant populations grown.

Plant Population	1974 Late	Plantings 1975 Early	1975 Late
P_1	*	*	*
S_1	*	*	*
F_1	*	*	*
F_2		*	*
BC_1		*	
BC_2		*	

populations were compared with the P_1 and F_1 distributions, to determine inheritance patterns.

1974 Field Experiments

A randomized complete block experiment with 3 replicates was planted. Seed from the P_1 , S_1 , and F_1 populations were planted in greenhouse flats on June 28. Seedlings were mechanically transplanted 4 weeks later. Harvest began October 26 and ended November 20. A total of 1625 plants were harvested. The thumb pressure method was used to determine maturity. Other measures of maturity were used to obtain an objective measurement. These included: 1) pressure testing each cabbage head 4 times with a Magness-Taylor Penetrometer (16) and recording the pounds of force required for a 3/16" probe to penetrate 1/2" into the head and, 2) use of water displacement to determine head volume and density. Penetrometer head measurements increased to a peak and remained constant prior to over-maturity or bursting. Density readings increased toward 1.0 as air spaces inside the head diminished with maturity. These 2 measures were correlated to determine how well pressure readings predict density measures. For the 1625 cabbage heads measured, the correlation between the mean of 4 pressure readings per head and head density was a highly significant ($P < 0.01$) $r = 0.32$.

1975 Field Experiments

Two plantings were made. The first planting included the P_1 , S_1 , F_1 , F_2 , BC_1 and BC_2 populations. The second planting included all populations except the BC_1 and BC_2 populations. Each planting was a randomized complete block with 3 replications. The first planting was seeded in a cold frame with heating cable on May 5. The second planting

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was seeded on May 29. All seedlings were mechanically transplanted in the field. Harvesting began on August 9 for the early planting and on October 20 for the late planting. Above-ground plant parts were harvested when the mean reading of 2 penetrometer punches was equal to or exceeded the appropriate parent or midparent mean penetrometer reading determined in 1974. In addition each plant was classified for leaf color: red or green, for leaf type: normal or savoy, and for head shape: drum, pointed or flat. There were 7 dependent variables included for analysis (Table 3).

Cultivar Inbreeding Analysis

Because hybrids in genetic research should be both genotypically and phenotypically homogeneous, open-pollinated cultivars should be tested to measure their degree of homozygosity. Since the degree of homozygosity for each cultivar was unknown, analysis of variance (AOV) tests were applied to plot means of the P_1 and S_1 populations within each planting to determine whether added inbreeding significantly affected the mean performance of plant traits in this study. Comparisons were also made for cultivar variance across and within inbreeding levels to provide a measure of parental homozygosity assuming some dominant gene action was present. Cultivars with low variances possess greater homozygosity and phenotypic stability than do cultivars with large variances. Homozygous parents provide greater precision in estimating segregation ratios and environmental variance from F_1 and F_2 data. These tests provided a way of determining whether added inbreeding, as previously practiced (33), was actually required for this study. This AOV is shown in Table 4.

Table 3. Dependent variables used in this study.

Dependent Variable	Units of Measure	Variable Code
1. Days from transplanting to harvest	Days	Maturity
2. Head weight	Kilograms	Head Wt
3. Total non-wrapper leaf weight	Kilograms	Total Leaf Wt
4. Stalk size	Kilograms	Stalk Size
5. Non-wrapper leaf number	Leaves	Leaf No.
6. Efficiency Index (3 + 4) / (2)		E. I.
7. Non-wrapper leaf size	Kilograms	Leaf Size

Table 4. Analysis of variance for cultivar, inbreeding and planting effects. $Y_{hijkl} = \mu + \alpha_i + \beta_j + (\alpha\beta)_{ij} + \gamma_k + (\alpha\gamma)_{ik} + (\beta\gamma)_{jk} + (\alpha\beta\gamma)_{ijk} + R_h + e_{hijkl}$: Z_{hijk} will denote plot means in the k-th planting with μ common to all observations. α_i is the effect of cultivar, β_j is the effect of inbreeding, γ_k is the effect of planting and R_h is the effect of the h replication. The term e_{hijk} denotes error.

Source	Df	SS	MS	F
Total	60	$\sum_{hijk} z_{hijk}^2$		
CF	1	$\frac{z_{\dots}^2}{(3)(5)(2)(2)}$		
Replication (R)	2	$\sum_h \frac{z_{h\cdot\cdot\cdot}^2}{(3)(5)(2)} - CF$	SSR/2	
Cultivar (C)	4	$\sum_i \frac{z_{i\cdot\cdot\cdot}^2}{(3)(2)(2)} - CF$	SSC/4	MSC/MSE
Inbreeding (I)	1	$\sum_j \frac{z_{\cdot\cdot j\cdot\cdot}^2}{(3)(5)(2)} - CF$	SSI/1	MSI/MSE
(C) x (I)	4	$\sum_{ij} \frac{z_{\cdot\cdot ij\cdot}^2}{(3)(2)} - CF - SSC - SSI$	SSCI/4	MSCI/MSE
Planting (P)	1	$\sum_k \frac{z_{\cdot\cdot\cdot k}^2}{(3)(5)(2)} - CF$	SSP/1	MSP/MSE

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Table 4. (cont'd)

Source	Df	SS	MS	F
(C) x (P)	4	$\sum \sum_{ik} \frac{Z_{i.k}^2}{(3)(2)} - CF - SSC - SSP$	SSCP/4	MSCP/MSE
(I) x (P)	1	$\sum \sum_{jk} \frac{Z_{.jk}^2}{(3)(5)} - CF - SSI - SSP$	SSIP/1	MSIP/MSE
(C) x (P) x (I)	4	$\sum \sum \sum_{ijk} \frac{Z_{ijk}^2}{(3)} - CF - SSC - SSI - SSP - SSCI - SSCP - SSIP$	SSCPI/4	MSCPI/MSE
Error	38	$SST - CF - SSC - SSI - SSCI - SSCP - SSIP - SSP - SSCPI$	SSE/38	

Parental, Midparent, F_1 and F_2 Mean Analysis

For each trait studied, reciprocal F_1 and F_2 population means were compared to their appropriate parent and midparent means to determine maternal inheritance, additive and dominant gene action, degree and direction of dominance and the presence of abnormal gametic transmission. Evidence of maternal inheritance was noted where reciprocal F_1 population means significantly differed. The presence of either additive or dominant gene action was determined by comparing the reciprocal F_1 means with the appropriate midparent mean. The larger the difference between each F_1 and midparent mean, the greater the action of dominant genes. The closer each F_1 and midparent mean were, the greater the action of additive genes. The direction of dominance is toward the parent closest to the F_1 mean. Abnormal gametic transmission can be shown if differences exist between the F_1 and F_2 means.

Variance Component Analysis

Analysis was conducted on data from 3 plantings of the F_1 population. Although attempts were made to have each F_1 plot mean represented by an equal number of plants, poor seed production on some crosses and field losses due to inclement weather in 1975 contributed non-orthogonal data. Initial analysis of the means for F_1 data showed large differences between planting time, reciprocal crosses and female parents. Appropriate AOV tests were made to find whether these differences were significant. Based on these tests, the data were separated by planting time, reciprocal cross and female parent to provide 12 unique data groups each representing 3 F_1 crosses and 3 replications (Table 5). Within each data group, F_1 plants were related as paternal half sibs. Variance

Table 5. F_1 data separation for variance component analysis. Twelve (12) data groups each composed of nine elements, three crosses by three replications.

Plantings	1974 Late			1975 Early			1975 Late					
Cross Type	Reciprocal			Reciprocal			Reciprocal					
Original Male	Baby Head	Red Danish	Baby Head	Red Danish	Original Female Baby Head	Red Danish	Baby Head	Red Danish	Baby Head	Red Danish		
Badger Ballhead	3*	3	3	3	3	3	3	3	3	3		
P.I. 215514	3	3	3	3	3	3	3	3	3	3		
Chieftain Savoy	3	3	3	3	3	3	3	3	3	3		
Data Group	1	2	3	4	5	6	7	8	9	10	11	12

* 3 replications

component analysis was completed for each of the 12 data groups using one AOV based on unbalanced plot means and a second AOV based on individual data (1, 11). The variance components of this analysis are shown in Table 6. The first analysis provided estimates of paternal and between-plot variance. The second analysis provided a combined estimate of 3/4 additive genetic variance and environmental variance between full sib related individuals in the same plot. Use of the paternal variance and the variance from the second analysis provided estimates of heritability based on paternal half sib data.

Covariance, Correlation Analysis

Covariance and genetic correlations were calculated by taking the data for 7 traits and adding traits together in combinations of 2 without replacement to provide 18 new "traits" (Table 7). These new traits were analyzed using variance component AOV #1. Results of the AOV #1 tests for the original and combined traits (Table 8) were substituted into appropriate formula (11) to provide estimates of genetic correlation and covariance between traits. These formulas were derived from the following assumptions:

- 1) Expectations from Table 8 are:

$$E(V_u) = \sigma_{eu}^2 + r\sigma_{gu}^2$$

$$E(V_y) = \sigma_{ey}^2 + r\sigma_{gy}^2$$

$$E(V_z) = \sigma_{ez}^2 + r\sigma_{gz}^2$$

$$E(E_u) = \sigma_{eu}^2$$

Table 6. Variance component analysis for F_1 data. $Y_{ijk} = \mu + \alpha_i + R_j + e_k$: Z_{ij} denotes use of plot means in this analysis.

AOV #1				
Source	Df	SS	MS	EMS
Total	(R)(M)	$\sum_{ij} Z_{ij}^2$		
CF	1	Z^2 $\overline{RM}$		
Replication	R-1	$\frac{\sum_j Z_{.j}^2}{M} - Cf$	Rss/R-1	
Males	M-1	$\frac{\sum_k Z_{i.}^2}{R} - Cf$	Mss/M-1	$\sigma_C^2 + n_k \sigma_W^2 + R \sigma_m^2$
Error 1	(R-1)(M-1)	Tss-Cf-Rss-Mss	Ess/(R-1)(M-1)	$\sigma_C^2 + n_k \sigma_W^2$ *

Table 6. (cont'd)

AOV #2

Source	Df	SS	MS	EMS
Between Plots	$((R)(M)-1)$	$\sum_{ij} \frac{Y_{ij}^2}{n_{ij}} - Cf_{individual}$		
Within Plots	$n_{....} - (R)(M)$	$\sum_{ijk} Y_{ijk}^2 - \sum_{ij} \frac{Y_{ij}^2}{n_{ij}}$	$Wss/n_{....} - (R)(M)$	σ_w^2

* where $n_k = (1/RM)(\sum_{ij} \frac{1}{n_{ij}})$: Reciprocal of the harmonic mean of the individuals per plot.

Table 7. Seventeen trait combinations generated by adding data on one trait to data for another trait from the same cabbage head.

Original Trait	Original Trait	New Trait
Maturity	Head Wt.	U1
Maturity	Total Leaf Wt.	U2
Maturity	Stalk Size	U3
Maturity	Leaf Num.	U4
Maturity	E. I. *	U5
Maturity	Leaf Size	U6
Head Wt.	Total Leaf Wt.	U7
Head Wt.	Stalk Size	U8
Head Wt.	Leaf Num.	U9
Head Wt.	Leaf Size	U10
Leaf Wt.	Stalk Size	U11
Leaf Wt.	Leaf Num.	U12
Leaf Wt.	Leaf Size	U13
Stalk Size	Leaf Num.	U14
Stalk Size	Leaf Size	U15
Leaf Num.	E. I.	U16
Leaf Num.	Leaf Size	U17

* Efficiency index

Table 8. Genetic covariance and correlation analysis from AOV #1.

Source	df	Mean Squares			Mean Product
		Trait y	Trait z	Trait u=y+z	
Males	(R-1)	V_y	V_z	V_u	$V_{yz} = 1/2(V_u - V_y - V_z)$
Error 1	(R-1)(M-1)	E_y	E_z	E_u	$E_{yz} = 1/2(E_u - E_y - E_z)$

$$E(E_y) = \sigma_{ey}^2$$

$$E(E_z) = \sigma_{ez}^2$$

2) Therefore variance estimates were as follows:

$$A) \sigma_{gy}^2 = 1/r (V_y - E_y)$$

$$B) \sigma_{gz}^2 = 1/4 (V_z - E_z)$$

$$C) \sigma_{gyz} = 1/r (V_{yz} - E_{yz})$$

$$D) \sigma_{ey}^2 = E_y$$

$$E) \sigma_{ez}^2 = E_z$$

$$F) \sigma_{eyz} = E_{yz}$$

3) Which produces an estimate of genotypic correlation:

$$\rho_{gyz} = \frac{\sigma_{gyz}}{(\sigma_{gy}^2 \sigma_{gz}^2)^{1/2}} = \frac{C}{\sqrt{(A)(B)}}$$

4) And an estimate of the error correlation of y and Z:

$$\rho_{eyz} = \frac{\sigma_{eyz}}{(\sigma_{ey}^2 \sigma_{ez}^2)^{1/2}} = \frac{F}{\sqrt{(D)(E)}}$$

F₂ DATA ANALYSIS:

Individual F₂ frequency classes were produced by grouping small segments of F₂ data. Since most data occurred in frequency groups, i.e., 1,1,1; 0,0; 4,3,4; etc., groups with similar numbers could be pooled, i.e., 1, 0, 4. This pooling technique showed that a majority of groups were pooled over a fixed number of quantitative units. F₂ frequency distributions were redefined by dividing the range of data into groups of fixed length. This system provided groupings based on units of 0.49, 1, 2, 4, etc. Estimates of the number of genes involved and the location of phenotypic boundaries were provided using techniques developed by Powers *et al.* (23) and outlined by Leonard *et al.* (15). An estimate of the number of genes involved was provided by sequentially summing and comparing frequency percentages from the recessive parent and the F₂ distribution. The formula $(F_2/P_1) (100)$ was used. Estimates of 6.25 suggest a 2 gene model while a single gene model might produce a result of 25.0. Sequential results usually fluctuate around a given percentage, i.e., 25.0. or 6.25. A sudden increase in the formula estimate suggests the boundary for the recessive phenotype has been passed. Cultivar, F₁, and backcross means were also used in defining class boundaries. Theoretical ratios for F₂ populations were calculated normally if parental distributions did not overlap. Overlapping cultivar distributions were considered in the calculation of theoretical F₂ ratios by the use of a weighting factor. The weighting factor was calculated by subtracting the absolute value of the net overlap, found by subtracting the percentage of misclassified plants of 1 cultivar from the percentage misclassified from the other cultivar, from 100. This factor was divided by 100, multiplied by the expected frequency

of the deficient class and by the total number of F_2 plants in the sample to produce an expected ratio corrected for F_2 misclassification and cultivar overlap (17). Segregating F_2 populations were tested for heterogeneity prior to pooling the data for comparisons and interpretation. Chi-square tests were used to compare observed and theoretical ratios. In all cases a chi-square significance level of ($P = 0.05$) was used. The probability of rejecting a genetic model when it was correct was 5 per cent. Backcross ratios were also tested and used to support the postulated models.

RESULTS AND DISCUSSION

Populations in this study have been divided into 2 groups which include crosses between red and green cabbage and crosses between 2 green cabbage cultivars. This division was necessary since both groups differed in dominance direction for certain traits and showed further differences in other areas. The results and discussion which follow will show how and in what areas these 2 groups differed.

Maturity

One generation of inbreeding did not affect the maturity of the cultivars; however, significant differences were found between cultivars, plantings and the interaction cultivar x plantings (Table 9). Since no significant differences between inbreeding means were observed maturity may be genetically fixed or dominance may be absent. The significant cultivar x plantings interaction was caused, in part, by different responses to the environment in the 1975 early (E) planting. Two cultivars, Baby Head and Badger Ballhead matured earlier in 1975E than in the 1974 late (L) planting. The other 3 cultivars took longer to mature in the 1975L planting than in 1974L. Sequential plantings of Badger Ballhead should provide an orderly sequential harvest since its maturity is fairly constant for various planting dates. Baby Head appears to mature earlier when planted early in the season. If sequentially planted this cultivar may produce a prolonged harvest period. The other cultivars seem to mature earlier with later planting dates (Table 10).

Table 9. Analysis of variance table for cabbage maturity in days from transplanting to harvest.

Source of Variance	DF	Mean Square	F*
Replication (R)	2	14.16	0.42
Cultivar (C)	4	3190.12	94.22**
Inbreeding (I)	1	75.01	2.22
C x I	4	65.01	1.92
Plantings (P)	2	1413.20	41.74**
C x P	8	848.40	25.06**
I x P	2	6.36	0.19
C x I x P	8	11.34	0.33
Residual Error	58	33.86	

F test significant at the 5%, or 1%** level.

Table 10. Cultivar x planting interaction means in days from transplanting to harvest.

Cultivar	1974L	Plantings 1975E	1975L	Cultivar Means
Baby Head	99.73 b*	72.60 a	114.33 c	95.56 V
Badger Ballhead	107.33 b	100.58 a	115.38 c	107.76 W
P.I. 215514	113.82 a	129.52 b	141.96 c	128.11 Z
Red Danish	112.25 a	124.37 b	117.70 ab	118.11 X
Chieftain Savoy	116.67 a	132.42 c	124.13 b	124.41 Y
Planting Means	109.96 A	111.90 A	122.70 B	

*Mean separation within rows by Duncan's Multiple Range Test at the 5% level.

Early maturity has been reported by Pearson (20) and Rasmusson (24) as dominant. Both the 1975E and 1975L Baby Head x Badger Ballhead F_1 means suggest early maturity is dominant (Tables 11-13). Tables 14 and 15 show frequency distributions in percent for populations involved in this cross. Powers *et al.* (23) partitioning tests were applied to these distributions to determine the number of genes controlling maturity; and, to define the boundary between early and late phenotypic classes. Powers *et al.* (23) formula (F_2/P_2) was applied sequentially from the recessive ends of both the F_2 and P_2 distributions. Using the 1975E F_2 planting of Baby Head x Badger Ballhead (Table 14) as an example, the formula suggested recessive frequencies of 10.4/0 for the 144 day class, 16.4/0 for the 126 day class, 20.4/92.3 or 0.22 for the 104 day class and 53.7/92.3 or 0.58 for the 96 day class. This frequency, 0.22, exhibited close agreement to an expected frequency of 0.25 from a 3:1 model. A monogenic model with a dividing point between the 96 and 104 day classes was proposed (Table 14). The 1975E reciprocal F_2 population produced a different recessive frequency estimate. As in the previous example, the formula (F_2/P_2) suggested frequencies of 13.3/0 for the 144 day class, 14.9/0 for the 126 day class, 28.6/92.3 or 0.31 for the 104 day class and 36.7/92.3 or 0.40 for the 96 day class. The 88 day class produced an estimate of 86.7/92.3 or 0.94. A dividing point between the 88 and 96 day classes seems apparent. The observed frequency of 0.40 shows close agreement to the 0.44 frequency expected from a 9:7 model (Table 14). Since Powers *et al.* (23) tests suggest a 2 locus model for other F_2 populations in this study, a multiple allelic 2 locus system was tested for each population. The postulated loci, *a* and *b*, each have 5 alleles which were inherited in the following manner: for the 1975E planting a_5 was dominant to *a* and

Table 11. 1974L Cultivar and F_1 performance means.

Cultivar	Maturity	Head Wt.	Leaf Wt.	Stalk Size	Leaf Num.	E.I.*	Leaf Size
	Days	kg.	kg.	kg.	Leaves	kg.	kg.
1. Baby Head	99.08	1.14	0.23	0.07	8.25	0.33	0.03
2. Badger	106.96	2.25	1.79	0.28	18.28	1.12	0.10
3. Ballhead							
3. P.I. 215514	113.00	1.74	2.35	0.60	24.00	1.68	0.10
4. Red Danish	108.22	1.26	1.85	0.28	14.80	2.01	0.12
5. Chieftain	116.32	1.55	2.59	0.34	20.30	2.20	0.13
Savoy							
F_1							
1 x 2	99.34	2.22	0.65	0.11	11.96	0.35	0.06
2 x 1	98.39	2.34	0.62	0.11	11.81	0.32	0.05
1 x 3	106.07	3.20	1.34	0.28	13.57	0.51	0.10
3 x 1	103.74	2.98	1.24	0.27	13.45	0.56	0.09
1 x 5	106.60	2.55	1.55	0.26	18.18	0.87	0.08
5 x 1	104.60	2.38	1.39	0.21	18.21	0.76	0.08
4 x 2	106.60	1.24	2.26	0.42	20.72	2.90	0.11
2 x 4	107.74	1.26	2.16	0.43	20.28	2.62	0.11
4 x 3	119.55	0.99	2.70	0.62	20.72	4.34	0.13
3 x 4	114.03	1.51	3.07	0.70	21.16	2.99	0.14
4 x 5	117.14	1.14	2.73	0.49	20.46	3.56	0.13
5 x 4	112.68	1.42	2.98	0.49	21.39	2.96	0.14

*Efficiency Index

Table 12. 1975E Cultivar, F_1 and F_2 performance means.

Cultivar	Maturity	Head Wt.	Leaf Wt.	Stalk Size	Leaf Num.	E.I.*	Leaf Size
	Days	kg.	kg.	kg.	Leaves	kg.	kg.
1. Baby Head	69.36	0.70	0.38	0.09	14.19	0.71	0.03
2. Badger Ballhead	99.38	3.09	1.23	0.26	15.85	0.59	0.08
3. P.I. 215514	129.67	3.29	2.21	0.61	23.78	0.96	0.09
4. Red Danish	121.88	2.15	1.44	0.38	16.43	0.90	0.09
5. Chieftain Savoy	135.94	2.95	1.17	0.32	16.94	0.56	0.07
F_1							
1 x 2	74.93	1.33	0.76	0.14	16.57	0.74	0.05
2 x 1	74.92	1.41	0.71	0.12	16.08	0.65	0.04
1 x 3	95.62	2.99	1.03	0.23	14.12	0.46	0.07
3 x 1	97.33	3.28	1.12	0.23	13.88	0.43	0.08
1 x 5	115.48	2.73	0.78	0.24	12.52	0.48	0.07
5 x 1	120.25	3.37	0.86	0.28	11.52	0.36	0.07
4 x 2	99.21	2.89	1.68	0.34	17.20	0.79	0.10
2 x 4	99.00	2.38	1.68	0.42	18.29	1.00	0.09
4 x 3	112.57	2.91	2.21	0.62	19.65	1.12	0.11
3 x 4	104.89	2.75	2.48	0.68	21.06	1.27	0.12
4 x 5	122.33	3.80	2.27	0.62	19.09	0.90	0.12
5 x 4	123.02	3.36	2.15	0.60	19.68	0.91	0.11
F_2							
1 x 2	96.04	2.05	0.73	0.18	13.73	0.51	0.05
2 x 1	94.68	1.44	0.55	0.13	12.84	0.56	0.04
1 x 3	105.02	2.12	0.78	0.22	13.38	0.49	0.06
3 x 1	106.96	2.76	1.00	0.27	13.26	0.47	0.07
1 x 5	119.48	2.51	0.71	0.22	11.39	0.38	0.06
5 x 1	117.39	2.38	0.73	0.23	14.57	0.45	0.05
4 x 2	123.84	2.34	1.45	0.45	19.24	0.91	0.08
2 x 4	119.21	2.33	1.46	0.41	19.03	0.96	0.08
4 x 3	-	-	-	-	-	-	-
3 x 4	122.92	2.65	2.12	0.69	21.49	1.34	0.10
4 x 5	126.11	2.74	1.97	0.58	20.13	1.08	0.10
5 x 4	131.46	2.56	2.28	0.68	21.46	1.47	0.11

*Efficiency Index

Collective

1. Bad

2. Bad

3. Bad

4. P.I.

4. Red

5. Chie

Savo

F.

1

1 x 2

2 x 1

1 x 3

3 x 1

1 x 5

5 x 1

4 x 2

2 x 4

4 x 3

3 x 4

4 x 5

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2

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1

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5

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Collector

Table 13. 1975L Cultivar, F_1 and F_2 performance means.

Cultivar	Maturity	Head Wt.	Leaf Wt.	Stalk Size	Leaf Num.	E.I.*	Leaf Size
	Days	kg.	kg.	kg.	Leaves	kg.	kg.
1. Baby Head	113.23	0.84	0.06	0.07	3.08	0.17	0.02
2. Badger Ballhead	114.26	2.12	0.43	0.21	10.14	0.35	0.04
3. P.I. 215514	142.00	3.60	1.96	0.69	19.23	0.87	0.10
4. Red Danish	114.69	1.12	0.64	0.19	11.12	0.90	0.05
5. Chieftain Savoy	127.51	1.24	0.65	0.23	15.14	0.84	0.04
F_1							
1 x 2	112.79	1.37	0.35	0.11	9.55	0.33	0.03
2 x 1	114.88	1.35	0.12	0.15	3.87	0.35	0.03
1 x 3	114.70	1.79	0.29	0.21	7.88	0.30	0.04
3 x 1	114.49	2.06	0.37	0.25	8.48	0.32	0.04
1 x 5	138.25	2.24	0.37	0.18	9.80	0.32	0.04
5 x 1	121.74	2.03	0.25	0.16	7.24	0.24	0.03
4 x 2	112.48	1.42	0.52	0.26	12.74	0.84	0.04
2 x 4	115.84	1.00	0.53	0.23	13.42	1.09	0.04
4 x 3	121.00	1.62	0.83	0.47	15.00	1.34	0.05
3 x 4	125.14	0.94	1.13	0.37	20.25	1.98	0.06
4 x 5	112.46	1.67	0.92	0.26	9.32	0.84	0.10
5 x 4	112.30	1.79	0.89	0.26	8.57	0.70	0.10
F_2							
1 x 2	114.31	1.27	0.17	0.13	5.82	0.27	0.03
2 x 1	114.08	1.07	0.17	0.11	5.94	0.29	0.03
1 x 3	116.43	1.10	0.36	0.19	9.98	0.66	0.04
3 x 1	114.62	1.45	0.33	0.19	8.68	0.44	0.04
1 x 5	114.79	1.56	0.26	0.16	7.40	0.30	0.03
5 x 1	119.98	1.23	0.26	0.13	8.70	0.41	0.03
4 x 2	116.30	0.99	0.65	0.26	14.43	1.29	0.04
2 x 4	113.80	1.06	0.67	0.32	13.60	1.04	0.04
4 x 3	-	-	-	-	-	-	-
3 x 4	-	-	-	-	-	-	-
4 x 5	125.71	1.11	0.86	0.33	17.54	1.54	0.05
5 x 4	121.28	1.00	0.94	0.33	18.19	1.73	0.05

*Efficiency Index

Table 14. Parent, F_1 , F_2 and backcross maturity distributions in percent for the 1975E planting of the cross Baby Head x Badger Ballhead.

	No. of Plants	Days From Transplanting to Harvest Upper Limit of Class							Mean
		72	80	88	96	104	126	144	
Baby Head (P_1)	42	92.8		7.1					69 ± 5
Badger Ballhead (P_2)	39	7.7				92.3			99 ± 9
(P_1 x P_2)	83	60.2	30.2	4.8			4.8		75 ± 13
(P_2 x P_1)	89	44.9	50.6	3.4	1.1				75 ± 6
(P_1 x P_2) F_2	252	1.6		44.8	33.3	4.0	6.0	10.4	96 ± 17
(P_2 x P_1) F_2	248	6.0	7.2	50.0	8.1	13.7	1.6	13.3	95 ± 20
(P_2 x P_1) x P_2	33			15.2	60.6	18.2		6.0	96 ± 12

Table 15. Parent, F_1 and F_2 maturity distributions in percent for the 1975L planting of the cross Baby Head x Badger Ballhead.

Days From Transplanting to Harvest Upper Limit of Class													
No. of Plants	110	111	112	114	115	116	118	119	136	139	Mean		
Baby Head (P_1)	53	28.3		32.1	39.6						113 ±	2	
Badger Ballhead (P_2)	49		32.6	32.6		26.6	4.1	4.1			114 ±	3	
($P_1 \times P_2$)	38	63.2		5.3	21.0		10.5				113 ±	3	
($P_2 \times P_1$)	77			27.3	40.2	29.9		2.6			115 ±	1	
($P_1 \times P_2$) F_2	130		36.9	17.7	10.0		14.6	5.4	7.7	1.5	6.2	114 ±	7
($P_2 \times P_1$) F_2	211		16.6	14.2	25.6	15.6	11.4	1.9	10.9			114 ±	5

A was dominant to a_3 and a_4 . In 1975E, red x green cabbage crosses a_5 was dominant to a_2 and a_2 was dominant to a_3 and a_4 . The b locus was inherited in the same manner as the a locus. Allelic inheritance patterns for the 1975L planting suggest a was dominant to a_3 , a_4 and a_5 for green cabbage crosses. In red x green cabbage crosses a_2 was dominant to a_3 , a_4 and a_5 . The b locus was inherited in a similar manner. Postulated genotypes for each cultivar and F_1 are shown in Tables 16 and 17. In cases where parental distributions overlap, a weighting factor was used to weight the expected segregation ratio. The 1975E planting of Baby Head x Badger Ballhead will again be used as an example (Table 14). For a division point of 96 days, the parental distributions suggest that Badger Ballhead produces less than 100% of its plants in the same phenotypic class. This class, lateness will be deficient when F_2 segregation ratios are obtained. In this study, the net overlap, 7.7%, was subtracted from 100%, divided by 100 and multiplied by the expected probability of the deficient class and the total number of F_2 plants sampled to obtain an expected segregation ratio. The number of recessive plants was $((100-7.7)/100)(0.25)(252) = 58.15$. The number of dominant plants was found by subtraction, $(252-58.15) = 193.85$. The observed F_2 segregation ratio of 201:51 for the 1975E planting of Baby Head x Badger Ballhead fits ($P=0.23$) the expected 193.85 early maturity ; 58.14 late maturity expected from a weighted 3:1 segregation ratio (Table 18). The 3:1 segregation ratio suggests that the presence of a single A allele in the genotype produces an early phenotype. The dominant A allele was contributed by Baby Head ($AABB$) while the recessive genotype $a_3a_3b_3b_3$ was contributed by Badger Ballhead. The reciprocal F_2 populations were significantly different. The observed ratio of 157

Table 16. Postulated cultivar genotypes for the 1975E planting.

Cultivar	Genotype*
Baby Head	A A B B C C d d E E G G H H I I J J K K L L m m N N O O
Badger Ballhead	a ₃ a ₃ b ₃ b ₃ C ₃ C ₃ D ₃ D ₃ E ₃ E ₃ G ₃ G ₃ H ₃ H ₃ I ₃ I ₃ J ₃ J ₃ K ₃ K ₃ L ₃ L ₃ M ₃ M ₃ N ₃ N ₃ O ₃ O ₃
P.I. 215514	a ₄ a ₄ b ₄ b ₄ C ₄ C ₄ D ₄ D ₄ E ₄ E ₄ G ₄ G ₄ H ₄ H ₄ I ₄ I ₄ J ₄ J ₄ K ₄ K ₄ L ₄ L ₄ M ₄ M ₄ N ₄ N ₄ O ₄ O ₄
Red Danish	A ₂ A ₂ B ₂ B ₂ C ₂ C ₂ D ₂ D ₂ E ₂ E ₂ G ₂ G ₂ H ₂ H ₂ I ₂ I ₂ J ₂ J ₂ K ₂ K ₂ L ₂ L ₂ M ₂ M ₂ N ₂ N ₂ O ₂ O ₂
Chieftain Savoy	A ₅ A ₅ B ₅ B ₅ C ₅ C ₅ D ₅ D ₅ E ₅ E ₅ G ₅ G ₅ H ₅ H ₅ I ₅ I ₅ J ₅ J ₅ K ₅ K ₅ L ₅ L ₅ M ₅ M ₅ N ₅ N ₅ O ₅ O ₅

*a, b = Late Maturity
 C, D = Large Head
 e, g = Heavy Total Leaf Weight
 h, i = Large Stalk Size
 j, k = Many Leaves
 l, m = Inefficient
 n, o = Large Leaf Size

Table 17. Postulated F₁ genotypes for the 1975E planting.

Cultivar	Genotype*
Baby Head x Badger Ballhead	A a ₃ B b ₃ C c ₃ d ₃ E e ₃ G g ₃ H h ₃ I i ₃ J j ₃ K k ₃ L l ₃ ^m M m ₃ N n ₃ O o ₃
Baby Head x P.I. 215514	A a ₄ B b ₄ C c ₄ d ₄ E e ₄ G g ₄ H h ₄ I i ₄ J j ₄ K k ₄ L l ₄ ^m M m ₄ N n ₄ O o ₄
Baby Head x Chieftain Savoy	A A ₅ B B ₅ C c ₅ d ₅ E e ₅ G g ₅ H h ₅ I i ₅ J j ₅ K k ₅ L l ₅ ^m M m ₅ N n ₅ O o ₅
Red Danish x Badger Ballhead	A ₂ a ₃ B b ₃ C c ₃ D d ₃ e e ₃ g g ₃ H h ₃ I i ₃ J j ₃ K k ₃ L l ₃ ^m M m ₃ N n ₃ O o ₃
Red Danish x P.I. 215514	A ₂ a ₄ B b ₄ C c ₄ D d ₄ e e ₄ g g ₄ H h ₄ I i ₄ J j ₄ K k ₄ L l ₄ ^m M m ₄ N n ₄ O o ₄
Red Danish x Chieftain Savoy	A ₂ A ₅ B B ₅ C c ₅ D d ₅ e e ₅ g g ₅ H h ₅ I i ₅ J j ₅ K k ₅ L l ₅ ^m M m ₅ N n ₅ O o ₅

*a, b = Late Maturity

C, D = Large Head

e, g = Heavy Total Leaf Weight

h, i = Large Stalk Size

j, k = Many Leaves

l, m = Inefficient

n, o = Large Leaf Size

Table 18. Chi-square test for goodness of fit to the postulated model for maturity in the F_2 generation (1975E planting).

Cross	Observed	Expected	Model	χ^2	P
Baby Head x Badger Ballhead					
F_2	201: 51	193.85: 58.15*	3: 1	1.4400	0.23
RF_2	157: 91	147.85:100.15*	9: 7	1.4034	0.24
Baby Head x P.I. 215514					
F_2	197: 62	194.25: 64.75	3: 1	0.1557	0.69
RF_2	331:120	338.25:112.75	3: 1	0.6216	0.43
Pooled	528:182	532.50:177.50	3: 1	0.1521	0.70
Baby Head x Chieftain Savoy					
F_2	45:147	48.00:144.00	1: 3	0.2500	0.64
RF_2	61:136	49.25:147.75	1: 3	3.7377	0.05
Red Danish x Badger Ballhead					
F_2	51:158	52.25:156.75	1: 3	0.0399	0.84
RF_2	51:103	38.50:115.50	1: 3	5.4112	0.02
Pooled	102:261	90.75:272.25	1: 3	1.8595	0.17
Red Danish x P.I. 215514					
F_2	150:161	144.39:166.61	9: 7	0.4064	0.52
Red Danish x Chieftain Savoy					
F_2	68: 39	60.19: 46.81	9: 7	2.3179	0.13
RF_2	50: 52	57.38: 44.62	9: 7	2.1668	0.14
Pooled	118: 91	117.56: 91.44	9: 7	0.0037	0.25

* = Weighted

early maturity: 91 late maturity fit ($P=0.24$) a weighted 9:7 expected ratio of 148:100 (Table 18). A segregation ratio of 9:7 suggests that the presence of 1 dominant allele at each locus, A or B conditions an early phenotype. The dominant A and B alleles were contributed by Baby Head while the recessive a_3 and b_3 alleles came from Badger Ballhead. Backcrossing the reciprocal F_1 to the recessive cultivar, Badger Ballhead produced a 5:28 ratio. This ratio fit ($P=0.21$) a 1:3 model with an expected ratio of 8.25:24.75 (Table 14). The observed data fit the postulated model. Following a chi-square test for homogeneity, both 1975L F_2 populations of Baby Head x Badger Ballhead were pooled. Using a dividing point of 116 days, calculated as illustrated (23), an observed ratio of 276 early to 62 late gave a good fit ($P=0.79$) to a 13:3 model (Table 19). A segregation ratio of 13:3 results when a dominant genotype at 1 locus, A and the recessive genotype at the other locus, b_3b_3 produce the same phenotype, earliness. The dominant A allele was contributed by Baby Head while the recessive b_3 allele was contributed by Badger Ballhead. The genotype a_3a_3BB conditions lateness (Table 15).

F_1 populations of Baby Head x P.I. 215514 show early maturity to be dominant in both the 1975E and 1975L plantings. Since the 1974L mid-parent and F_2 means were similar, additive inheritance for maturity in the planting seems apparent (Tables 11-13). Within each planting F_2 populations of Baby Head x P.I. 215514 were pooled as suggested by chi-square homogeneity tests. The dividing points for the 1975E and 1975L plantings were 120 and 119 days respectively. These points were calculated as previously explained (23). An observed ratio of 528:182 for the 1975E planting gave a good fit ($P=0.70$) to a 3:1 model of 532:178 (Table 18). The 3:1 model suggests that the presence of 1 dominant

Table 19. Chi-square test for goodness of fit to the postulated model for maturity in the F_2 generation (1975L planting).

Cross	Observed	Expected	Model	χ^2	P
Baby Head x Badger Ballhead					
F_2	103: 27	105.62: 24.38	13: 3	0.3479	0.56
RF_2	176: 35	171.44: 39.56	13: 3	0.6476	0.42
Pooled	279: 62	277.06: 63.94	13: 3	0.0722	0.79
Baby Head x P.I. 215514					
F_2	148: 20	157.50: 10.50	15: 1	9.1682	<0.01
RF_1	229: 15	228.75: 15.25	15: 1	0.0044	0.95
Pooled	377: 35	386.25: 25.75	15: 1	3.5442	0.06
Baby Head x Chieftain Savoy					
F_2	143: 72	136.25: 78.75*	7: 9	0.9126	0.34
RF_2	93: 85	91.07: 86.93*	1: 3	0.0837	0.77
Red Danish x Badger Ballhead					
F_2	105:186	92.52:198.48*	1: 3	2.4702	0.12
RF_2	14: 16	9.54: 20.46*	1: 3	3.0610	0.08
Pooled	119:202	102.05:218.95*	1: 3	4.1262	0.04
Red Danish x Chieftain Savoy					
F_2	34:165	39.12:159.88*	1: 3	0.8342	0.36
RF_2	42:182	44.03:179.96*	1: 3	0.1170	0.73
Pooled	76:347	83.16:339.84*	1: 3	0.7663	0.38

* = Weighted

a allele in the genotype conditions an early phenotype. The dominant a allele was contributed by Baby Head and the recessive a_4 and b_4 alleles were contributed by P.I. 215514 (Table 20). The pooled F_2 population from the 1975L planting produced a 377:35 segregation ratio which fit ($P=0.06$) a 15:1 model (Table 19). A 15:1 segregation ratio suggests that only 1 dominant allele, a or b, was required to produce an early phenotype. Only the recessive genotype $a_4a_4b_4b_4$ from P.I. 215514 produced a late phenotype (Table 21).

Planting time influenced the F_1 performance of Baby Head x Chieftain Savoy. The 1974L planting data show maturity to be inherited additively with an F_1 mean of 106 and a midparent mean of 107. However, both the 1975E and 1975L plantings show incomplete dominance for lateness (Tables 11-13). The 1975E F_2 division point was shown to be 116 days while the reciprocal F_2 division point was 104 days (23). The separation of classes for the 1975L F_2 planting of Baby Head x Chieftain Savoy was at 115 days. The 1975E F_2 population of Baby Head x Chieftain Savoy produced a segregation ratio of 45:147, while the reciprocal F_2 population produced a ratio of 61:136. Both populations fit ($P=0.64, 0.05$) a 1:3 model (Table 18). In each population, the 1:3 segregation ratio suggests that the presence of the b_5 allele in the genotype conditions lateness regardless of the condition of the a locus. Baby Head contributed $AABB$ and Chieftain Savoy contributed $A_5A_5B_5B_5$. The genotypes A_5A_5bb and $aabb$ condition earliness (Table 22). Backcrosses to the dominant cultivar, Chieftain Savoy, fit the 0:1 model. Backcrossing the reciprocal F_1 to the recessive cultivar produced a ratio of 9:46. This ratio showed poor fit ($P<0.005$) to the expected 1:1 ratio (Table 22). Due to an overlap of the 1975L cultivar distributions, a

Table 20. Parent, F₁ and F₂ maturity distributions in percent for the 1975E planting of the cross Baby Head x P.I. 215514.

Days From Transplanting to Harvest Upper Limit of Class													
No. of Plants	72	80	88	96	104	112	120	126	132	140	144	Mean	
Baby Head (P_1)	42	92.8	7.1									69 ± 5	
P.I. 215514 (P_3)	18							44.4	22.3	33.3		129 ± 6	
($P_1 \times P_3$)	86	7.0		54.6	36.1					2.3		96 ± 11	
($P_3 \times P_1$)	70			60.0	38.6					1.4		97 ± 6	
($P_1 \times P_3$) F_2	259	2.3		27.8	45.9			6.2		17.0	0.8	105 ± 18	
($P_3 \times P_1$) F_2	451	0.4		7.5	26.8	27.0	0.2	11.3	8.6	5.3	9.1	3.5	107 ± 18

Table 21. Parent, F₁ and F₂ maturity distributions in percent for the 1975L planting of the cross Baby Head x P.I. 215514.

Days From Transplanting to Harvest Upper Limit of Class														
	No. of Plants	110	111	112	114	115	116	118	119	136	139	145	Mean	
Baby Head (P_1)	53	28.3		32.1	39.6								113 $\pm$ 2	
P.I. 215514 (P_3)	13										46.1	53.9	142 $\pm$ 2	
($P_1 \times P_3$)	73	32.9			11.0	31.5	17.8		6.8				115 $\pm$ 3	
($P_3 \times P_1$)	81		22.2	32.1	27.2			12.3	6.2				114 $\pm$ 3	
($P_1 \times P_3$) F_2	168	7.1	8.9	11.9	27.4	4.8		9.5	18.4	3.6	8.3		116 $\pm$ 8	
($P_3 \times P_1$) F_2	244	7.0	5.7	29.9	12.3	6.6	15.2	5.7	11.5	1.2	4.9		115 $\pm$ 6	

Table 22. Parent, F₁, F₂, and backcross maturity distributions in percent for the 1975E planting of the cross Baby Head x Chieftain Savoy.

Days From Transplanting to Harvest Upper Limit of Class													
No. of Plants	72	80	88	96	104	116	120	126	132	140	144	Mean	
Baby Head (P_1)	52	92.8		7.1								69 ± 5	
Chieftain Savoy (P_5)	34								29.4	70.6		136 ± 3	
($P_1 \times P_5$)	52	13.5	23.0							63.5		115 ± 31	
($P_5 \times P_1$)	83		2.4				62.7	7.2	27.7			120 ± 9	
($P_1 \times P_5$) F_2	192				9.4	2.1	12.0	10.9	25.5	33.8	4.7	1.6	119 ± 12
($P_5 \times P_1$) F_2	197	0.5		9.6	21.3		3.0	12.7	8.2	7.6	35.0	2.1	117 ± 21
($P_1 \times P_5$) $\times P_5$	32							37.5	62.5				120 ± 2
($P_5 \times P_1$) $\times P_5$	15							53.3	46.7				120 ± 3
($P_5 \times P_1$) $\times P_1$	55			16.4				27.3	10.9		34.5	10.9	122 ± 19

weighting factor was used as previously described (23) to obtain a weighted theoretical segregation ratio for the 1975L F_2 populations. The F_2 population produced a 143:72 ratio which fit ($P=0.34$) a 7:9 weighted theoretical ratio. An F_2 ratio of 7:9 suggests that the presence of 1 or more homozygous recessive loci in the F_2 genotype conditions early maturity. The recessive alleles, $aabb$, were contributed by Baby Head, and the dominant alleles, $A_5A_5B_5B_5$, were contributed by Chief-tain Savoy. The genotype A_5B_5 conditions a late phenotype (Table 23). The reciprocal F_2 population produced a ratio of 93:85 which showed good fit ($P=0.77$) to a weighted 1:3 ratio (Table 19). The 1:3 segregation ratio suggests that the presence of the B_5 allele in the genotype conditions lateness regardless of the condition of the a locus. The genotypes A_5A_5bb and $aabb$ condition earliness (Table 23).

The mean performance of 6 red x green cabbage crosses also show dominance for earliness; however, the environment greatly affected the performance estimates. Both the 1974L and 1975L F_1 population means of Red Danish x Badger Ballhead show maturity to be additively inherited; however, the 1975E F_1 population mean shows early maturity to be dominant (Tables 11-13). The 1975E F_2 populations of Red Danish x Badger Ballhead were pooled. The division point of 124 days was calculated as suggested by Powers *et al.* (23). The pooled segregation ratio of 102:261 agreed ($P=0.17$) with the expected 1:3 ratio of 91:272 (Table 18). The 1:3 segregation ratio suggests that the presence of a single A_2 allele in the genotype was sufficient to condition a late phenotype irrespective of the genotypic make up of the b locus. Red Danish contributed dominant alleles $A_2A_2B_2B_2$ for lateness while Badger Ballhead contributed recessive genes $a_3a_3b_3b_3$ for earliness (Table 24). Due to a limited

Table 23. Parent, F₁ and F₂ maturity distributions in percent for the 1975L planting of the cross Baby Head x Chieftain Savoy.

	No. of Plants	Days From Transplanting to Harvest Upper Limit of Class												Mean
		110	111	112	114	115	116	118	119	136	139	145		
Baby Head (P_1)	53	28.3		32.1	39.6									113 ± 2
Chieftain Savoy (P_5)	43	11.6			23.2			14.1	2.3	48.8				128 ± 12
($P_1 \times P_5$)	20									45.0	15.0	30.0		138 ± 2
($P_5 \times P_1$)	59			16.9	8.5	42.4		3.4	3.4		25.4			122 ± 11
($P_1 \times P_5$) F_2	215	14.4	6.5	19.5	11.2	14.9	7.4	6.5	12.2	2.3	5.1			115 ± 7
($P_5 \times P_1$) F_2	178	5.6	3.4	15.2	20.8	7.3		4.5	15.2	10.6	17.4			120 ± 11

number of backcross plants, the backcross data suggest different models. Backcrossing the F_1 to the recessive parent, Badger Ballhead, produced a 0:12 ratio while backcrossing the reciprocal F_1 to the dominant parent, Red Danish, produced a 14:33 ratio. Although Badger Ballhead was dominant in the F_1 no F_2 plants with the F_1 phenotype were recovered. Chi-square tests suggest the 1975L F_2 populations should not be pooled. Using a dividing point of 112 days (23) the 1975L F_2 population produced a segregation ratio of 105:186 which fit ($P=0.12$) a 1:3 weighted theoretical ratio of 93:198 (Table 19). The reciprocal F_2 population also fit ($P=0.08$) a 1:3 weighted theoretical segregation ratio (Table 19). In both plantings the 1:3 segregation ratio suggests that the a_2 allele was completely dominant to the a_3 allele and masks the action of the b locus. The recessive genotype a_3a_3 conditions earliness (Table 25).

The F_1 population means of Red Danish x P.I. 215514 were affected by the environment. Both the 1975E and 1975L population means show early maturity to be completely to incompletely dominant. The 1974L planting shows complete dominance for late maturity (Tables 11-13). The Red Danish x P.I. 215514 F_2 population was only grown in the 1975E planting due to short seed supply. Using a dividing point of 124 days (23) the F_2 produced a segregation ratio of 150:161. This ratio fit ($P=0.52$) a 9:7 weighted segregation ratio (Table 18). The 9:7 segregation ratio suggests that homozygous recessive genotypes at either loci condition lateness. Dominant alleles for earliness, $a_2a_2b_2b_2$ were contributed by Red Danish while recessive alleles for lateness, $a_4a_4b_4b_4$, were contributed by P.I. 215514. The genotype $a_2_b_2_$ conditioned earliness (Table 26).

Table 24. Parent, F_1 , F_2 , and backcross maturity distributions in percent for the 1975E planting of the cross Red Danish x Badger Ballhead.

	No. of Plants	Days From Transplanting to Harvest Upper Limit of Class							Mean
		76	100	108	124	128	136	144	
Red Danish (P_4)	35				71.4	28.6			122 + 2
Badger Ballhead (P_2)	39	7.7		92.3					99 + 9
($P_4 \times P_2$)	96		97.8					2.2	99 + 6
($P_2 \times P_4$)	90		100.0						99 + 0
($P_4 \times P_2$) F_2	209	0.6			23.9	72.2		3.3	124 + 5
($P_2 \times P_4$) F_2	154	0.6		32.5		44.8	20.2	1.9	119 + 10
($P_4 \times P_2$) $\times P_2$	12					100.0			125 + 1
($P_2 \times P_4$) $\times P_4$	47				29.8	70.2			123 + 4

Table 25. Parent, F₁ and F₂ maturity distributions in percent for the 1975L planting of the cross Red Danish x Badger Ballhead.

	No. of Plants	Days From Transplanting to Harvest Upper Limit of Class										Mean
		110	111	112	114	115	116	118	119	136	139	
Red Danish (P_4)	32			43.8		56.2						115 ± 2
Badger Ballhead (P_2)	49		32.6	32.6			26.6	4.1	4.1			114 ± 3
($P_4 \times P_2$)	23	34.8	8.7	39.1	8.7	8.7						112 ± 2
($P_2 \times P_4$)	19			21.0		47.4	26.3		5.3			116 ± 2
($P_4 \times P_2$) F_2	291	5.2	10.0	21.0	14.4	12.0	12.7	4.5	5.8	7.2	7.2	116 ± 9
($P_2 \times P_4$) F_2	30		23.3	23.3	30.0	10.0		6.8	3.3	3.3	3.3	114 ± 6

Table 26. Parent, F₁ and F₂ maturity distributions in percent for the 1975E planting of the cross Red Danish x P.I. 215514.

	No. of Plants	Days From Transplanting to Harvest Upper Limit of Class							Mean
		100	108	124	128	136	144		
Red Danish (P ₄)	35			71.4	28.6				122 ± 2
P.I. 215514 (P ₃)	18			11.4	44.4	11.2	33.3		130 ± 6
(P ₄ x P ₃)	85	55.3	31.8				12.9		105 ± 14
(P ₃ x P ₄)	89		61.8		31.5		6.7		113 ± 12
(P ₄ x P ₃) F ₂	311		2.9	45.3	27.3	17.0	7.4		123 ± 7

Both the 1975E and 1975L F_1 population means of Red Danish x Chieftain Savoy show complete dominance for early maturity while the 1974L planting shows dominance for late maturity (Tables 11-13). The 1975E F_2 populations of Red Danish x Chieftain Savoy were pooled. A dividing point of 128 days (23) produced a pooled ratio of 118 early maturity:91 late maturity (Table 28). The data showed a good fit ($P=0.95$) to a 9:7 segregation ratio (Table 18). An F_2 segregation ratio of 9:7 suggests that homozygous recessive genotypes at either loci condition lateness. Dominant alleles for earliness, $A_2A_2B_2B_2$, were contributed by Red Danish while recessive alleles for lateness, $a_5a_5b_5b_5$, were contributed by Chieftain Savoy. The genotype A_2-B_2- conditioned earliness (Table 18). Backcrosses to the dominant Red Danish parent fit the expected 1:0 ratio and support the postulated model. The A_2-B_2- genotype was dominant for lateness in the 1975L planting (Table 29). The 1975L F_2 data were pooled and a dividing point of 114 days (23) produced an observed segregation ratio of 76:347. This ratio fit ($P=0.38$) a 1:3 weighted theoretical ratio of 83:340 (Table 29). The 1:3 segregation ratio suggests that the presence of 1 allele from Red Danish masked the action of the b locus and conditioned a late phenotype. The recessive genotype $a_5a_5b_5b_5$ conditioned an early phenotype (Table 19).

These F_2 populations show that in all but one case, Baby Head provided dominant genes for earliness. In red x green cabbage crosses, the 1975E planting data showed Red Danish phenotypes to be dominant; however, in the 1975L planting Red Danish genes were dominant only if their phenotype was later than the other parental phenotype.

Table 27. Parent and F₁ maturity distributions in percent for the 1975L planting of the cross Red Danish x P.I. 215514.

	No. of Plants	Days From Transplanting to Harvest Upper Limit of Class										Mean
		112	114	115	116	118	119	136	139	145		
Red Danish (P_4)	32	43.8		56.2							115 ± 2	
P.I. 215514 (P_3)	13							46.2	53.8		142 ± 2	
($P_4 \times P_3$)	44	4.5	22.7			18.2	18.2	11.4	25.0		125 ± 11	
($P_3 \times P_4$)	14		28.6	28.6	28.6	14.2		28.6			121 ± 7	

Table 28. Parent, F₁, F₂, and backcross maturity distributions in percent for the 1975E planting of the cross Red Danish x Chieftain Savoy.

	No. of Plants	Days From Transplanting to Harvest Upper Limit of Class							Mean
		108	124	128	136	144			
Red Danish (P ₄)	35		71.4	28.6					122 ± 2
Chieftain Savoy (P ₅)	34				100.0				136 ± 3
(P ₄ x P ₅)	33		33.3	66.7					122 ± 4
(P ₅ x P ₄)	80		58.8	38.8		2.4			123 ± 3
(P ₄ x P ₅) F ₂	107		30.8	32.7	25.1	11.2			126 ± 5
(P ₅ x P ₄) F ₂	102		7.8	41.1		51.1			131 ± 7
(P ₄ x P ₅) x P ₄	18			100.0					126 ± 1
(P ₅ x P ₄) x P ₄	37	67.6	32.4						108 ± 9

Table 29. Parent, F₁ and F₂ maturity distributions in percent for the 1975L planting of the cross Red Danish x Chieftain Savoy.

	No. of Plants	Days From Transplanting to Harvest Upper Limit of Class											Mean
		110	111	112	114	115	116	118	119	136	139		
Red Danish (P ₄)	32			43.8		56.2							115 ± 2
Chieftain Savoy (P ₅)	43	11.6			23.2			14.1	2.3		48.8		128 ± 12
(P ₄ x P ₅)	28	57.2		7.2	17.8	17.8							112 ± 2
(P ₅ x P ₄)	30	56.6		10.0	13.3	20.1							112 ± 3
(P ₄ x P ₅) F ₂	199			1.0	16.1	3.0	5.5	10.6	17.6	6.1	40.1		126 ± 11
(P ₅ x P ₄) F ₂	224		7.1	6.7	4.9	4.9	14.3	13.8	20.3	6.7	21.3		121 ± 10

Swarup (30) and Chiang (3) have previously estimated heritabilities for maturity to be 0.80 and 0.83 respectively. This study shows heritability estimates of some of the traits to be greater than 1 or less than 0 (Table 30). Heritability estimates greater than 1 may be produced when $\sigma_w^2 < 3\sigma_s^2$. Since residual error mean square for AOV #1 (Table 6) is equal to $\sigma_c^2 + n_k \sigma_w^2$, small values for σ_w^2 may occur when σ_c^2 , the environmental variance of the differences between plots common to all individuals within a plot, is large. Large heritability estimates may also occur when σ_s^2 , the covariance of paternal half sib data, is large relative to σ_w^2 or $\sigma_c^2 + n_k \sigma_w^2$. Robinson et al. (25) reported negative heritabilities in corn and suggested these estimates might arise by chance. Thompson and Moore (34) suggest negative estimates of variance components, used in estimating heritability, may occur because of sampling error. Gill and Jensen (8) have calculated the probability of obtaining negative heritability estimates. In this study $\bar{h}^2$ will denote the mean heritability estimate taken from all estimates between 0 and 1. The term $\bar{h}_x^2$ will denote the mean heritability estimate of all estimates, where estimates greater than 1 are set to 1 and negative estimates are set to 0. Both $\bar{h}^2$ and $\bar{h}_x^2$ estimates were calculated in the following manner. Each h^2 estimate to be included in a mean estimate was weighted by the factor $1/(\text{S.E. estimate})^2$. Weighted estimates were summed and divided by the sum of the various weights, i.e., $\Sigma(h^2/(\text{S.E. estimate})^2)/\Sigma(1/(\text{S.E. estimate})^2) = \bar{h}^2$ or $\bar{h}_x^2$ depending on the type of h^2 estimates included in the calculation. Standard errors were calculated as $\sqrt{1/\Sigma(1/(\text{S.E. estimate})^2)}$. The $\bar{h}^2$ estimate for green cabbage F_1 maturity was 0.62 ± 0.38 while the $\bar{h}_x^2$ estimate was 0.66 ± 0.36 . Heritability estimates between 0 and 1 ranged

Table 30. Heritability estimates for seven traits from green and red x green cabbage crosses grown in three plantings.

1974L Trait	F ₁ Cabbage Populations			
	Green	Green Reciprocal	Red	Red Reciprocal
Maturity	0.61	0.62	A	B
Head Wt.	A	0.89	B	0.05
Total Leaf Wt.	A	A	0.17	A
Stalk Size	A	A	0.57	A
Leaf Num.	A	A	B	B
E. I. *	0.96	A	0.15	B
Leaf Size	A	A	0.40	A

1975E Trait	F ₁ Cabbage Populations			
	Green	Green Reciprocal	Red	Red Reciprocal
Maturity	A	A	A	A
Head Wt.	A	A	0.17	A
Total Leaf Wt.	0.54	A	A	A
Stalk Size	0.96	A	A	A
Leaf Num.	0.67	A	0.42	0.57
E. I.	A	0.18	A	0.56
Leaf Size	0.52	A	0.50	0.70

1975L Trait	F ₁ Cabbage Populations			
	Green	Green Reciprocal	Red	Red Reciprocal
Maturity	A	A	A	A
Head Wt.	0.86	A	B	0.93
Total Leaf Wt.	B	A	0.88	A
Stalk Size	0.78	0.28	A	A
Leaf Num.	B	A	B	A
E. I.	B	B	B	A
Leaf Size	B	0.84	A	A

*Efficiency Index

A = Estimate greater than 1

B = Estimate less than 0

from 0.61 to 0.62. Red x green cabbage F_1 's provided 5 estimates of h^2 greater than 1 and 1 negative estimate. The $\bar{h}_x^2$ estimate was 1.0 ± 0.81 . It appears that red x green cabbage heritability for this trait is large. The green cabbage cross $\bar{h}^2$ estimate suggests 62% of the total variance in these crosses was due to additive genetic variance. This additive portion may be genetically fixed using inbreeding and selection techniques. The other 38% is dominance, to be used to an advantage in F_1 hybrids, and an environmental effect (Table 30).

Genetic correlation (r_g) estimates between some traits in this study were greater than 1 and less than negative 1 (Table 31). Genetic correlation values greater than 1 occur when the covariance between 2 traits is greater than the square root of the product of 2 trait variances. Genetic correlation values less than -1 can occur if the covariance is negative and larger than the square root of the product of 2 trait variances. The term $\bar{r}_g$ will be used to denote a mean genetic correlation of all estimates between +1 and -1 and the term $\bar{r}_{gx}$ will denote a mean genetic correlation of all estimates where estimates greater than 1 are set to 1 and estimates less than negative 1 are set to negative 1. Both the $\bar{r}_g$ and the $\bar{r}_{gx}$ estimates were calculated by weighting each r_g estimate by the inverse of its variance and summing all estimates. The final answer was divided by the sum of the inverse variances to produce a formula similar to that for $\bar{h}^2$. Genetic correlation variances were calculated using Scheinberg's method (27). Standard errors for both $\bar{r}_g$ and $\bar{r}_{gx}$ were calculated similar to those for $\bar{h}^2$. Genetic correlations between maturity and other above ground plant parts in cabbage have not been previously reported. For green cabbage crosses the mean genetic correlation between maturity

Table 31. Genetic correlation between maturity and six other traits in cabbage.

Traits	Plantings	Green Crosses		Red Crosses	
			R*		R*
Maturity x Head Weight	1974L	0.92	0.37	-0.10	-0.58
	1975E	0.75	0.88	A	A
	1975L	A	0.54	B	B
Maturity x Total Non-wrapper Leaf Weight	1974L	A	A	A	B
	1975E	-0.28	0.34	A	0.48
	1975L	0.03	0.01	-0.02	0.65
Maturity x Stalk Size	1974L	A	0.92	A	B
	1975E	0.94	0.99	0.95	0.53
	1975L	0.10	-0.54	A	0.91
Maturity x Non-wrapper Leaf Number	1974L	0.91	0.91	0.11	A
	1975E	B	B	A	0.04
	1975L	-0.14	0.31	0.45	A
Maturity x Efficiency Index	1974L	0.88	A	A	A
	1975E	-0.85	B	A	-0.68
	1975L	0.29	0.98	0.23	A
Maturity x Non-wrapper Leaf Size	1974L	A	0.89	A	-0.83
	1975E	0.70	0.74	A	0.82
	1975L	-0.08	-0.44	-0.13	-0.53

*Reciprocal cross

A = Correlation estimates greater than 1.0

B = Correlation estimates less than -1.0

and head weight was $\bar{r}_g = 0.84 \pm 0.53$ while $\bar{r}_{gx} = 0.98 \pm 0.20$. Genetic correlation estimates ranged from 0.37 to 0.92 (Table 31). Mean genetic correlation between maturity and total non-wrapper leaf weight was low, $\bar{r}_g = 0.05 \pm 0.99$, however, numerous estimates were larger than 1 showing $\bar{r}_{gx} = 0.89 \pm 0.34$. Estimates ranged from -0.28 to 0.34. The $\bar{r}_g$ estimate between maturity and stalk size was 0.98 ± 0.12 suggesting late maturity might be related to regulatory genes controlling stalk size. Estimates ranged from -0.54 to 0.99. Genetic correlations between maturity and non-wrapper leaf number, efficiency index and non-wrapper leaf size were 0.63 ± 0.73 , 0.11 ± 0.54 and 0.41 ± 0.42 respectively. However, $\bar{r}_{gx}$ values were -0.86 ± 0.21 , -0.75 ± 0.20 and 0.60 ± 0.35 respectively. Genetic correlation estimates ranged from -0.14 to 0.91, -0.85 to 0.98 and -0.44 to 0.89 respectively. Environmental effects on various r_g values were evident. Correlations between maturity and total non-wrapper leaf weight in the 1975E planting were -0.28 for crosses and 0.34 for reciprocal crosses. It is also evident in genetic correlations between maturity and efficiency index where the 1974L, 1975E and 1975L plantings gave r_g estimates of 0.88, -0.85 and 0.29 respectively. Red x green cabbage crosses exhibit generally lower genetic correlations compared to green cabbage crosses. The genetic correlation between maturity and head weight was negative and low, $\bar{r}_g = -0.20 \pm 0.81$ although the $\bar{r}_{gx}$ is 0.76 ± 0.73 . Genetic correlation estimates range from -0.58 to -0.10. Mean genetic correlation estimates between maturity and total non-wrapper leaf weight, stalk size and non-wrapper leaf number were 0.50 ± 0.67 , 0.93 ± 0.34 and 0.16 ± 0.89 while $\bar{r}_{gx}$ values were 0.98 ± 0.22 , 0.92 ± 0.33 and 1.00 ± 0.12 respectively. Genetic correlation estimates ranged from -0.02 to 0.65, 0.53 to 0.95 and 0.04 to 0.45 respectively. Mean genetic correlations between maturity and efficiency index and

non-wrapper leaf size were -0.28 ± 0.76 and 0.13 ± 0.59 . Values from $\bar{x}_{gx}$ were larger, 0.85 ± 0.52 and 0.98 ± 0.18 respectively. It appears that both green and red x green cabbage crosses grown in the 1975L planting showed negative correlations between maturity and non-wrapper leaf size although prior plantings produced high positive correlation estimates. The negative correlation between maturity and head weight for red x green cabbage crosses compared to a high positive correlation for green cabbage crosses suggests different directions of dominance for head weight.

Head Weight

Analysis for head weight showed significant differences between treatment means for cultivar, inbreeding and planting time. Significant interactions include cultivar x plantings and cultivar x inbreeding (Table 32). The cultivar x plantings interaction was significant since the head weight of Baby Head showed no increase or decrease for the 3 plantings while Badger Ballhead, Red Danish and Chieftain Savoy all produced significantly heavier heads in the 1975E planting when compared to the other 2 plantings. P.I. 215514 produced significantly heavier heads in the 1975L planting than in the 1974L planting. Head weights ranged from 0.78 kilograms for Baby Head to 2.98 kilograms for P.I. 215514. An increase in head weight of 1 kilogram or more may be achieved by planting cabbage earlier in the growing season (Table 33). The interaction, cultivar x inbreeding suggests that 1 generation of inbreeding did not have the same effect on each cultivar. Inbreeding had no effect on the head weight of 4 cultivars; while, 1 generation of inbreeding a randomly selected plant of Badger Ballhead produced a significant reduction in head weight (Table 34). Although inbreeding produced significant differences, the

Table 32. Analysis of variance table for head weight in kilograms.

Source of Variance	DF	Mean Square	F*
Replication (R)	2	0.58	2.89
Cultivar (C)	4	12.02	59.89**
Inbreeding (I)	1	1.19	5.91*
C x I	4	0.54	2.70*
Plantings (P)	2	7.40	36.88**
C x P	8	2.20	10.94**
I x P	2	0.36	1.77
C x I x P	8	0.15	0.73
Residual Error	58	0.20	

F test significant at the 5%, or 1%** level.

Table 33. Cultivar x planting interaction means for head weight in kilograms.

Cultivar	1974L	Plantings 1975E	1975L	Cultivar Means
Baby Head	1.01 a *	0.66 a	0.68 a	0.78 W
Badger Ballhead	1.96 a	2.66 b	1.63 a	2.08 Y
P.I. 215514	1.94 a	3.40 b	3.62 b	2.98 Z
Red Danish	1.21 a	2.27 b	0.76 a	1.41 X
Chieftain Savoy	1.27 a	2.96 b	1.25 a	1.83 Y
Planting Means	1.48 A	2.39 B	1.59 A	

***Mean separation, within rows, by Duncan's Multiple Range Test at the 5% level.**

Table 34. Cultivar x inbreeding interaction means for head weight in kilograms.

Cultivar	Inbreeding		Cultivar Means
	P_1	S_1	
Baby Head	0.89 a*	0.67 a	0.78 W
Badger Ballhead	2.49 b	1.68 a	2.08 Y
P.I. 215514	2.93 a	3.04 a	2.98 Z
Red Danish	1.45 a	1.37 a	1.41 X
Chieftain Savoy	1.89 a	1.76 a	1.83 Y
Inbreeding Means	1.93 B	1.70 A	

*Mean separation, within rows, by Duncan's Multiple Range Test at the 5% level.

200 gram difference noted may not be great enough to justify an extra year of inbreeding for head weight within these cultivars prior to using them in a breeding program.

It has been previously reported by Rasmusson (24) that large head weights are dominant to small head weights. Data from green cabbage crosses in this study support Rasmusson's conclusions (Tables 11-13). During 1974, all of the F_1 green cabbage crosses showed dominance and overdominance for large head weight. Due to environmental influences in the 1975L planting, dominance for this trait was reduced. The F_1 populations of Baby Head x Badger Ballhead grown in both the 1975E and 1975L plantings suggest incomplete dominance for small head weight. The 1974L F_1 planting of this cross showed overdominance for large head weight (Tables 11-13). Tables 35 and 36 show frequency distributions in percent for populations involved in the cross Baby Head x Badger Ballhead. Powers *et al.* (23) partitioning tests were applied to these distributions to determine the number of genes controlling head weight and to define the boundary between small and large head weight classes. Powers *et al.* (23) formula (F_2/P_1) was applied sequentially from the recessive ends of both the F_2 and P_1 distributions. Using the 1975E planting of Baby Head x Badger Ballhead (Table 35) as an example the formula suggests recessive frequencies of 0.4/19.0 or 0.02 for the 0.5 kg class, 7.5/90.5 or 0.08 for the 1.0 kg class and 28.9/100 or 0.29 for the 1.5 kg class. The large increase in frequency between the 1.0 kg and 1.5 kg classes suggest a dividing point of 1 kg. The mean of estimates for the 0.5 kg and 1.0 kg classes was 0.05. This closely approximates the 0.06 estimate expected from a 1:15 model (Table 35). The 1975E reciprocal F_2 population of Baby Head x Badger

Table 35. Parent, F₁, F₂, and backcross head weight distributions in percent for the 1975E planting of the cross Baby Head x Badger Ballhead.

	No. of Plants	Head Weight in Kilograms Upper Limit of Class											Mean
		0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	
Baby Head (P ₁)	42	19.0	71.5	9.5									0.7 ± 0.2
Badger Ballhead (P ₂)	39		12.8	2.6	7.8	10.2	12.8	10.2	12.8	10.2	12.8	7.8	3.1 ± 1.4
(P ₁ × P ₂)	83	1.2	26.5	33.8	26.5	9.6	2.4						1.3 ± 0.5
(P ₂ × P ₁)	89	1.1	29.2	29.2	22.5	12.4	4.5	1.1					1.4 ± 0.6
(P ₁ × P ₂) F ₂	252	0.4	7.1	21.4	24.2	22.6	13.9	5.2	1.6	0.8	0.8	2.0	2.1 ± 1.0
(P ₂ × P ₁) F ₂	248	12.1	22.3	30.7	18.1	6.4	4.4	1.2	0.4	1.6	1.2	1.6	1.4 ± 1.0
(P ₂ × P ₁) × P ₂	33		3.0	12.1	18.2	21.2	27.4	12.1		3.0		3.0	2.4 ± 0.9

Ballhead suggests small head weights were dominant. Applying the same formula (F_2/P_2) to the recessive end of the Badger Ballhead distribution, frequencies of 1.6/7.8 or 0.20 for the 9.5 kg class, 2.8/10.6 or 0.26 for the 5.0 kg class, 4.4/30.8 or 0.14 for the 4.5 kg class, 4.8/43.6 or 0.11 for the 4.0 kg class, 6.0/53.8 or 0.11 for the 3.5 kg class, 10.4/66.6 or 0.16 for the 3.0 kg class, 16.8/76.8 or 0.22 for the 2.5 kg class and 34.9/84.6 or 0.41 for the 2.0 kg class were observed (Table 35). The increase in frequency between the 2.5 kg and 2.0 kg classes suggest a division point of 2.0 kg to separate the small and large head weight phenotypes. The mean of frequency estimates from classes 2.5 kg and larger was 0.17. This result suggests that a 3:1 model with a frequency equal to 0.25 might be appropriate. In both the F_2 and reciprocal F_2 populations, overlap of the cultivar distributions was accounted for by weighting the expected genetic ratios in the following manner. For the 1975E F_2 Baby Head x Badger Ballhead population a net overlap of $(12.8-9.5) = 3.3$ was observed with the large head weight class deficient (Table 35). The expected number of plants in the deficient class was calculated to be $((100-3.3)/100)(0.9375)(252) = 228.45$. The expected number of recessive plants was $252-228.45 = 23.55$ (Table 37). The expected ratio in the 1975E reciprocal F_2 population was calculated in a similar fashion. The net overlap from a 2.0 kg dividing point was $(12.8 + 2.6 + 7.8) = 23.2$ (Table 35). Again the large head weight class was deficient. The expected number of plants in the deficient class was $((100-23.2)/100)(0.25)(248) = 47.62$. The expected number of early plants was $(248-47.62) = 200.38$ (Table 37). Similar results for other crosses suggested head weight might be controlled by 2 loci. The simplest system available to insure a digenic inheritance system and explain the cultivar differences

Table 36. Parent, F₁ and F₂ head weight distributions in percent for the 1975L planting of the cross Baby Head x Badger Ballhead.

	No. of Plants	Head Weight in Kilograms Upper Limit of Class										Mean	
		0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0		9.5
Baby Head (P_1)	53	17.0	52.8	30.2									0.8 ± 0.3
Badger Ballhead (P_2)	49	2.0	12.2	12.2	26.6	14.3	10.2	10.2	8.2	4.1			2.1 ± 1.0
($P_1 \times P_2$)	38		21.0	47.4	15.8	15.8							1.4 ± 0.5
($P_2 \times P_1$)	77	1.3	24.6	36.4	26.0	11.7							1.4 ± 0.5
($P_1 \times P_2$) F_2	130	10.8	28.5	31.5	12.3	10.0	3.1	1.5	1.5		0.8		1.3 ± 0.8
($P_2 \times P_1$) F_2	211	12.3	39.3	29.4	11.9	3.3	2.8		0.5	0.5			1.1 ± 0.6

Table 37. Chi-square test for goodness of fit to the postulated model for head weight in the F_2 generation (1975E planting).

Cross	Observed	Expected	Model	χ^2	P
Baby Head x Badger Ballhead					
F_2	19:233	23.55:228.46*	1:15	0.9653	0.32
RF_2	206: 42	200.38: 47.62*	3: 1	0.8208	0.40
Baby Head x P.I. 215514					
F_2	60:199	64.75:194.25*	1: 3	0.4646	0.50
RF_2	40:411	51.68:399.32*	1:15	2.9801	0.08
Baby Head x Chieftain Savoy					
F_2	25:167	33.18:158.82*	1:15	2.4360	0.12
RF_2	33:164	34.04:162.96*	1:15	0.0384	0.84
Pooled	58:331	67.22:321.78*	1:15	1.5278	0.22
Red Danish x Badger Ballhead					
F_2	128: 81	121.92: 87.08*	9: 7	0.7285	0.39
RF_2	102: 52	89.83: 64.17*	9: 7	3.9547	0.05
Pooled	230:133	211.75:151.25*	9: 7	3.7750	0.05
Red Danish x P.I. 215514					
F_2	158:153	154.11:156.84*	7: 9	0.1945	0.66
Red Danish x Chieftain Savoy					
F_2	46: 61	49.09: 57.91*	7: 9	0.3590	0.55
RF_2	56: 46	59.06: 42.94*	9: 7	0.3772	0.54

* = Weighted

observed was a 2 locus multiple allelic system with 5 alleles per loci. The loci were designated C and D since the small heads of the base cultivar, Baby Head, were recessive in most crosses. Tables 16 and 17 show the cultivar and F_1 genotypes under this system. Allelic inheritance patterns for 1975E green cabbage crosses suggest, C_5 , C_4 and C_3 were all dominant to c . The D locus exhibited a similar pattern. The inheritance pattern for both loci was reversed in the 1975L planting with c_5 , c_4 and c_3 recessive to C . Red x green cabbage crosses in the 1975E planting showed an allelic dominance pattern of C_5 and C_4 being dominant to C_2 , and C_2 being dominant to C_3 . A similar pattern was observed for the D locus. Only the F_2 populations of Red Danish x Badger Ballhead were evaluated in the 1975L planting. No seed of Red Danish x P.I. 215514 was available and no segregation for head weight occurred from the cross Red Danish x Chieftain Savoy. The Red Danish x Badger Ballhead cross suggests an allelic inheritance pattern where C_2 was dominant to C_3 and D_2 was dominant to d_3 . The results of chi-square homogeneity tests within both the 1975E and 1975L F_2 plantings of Baby Head x Badger Ballhead suggest the F_2 and reciprocal F_2 populations within each planting should not be pooled. Using a dividing point of 1 kg the 1975E F_2 data produced an observed ratio of 19 small:233 large heads which compared favorably ($P=0.32$) with a 1:15 weighted theoretical ratio of 23.6:228.4 (Table 37). The 1:15 segregation ratio suggests that dominant alleles, $C_3C_3D_3D_3$, were produced by Badger Ballhead while recessive alleles, $ccdd$, were produced by Baby Head. The genotype $ccdd$ produced a small head phenotype (Table 35). The 1975E reciprocal F_2 population, using a dividing point of 2.0 kg, produced a segregation ratio of 206 small:42 large heads. This ratio fit ($P=0.40$) a 3:1 weighted theoretical ratio of 200:48 (Table 37). A

segregation ratio of 3:1 suggests that the presence of 1 dominant *c* allele conditioned the production of a small cabbage head. The genotype c_3c_3- conditioned a large head phenotype. A backcross of the recessive cultivar Badger Ballhead to the reciprocal F_1 produced an observed ratio of 11:22. The ratio fit ($P=0.05$) an expected 1:1 model of 16.5:16.5. Backcross data support the postulated model. Since the F_2 population was dominant for large heads as its male parent Badger Ballhead and the reciprocal F_2 population was dominant for small heads as its male parent Baby Head some evidence for a male inheritance factor exists (Table 35). Both F_2 populations grown in the 1975L planting showed dominance for small heads. The observed ratio of 92 small:38 large heads from a 1.5 kg division point fit ($P=0.48$) a 9:7 weighted theoretical ratio of 88:42 (Table 38). Homozygous recessive genotypes at either loci produced a large cabbage head. Small head weights were conditioned by the presence of 1 or more dominant alleles at each loci. Using a 1.5 kg dividing point the reciprocal F_2 population produced a ratio of 171:40 which fit ($P=0.82$) a 3:1 weighted theoretical ratio of 172:39 (Table 38). The presence of 1 dominant *c* allele conditioned small heads. In both cases dominant alleles, *CCDD*, were contributed by Baby Head and recessive alleles, $c_3c_3d_3d_3$, were contributed by Badger Ballhead (Table 36).

Both the 1973E and 1974L plantings of Baby Head x P.I. 215514 F_1 showed incomplete to overdominance for large head weights. The 1975L F_1 planting suggested incomplete dominance for small head weights (Tables 11-13). Chi-square homogeneity tests suggest that both 1975E F_2 populations of Baby Head x P.I. 215514 were statistically different and therefore were analyzed separately. Using a dividing point of 1.5 kg, calculated as shown previously (23), the F_2 population produced a

Table 38. Chi-square test for goodness of fit to the postulated model for head weight in the F_2 generation (1975L planting).

Cross	Observed	Expected	Model	χ^2	P
Baby Head x Badger Ballhead					
F_2	92: 38	88.21: 41.78*	9: 7	0.5055	0.48
RF_2	171: 40	172.24: 38.76*	3: 1	0.0490	0.82
Baby Head x P.I. 215514					
F_2	126: 42	135.69: 32.31*	3: 1	3.6000	0.06
RF_2	202: 42	197.08: 46.92*	3: 1	0.6395	0.42
Baby Head x Chieftain Savoy					
F_2	204: 11	201.56: 13.44*	15: 1	0.4717	0.49
RF_2	168: 10	162.99: 15.00*	15: 1	1.8236	0.18
Red Danish x Badger Ballhead					
F_2	241: 50	232.67: 58.33*	13: 3	1.4886	0.22
RF_2	25: 5	23.99: 6.01*	13: 3	0.2136	0.64
Pooled	266: 55	256.65: 64.34*	13: 3	1.6977	0.19

* = Weighted

segregation ratio of 60:199 (Table 39). Due to an overlap of parental distributions the data were compared ($P=0.50$) to a 1:3 ratio of 65:194 (Table 37). The observed 1:3 segregation ratio suggests only 1 dominant allele C_4 was required to produce a large head. The absence of C_4 alleles conditioned small cabbage heads. The dominant alleles, $C_4C_4D_4D_4$, were contributed by P.I. 215514. The reciprocal F_2 population produced a segregation ratio of 40:411 using a dividing point of 1.5 kg. The ratio fit ($P=0.08$) a 1:15 weighted theoretical ratio of 52:399 (Table 37). The presence of 1 dominant allele at either loci was required for a large head phenotype. The genotype $ccdd$ conditioned small cabbage heads. Chi-square homogeneity tests suggest differences between the 1975L F_2 populations of Baby Head x P.I. 215514 (Table 40). The populations were each analyzed separately. The observed F_2 segregation ratio of 126:42 was produced using a dividing point of 1.5 kg. The data fit ($P=0.06$) a 3:1 weighted theoretical ratio of 135.6:32.3. Using a dividing point of 2.0 kg the reciprocal F_2 population produced an observed ratio of 202:42 which fit ($P=0.42$) a 3:1 weighted expected ratio of 197:47 (Table 38). Large heads were produced by the genotype $C_4C_4d_4d_4$. Only 1 dominant C allele was required to produce small heads in this planting (Tables 16-17). In both the 1975E and 1975L plantings the genotype $ccDD$ produced small head weights (Tables 15-16). In summary F_2 performance in 2 plantings during the same year, 1975, suggest that alleles behaved differently under different growing conditions.

Three F_1 plantings, 1974L, 1975E and 1975L, suggest large head weights were overdominant in Baby Head x Chieftain Savoy F_1 (Tables 11-13). 1975E F_2 populations of Baby Head x Chieftain Savoy were pooled. Using a dividing point (23) of 1.5 kg an observed ratio of 58:331 was

Table 39. Parent, F₁ and F₂ head weight distributions in percent for the 1975E planting of the cross Baby Head x P.I. 215514.

	No. of Plants	Head Weight in Kilograms Upper Limit of Class											Mean
		0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	9.5	
Baby Head (P ₁)	42	19.0	71.5	9.5									0.7 ± 0.2
P.I. 215514 (P ₃)	18			5.6	16.7	16.7	11.0	22.2			11.0	16.8	3.3 ± 1.6
(P ₁ x P ₃)	86	2.3	2.3	4.6	3.5	8.2	23.2	29.1	12.8	12.8		1.2	3.0 ± 1.0
(P ₃ x P ₁)	70		1.4	2.8	5.7	7.2	8.6	28.6	28.6	14.3	2.8		3.3 ± 0.8
(P ₁ x P ₃) F ₂	259	2.3	8.1	12.7	24.3	23.6	12.0	10.8	3.1	1.5	0.4	1.2	2.1 ± 0.9
(P ₃ x P ₁) F ₂	451	0.2	1.6	7.1	15.3	18.0	22.9	15.3	8.4	4.9	2.2	4.1	2.8 ± 1.1

Table 40. Parent, F₁ and F₂ head weight distributions in percent for the 1975L planting of the cross Baby Head x P.I. 215514.

	No. of Plants	Head Weight in Kilograms Upper Limit of Class										Mean	
		0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0		5.5
Baby Head (P_1)	53	17.0	52.8	30.2									0.8 $\pm$ 0.3
P.I. 215514 (P_3)	13			23.0			38.5		7.7		30.8		3.6 $\pm$ 2.1
($P_1 \times P_3$)	73	9.6	31.5	20.6	21.9	11.0	2.7	2.7					1.8 $\pm$ 0.7
($P_3 \times P_1$)	81		6.2	16.0	27.2	25.9	16.0	3.7	2.5	2.5			2.1 $\pm$ 0.8
($P_1 \times P_3$) F_2	168	11.3	39.9	23.8	13.7	8.9	1.8	0.6					1.1 $\pm$ 0.6
($P_3 \times P_1$) F_2	244	4.1	22.1	28.8	27.9	9.0	6.1	1.2	0.4	0.4			1.4 $\pm$ 0.7

produced. Due to parental overlap (Table 41) a 1:15 weighted theoretical ratio was used. The observed data fit ($P=0.22$) the weighted theoretical ratio (Table 37). Small head weights were recessive and conditioned by the *codd* genotype. The presence of either a dominant C_5 or D_5 allele in the genotype conditioned large heads. The dominant C_5 and D_5 alleles were contributed by Chieftain Savoy. The model was further supported by backcross data. Backcrossing the F_1 and reciprocal F_1 to the dominant cultivar Chieftain Savoy produced ratios of 3:29 and 0:15 respectively (Table 41). 1975L F_2 populations of Baby Head x Badger Ballhead were not pooled. Both parents were small headed. However, in both of the F_2 populations segregants with head weights larger than either parent were observed (Table 42). Separating the F_2 data based on a dividing point (23) of 3.0 kg produced a segregation ratio of 204:11. The reciprocal F_2 population was separated using a 2.5 kg dividing point (23) to produce an observed segregation ratio of 168:10. Due to parental overlap a 15:1 weighted theoretical ratio was compared to both observed ratios. The data fit ($P=0.49, 0.18$) the weighted expected ratios of 201.6:13.4 and 163:15 respectively (Table 38). Since both cultivars were small headed large heads in the F_2 suggest that C was dominant to c_5 and D_5 was dominant to d . The presence of complementary homozygous loci, c_5c_5 and dd , in a genotype produced a large headed phenotype. Small head weights were produced by genotypes having 1 or more dominant alleles at either loci (Tables 16-17).

When Red Danish x Badger Ballhead F_1 population means were compared with their midparent means small head weight was incompletely dominant in both the 1974L and 1975L plantings and large heads were completely dominant in the 1975E planting (Tables 11-13). F_2 populations of Red Danish x Badger Ballhead grown in the 1975E planting were

Table 41. Parent, F₁, F₂, and backcross head weight distributions in percent for the 1975E planting of the cross Baby Head x Chieftain Savoy.

	No. of Plants	Head Weight in Kilograms Upper Limit of Class											Mean
		0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	
Baby Head (P ₁)	42	19.0	71.5	9.5									0.7 ± 0.2
Chieftain Savoy (P ₅)	34	2.9	5.9	2.9	8.8	11.9	20.6	14.7	20.6		2.9	8.8	3.0 ± 1.3
(P ₁ × P ₅)	52		1.9	19.2	11.5	11.5	11.5	13.7	15.4	9.6	3.8	1.9	2.7 ± 1.2
(P ₅ × P ₁)	83		1.2	3.6	2.4	6.0	20.6	18.1	21.7	13.2	6.0	7.2	3.4 ± 1.0
(P ₁ × P ₅) F ₂	192	0.5	4.7	7.8	19.3	20.7	18.8	12.0	9.9	2.1	4.2		2.5 ± 0.9
(P ₅ × P ₁) F ₂	197	1.0	3.6	12.2	25.8	20.3	12.2	10.2	7.1	4.1	1.0	2.5	2.4 ± 1.0
(P ₁ × P ₅) × P ₅	32	3.1	3.1	3.1	12.5	15.7	9.4	9.4	12.5	15.7	6.2	9.3	3.2 ± 1.4
(P ₅ × P ₁) × P ₅	15				6.7	13.3	6.7		13.3	26.7	20.0	13.3	3.9 ± 1.2
(P ₅ × P ₁) × P ₁	55		5.4	12.7	20.0	25.5	7.3	18.2	7.3	3.6			2.4 ± 0.9

Table 42. Parent, F₁ and F₂ head weight distributions in percent for the 1975L planting of the cross Baby Head x Chieftain Savoy.

	No. of Plants	Head Weight in Kilograms Upper Limit of Class										Mean
		0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	9.5
Baby Head (P ₁)	53	17.0	52.8	30.2								0.8 ± 0.3
Chieftain Savoy (P ₅)	43	4.6	37.2	30.3	11.6	14.0	2.3					1.2 ± 0.6
(P ₁ x P ₅)	20		5.0	35.0	25.0	15.0		15.0	5.0			2.2 ± 1.0
(P ₅ x P ₁)	59	1.7	16.9	10.2	18.6	25.4	13.6	3.4	10.2			2.0 ± 0.9
(P ₁ x P ₅) F ₂	215	4.2	19.1	29.2	21.8	14.0	6.5	2.8	1.9	0.5		1.6 ± 0.8
(P ₅ x P ₁) F ₂	178	9.6	32.0	27.0	18.5	7.3	4.5	1.1				1.2 ± 0.6

pooled to produce a segregation ratio of 230:133. The dividing point (23) was 2.5 kg. This segregation ratio fit ($P=0.05$) a 9:7 weighted theoretical ratio of 212:151 (Table 37). A single dominant allele at each locus was required to produce a small cabbage head phenotype. Thus the genotype c_2d_2 conditioned a small head. Dominant alleles, c_2 and d_2 , were contributed by Red Danish. Backcrossing to the recessive cultivar Badger Ballhead produced a ratio of 1:11. The ratio fit ($P=0.20$) a 1:3 model of 3:9. Backcrossing to the dominant cultivar, Red Danish produced a 25:22 ratio (Table 43). F_2 populations for the 1975L planting were also pooled. The observed segregation ratio, 266:55, fit ($P=0.19$) a 13:3 weighted theoretical ratio of 257:64 (Table 38). A dividing point (23) of 1.5 kg was used (Table 44). Either a dominant genotype at the c locus or a recessive genotype at the d locus produced a small cabbage head. Large heads were produced by the genotype $c_3c_3d_2d_2$. Dominant alleles c_2 and d_2 were contributed by Red Danish. Recessive alleles, c_3 and d_3 , were contributed by Badger Ballhead.

1974L Red Danish x P.I. 215514 F_1 population means suggest head weight was additively inherited. The 1975E and 1975L F_1 means suggest large heads were incompletely dominant and small heads were incompletely dominant respectively (Tables 11-13). Due to limited seed, the Red Danish x P.I. 215514 F_2 population was grown only in the 1975E planting. Using a dividing point (23) of 2.5 kg an observed segregation ratio of 158:153 was produced (Table 45). This ratio was compared ($P=0.66$) to a 7:9 weighted theoretical ratio of 154:157 (Table 37). The presence of 1 dominant allele at each locus provided a basis for the ratio. Dominant c_4 and d_4 alleles were contributed by P.I. 215514 while Red Danish contributed the recessive alleles c_2 and d_2 . The genotype c_4d_4 conditioned a large head weight (Table 45).

Table 43. Parent, F_1 , F_2 , and backcross head weight distributions in percent for the 1975E planting of the cross Red Danish x Badger Ballhead.

	No. of Plants	Head Weight in Kilograms Upper Limit of Class											Mean
		0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	
Red Danish (P_4)	35		5.7	17.1	20.0	28.7	14.3	5.7	2.8	5.7			2.1 ± 0.9
Badger Ballhead (P_2)	39		12.8	2.6	7.8	10.2	12.8	10.2	12.8	10.2	12.8	7.8	3.1 ± 1.4
($P_4 \times P_2$)	96		3.1	5.2	14.6	19.8	12.5	14.6	16.7	5.2	4.2	4.1	2.9 ± 1.1
($P_2 \times P_4$)	90	2.2	4.4	12.2	14.6	18.9	22.2	12.2	8.9	4.4			2.4 ± 0.9
($P_4 \times P_2$) F_2	209	1.0	3.8	14.3	21.5	20.7	16.3	10.0	5.7	2.4	2.9	1.4	2.3 ± 1.0
($P_2 \times P_4$) F_2	154	0.6	7.1	16.9	19.8	22.1	12.3	7.1	1.9	5.8	2.6	3.8	2.3 ± 1.2
($P_4 \times P_2$) x P_2	12					8.3		41.8	25.0	8.3		16.6	3.8 ± 1.0
($P_2 \times P_4$) x P_4	47		4.2	12.8	12.8	23.4	27.7	10.6	6.4	2.1			2.4 ± 0.8

Table 44. Parent, F₁ and F₂ head weight distributions in percent for the 1975L planting of the cross Red Danish x Badger Ballhead.

	No. of Plants	Head Weight in Kilograms Upper Limit of Class										Mean
		0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	
Red Danish (P ₄)	32	25.0	18.8	28.1	15.6	12.5						1.1 ± 0.6
Badger Ballhead (P ₂)	49	2.0	12.2	12.2	26.6	14.3	10.2	10.2	8.2	4.1		2.1 ± 1.0
(P ₄ x P ₂)	23	17.4	21.8	13.0	21.8	13.0	13.0					1.4 ± 0.8
(P ₂ x P ₄)	19	21.0	42.1	10.5	15.8	5.3	5.3					1.0 ± 0.7
(P ₄ x P ₂) F ₂	291	22.0	37.8	23.0	10.0	4.1	1.4	1.0		0.7		1.0 ± 0.6
(P ₂ x P ₄) F ₂	30	20.0	33.4	30.0	10.0	3.3					3.3	1.1 ± 0.8

Table 45. Parent, F₁ and F₂ head weight distributions in percent for the 1975L planting of the cross Red Danish x P.I. 215514.

	No. of Plants	Head Weight in Kilograms Upper Limit of Class											Mean
		1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	
Red Danish (P ₄)	35	5.7	17.1	20.0	28.7	14.3	5.7	2.8	5.7				2.1 ± 0.9
P.I. 215514 (P ₃)	18		5.6	16.7	16.7	11.0	22.2			11.0	16.8		3.3 ± 1.6
(P ₄ × P ₃)	85	2.4	8.2	15.3	15.3	29.3	10.6	5.9	5.9	3.5	3.6		2.7 ± 1.1
(P ₃ × P ₄)	89	2.2	3.4	20.2	15.7	13.6	15.7	10.1	9.0	3.4	6.7		2.9 ± 1.2
(P ₄ × P ₃) F ₂	311	6.8	15.4	13.5	15.1	11.9	11.2	9.4	8.4	4.2	4.1		2.6 ± 1.3

Red Danish x Chieftain Savoy F_1 population means for the 1974L planting show an additive inheritance pattern for head weight. However, both the 1975E and 1975L plantings suggest overdominance for large head weights (Tables 11-13). Differences in the dominance direction of head weight between plantings coupled with the relatively stable dominance direction of maturity may have contributed to problems in estimating the genetic correlation of these 2 traits. Both Red Danish and Chieftain Savoy distributions in the 1975L planting were nearly identical. Red Danish x Chieftain Savoy F_2 segregation patterns did not deviate from the parental patterns observed (Table 48). Based on these distributions no segregation could be detected in this planting (Table 48). 1975E Red Danish x Chieftain Savoy F_2 populations produced a segregation ratio of 46:61 using a division point (23) of 2.5 kg (Table 47). This ratio fit ($P=0.55$) a 7:9 weighted theoretical ratio of 49:58 (Table 37). Large heads were dominant and conditioned by a single dominant allele at each locus. The genotype c_5-d_5 produced a large head weight phenotype. Recessive alleles, c_2 and d_2 , were contributed by Red Danish. The reciprocal F_2 population of this cross produced an observed segregation ratio of 56:46 which fit ($P=0.54$) a 9:7 weighted expected ratio of 59:43 (Table 37). The dividing point (23) was 2.5 kg. The presence of a single dominant c_2 or d_2 allele from Red Danish at each locus conditioned a small head phenotype. Recessive alleles, c_5 and d_5 , were contributed by Chieftain Savoy. F_1 and reciprocal F_1 backcrosses to Red Danish produced observed ratios of 5:15 and 13:27 respectively. The data show poor fit ($P<0.005$) to expected ratios of 13.5:4.5 and 40:0. The backcross data suggest Red Danish was recessive and produced large head weights, however cultivar distributions suggest Red Danish produced small heads.

Table 46. Parent and F₁ head weight distributions in percent for the 1975L planting of the cross Red Danish x P.I. 215514.

	No. of Plants	Head Weight in Kilograms Upper Limit of Class										Mean	
		0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0		9.5
Red Danish (P_4)	32	25.0	18.8	28.1	15.6	12.5							1.1 $\pm$ 0.6
P.I. 215514 (P_3)	13			23.0			38.5		7.7			30.8	3.6 $\pm$ 2.1
($P_4 \times P_3$)	44	20.4	50.0	22.7	2.3		2.3		2.3				0.9 $\pm$ 0.7
($P_3 \times P_4$)	14	21.4	35.7	14.4					21.4	7.1			1.6 $\pm$ 1.4

Table 47. Parent, F_1 , F_2 , and backcross head weight distributions in percent for the 1975E planting of the cross Red Danish x Chieftain Savoy.

	No. of Plants	Head Weight in Kilograms Upper Limit of Class											Mean
		0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	
Red Danish (P_4)	35		5.7	17.1	20.0	28.7	14.3	5.7	2.8	5.7			2.1 ± 0.9
Chieftain Savoy (P_5)	34	2.9	5.9	2.9	8.8	11.9	20.6	14.7	20.6		2.9	8.8	3.0 ± 1.3
(P_4 x P_5)	33	3.0	6.1	6.1	6.1	18.2	12.1	9.1	21.2	12.1	3.0	3.0	3.8 ± 1.4
(P_5 x P_4)	80	2.5	1.2	3.8	6.2	7.5	10.0	15.0	26.3	12.5	8.8	6.2	3.4 ± 1.2
(P_4 x P_5) F_2	107	0.9	3.7	8.4	12.1	17.8	20.7	14.0	9.3	7.5	1.9	3.7	2.7 ± 1.2
(P_5 x P_4) F_2	102	2.9	3.9	10.8	26.5	10.8	11.8	10.8	9.8	3.9	2.9	5.9	2.6 ± 1.3
(P_4 x P_5) x P_4	18			5.6		22.2	16.6	33.3	5.6	5.6	11.1		3.0 ± 0.9
(P_5 x P_4) x P_4	37		8.1	8.1	8.1	10.8	29.8	21.6	5.4	8.1			2.6 ± 1.0

Table 48. Parent, F₁ and F₂ head weight distributions in percent for the 1975L planting of the cross Red Danish x Chieftain Savoy.

Head Weight in Kilograms Upper Limit of Class												
	No. of Plants	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5		Mean
Red Danish (P_4)	32	25.0	18.8	28.1	15.6	12.5						1.1 ± 0.6
Chieftain Savoy (P_5)	43	4.6	37.2	30.3	11.6	14.0	2.3					1.2 ± 0.6
($P_4 \times P_5$)	28	3.6	17.8	7.2	35.7	25.0	10.7					1.7 ± 0.7
($P_5 \times P_4$)	30	3.3	3.3	26.7	43.4	13.3	6.7	3.3				1.8 ± 0.6
($P_4 \times P_5$) F_2	199	18.6	37.2	22.7	9.0	4.5	4.0	3.0	0.5	0.5		1.1 ± 0.8
($P_5 \times P_4$) F_2	224	21.0	33.0	26.8	13.9	4.5	0.4	0.4				1.0 ± 0.6

Green cabbage F_1 heritability estimates for head weight have been previously shown by Swarup (30) to be 0.4 and by Chiang (3) to be 0.04. This study shows mean head weight heritability for green cabbage crosses to be large, $\bar{h}^2 = 0.87 \pm 0.49$ while $\bar{h}^2 = 0.06 \pm 0.12$ for head weight in red x green cabbage crosses. Heritability estimates between 0 and 1 ranged from 0.86 to 0.89 for green cabbage crosses and from 0.05 to 0.93 for red x green cabbage crosses (Table 30). The $\bar{h}_x^2$ values were 0.93 ± 0.36 and 0.08 ± 0.12 respectively. Reciprocal effects can be noted in the negative and positive h^2 estimates shown for head weight in the 1975L red x green cabbage F_1 planting. Environmental effects can be shown by comparing the 1974L red x green cabbage heritability estimate of $h^2 = 0.05$ with the 1975L estimate of $h^2 = 0.93$. These differences point out the need for numerous experiments prior to accepting a reliable heritability parameter for a given location (Table 30).

Genetic correlation estimates between head weight and total non-wrapper leaf weight for green cabbage crosses ranged from 0.35 to 0.92 (Table 49). The mean genetic correlation was 0.78 ± 0.48 and the $\bar{r}_{gx} = 0.78 \pm 0.48$. The mean genetic correlation between head weight and stalk size was 0.96 ± 0.18 with an $\bar{r}_{gx}$ value of 0.97 ± 0.17 . Genetic correlation estimates ranged from 0.33 to 0.98. A large number of negative correlation estimates were observed between head weight and non-wrapper leaf number. It appears that larger heads tend to have fewer non-wrapper leaves than smaller heads. The $\bar{r}_g$ estimate for head weight and non-wrapper leaf number was -0.73 ± 0.63 and the $\bar{r}_{gx}$ value was 0.39 ± 0.37 . The mean genetic correlation between head weight and non-wrapper leaf size was 0.83 ± 0.41 . The $\bar{r}_{gx}$ value was 0.93 ± 0.29 . These genetic correlations suggest that head weight was positively correlated with total non-wrapper leaf weight and a few large leaves rather than many

Table 49. Genetic correlation between head weight and four other traits in cabbage.

Traits	Plantings	Green Crosses		Red Crosses	
			R*		R*
Head Weight x Total Non-wrapper Leaf Weight	1974L	0.62	0.40	A	A
	1975E	0.56	0.77	A	0.46
	1975L	0.35	0.92	B	-0.07
Head Weight x Stalk Size	1974L	0.83	0.86	A	A
	1975E	A	0.98	0.98	0.62
	1975L	0.33	0.73	B	-0.85
Head Weight x Non-wrapper Leaf Number	1974L	0.08	-0.19	-0.94	B
	1975E	-0.84	-1.00	A	0.21
	1975L	0.12	A	A	B
Head Weight x Non-wrapper Leaf Size	1974L	0.95	0.83	A	A
	1975E	A	A	A	0.65
	1975L	0.12	0.60	-0.11	A

*Reciprocal cross

A = Correlation estimates greater than 1.0

B = Correlation estimates less than -1.0

smaller leaves. Red x green cabbage crosses produced a greater number of negative genetic correlation estimates than did green cabbage crosses (Table 49). The relationship between head weight and total non-wrapper leaf weight for red x green cabbage crosses was 0.34 ± 0.87 with an $\bar{r}_{gx}$ estimate of 0.36 ± 0.84 . Genetic correlation estimates ranged from -0.07 to 0.46. Genetic correlations between head weight and stalk size ranged from -0.85 to 0.98. The mean genetic correlation between these 2 traits was 0.36 ± 0.97 with a $\bar{r}_{gx}$ estimate of 0.58 ± 0.75 . Mean genetic correlations between head weight and non-wrapper leaf number and non-wrapper leaf size were -0.23 ± 0.93 and 0.54 ± 0.90 respectively. The $\bar{r}_{gx}$ estimates were -0.76 ± 0.67 and 0.76 ± 0.65 with r_g estimates ranging from -0.94 to 0.21 and -0.11 to 0.65 respectively (Table 49).

Total Non-Wrapper Leaf Weight

Cultivar analysis showed that differences exist within cultivars, inbreeding and plantings. Interactions between each of these effects were significant (Table 50). One generation of inbreeding significantly increased total non-wrapper leaf weight by 0.15 kg. This trait may not be genetically fixed in the cultivars since negative heterosis was still modifying the plant phenotype (Table 51). There was no difference between Red Danish and Chieftain Savoy for total non-wrapper leaf weight, however, the remaining cultivars were each significantly different from this group. Total non-wrapper leaf weight ranged from 0.19 kg for Baby Head to 2.43 kg for P.I. 215514 (Table 51). Differences between plantings for total non-wrapper leaf weight suggest different environmental conditions can produce leaf weights ranging from 0.78 to 1.97 kg (Table 52). The cultivar x inbreeding interaction was significant

Table 50. Analysis of variance table for total non-wrapper leaf weight in kilograms.

Source of Variance	DF	Mean Square	F*
Replication (R)	2	0.08	1.24
Cultivar (C)	4	11.70	169.81**
Inbreeding (I)	1	0.49	7.10**
C x I	4	0.38	5.58**
Plantings (P)	2	10.82	156.96**
C x P	8	0.92	13.33**
I x P	2	0.45	6.53**
C x P x I	8	0.30	4.41**
Residual Error	58	0.07	

F test significant at the 5%, or 1%** level.

Table 51. Cultivar x inbreeding interaction means in kilograms for total non-wrapper leaf weight.

Cultivar	Inbreeding		Cultivar Means
	P_1	S_1	
Baby Head	0.23 a*	0.15 a	0.19 W
Badger Ballhead	1.42 b	1.04 a	1.09 X
P.I. 215514	2.18 a	2.67 b	2.43 Z
Red Danish	1.26 a	1.70 b	1.48 Y
Chieftain Savoy	1.47 a	1.46 a	1.47 Y
Inbreeding Means	1.26 A	1.40 B	

*Mean separation, within rows, by Duncan's Multiple Range Test at the 5% level.

Table 52. Cultivar x planting interaction means in kilograms for total non-wrapper leaf weight.

Cultivar	1974L	Plantings 1975E	1975L	Cultivar Means
Baby Head	0.17 a*	0.36 a	0.04 a	0.19 W
Badger Ballhead	1.69 c	1.19 b	0.39 a	1.09 X
P.I. 215514	3.02 b	2.17 a	2.09 a	2.43 Z
Red Danish	2.45 c	1.27 b	0.73 a	1.48 Y
Chieftain Savoy	2.52 c	1.25 b	0.63 a	1.47 Y
Planting Means	1.97 C	1.25 B	0.78 A	

*Mean separation, within rows, by Duncan's Multiple Range Test at the 5% level.

due to an increase in total non-wrapper leaf weight after 1 additional generation of inbreeding Red Danish. The other 3 cultivars were not effected by inbreeding (Table 51). The cultivar x planting interaction was significant due to differences in total non-wrapper leaf weight for both Baby Head and P.I. 215514. Baby Head showed no difference in total non-wrapper leaf weight for the 1974L and 1975E plantings; however, P.I. 215514 and the remaining cultivars showed a decrease in total non-wrapper leaf weight between these 2 planting times. Significant reductions in total non-wrapper leaf weight were noted for all cultivars except Baby Head and P.I. 215514 between the 1975E and 1975L plantings (Table 52). The significance of the inbreeding x planting interaction was due to an increase in total non-wrapper leaf weight after a generation of inbreeding in the 1974L planting. Inbreeding did not effect total non-wrapper leaf weight for the other plantings (Table 53). The significance of the second order interaction cultivar x inbreeding x planting can be attributed to differences due to inbreeding in the 1974L planting for Red Danish and P.I. 215514. The data show a significant increase in total non-wrapper leaf weight after 1 generation of inbreeding for both of these lines while no differences were shown for the other 3 cultivars. Total non-wrapper leaf weight was not affected by 1 generation of inbreeding in either the 1975E or 1975L plantings (Table 54).

Means of F_1 green cabbage crosses lie near the midparent mean and show incomplete dominance for non-wrapper leaf weight. Although the magnitude of the cultivar and F_1 population means seem to be affected by the environment, the F_1 means lie near the midparent mean for each planting. All 3 F_1 plantings of Baby Head x Badger Ballhead suggest

Table 53. Inbreeding x plantings interaction means in kilograms for total non-wrapper leaf weight.

Inbreeding	1974L	Plantings 1975E	1975L	Inbreeding Means
P ₁	1.76 a *	1.27 a	0.75 a	1.26 Y
S ₁	2.18 b	1.23 a	0.80 a	1.40 Z
Planting Means	1.97 C	1.25 B	0.78 A	

* Mean separation, within columns, by Duncan's Multiple Range Test at the 5% level.

Table 54. Cultivar x inbreeding x planting interaction means
in kilograms for total non-wrapper leaf weight.

Cultivar	Inbreeding	1974L	Plantings 1975E	1975L
Baby Head	P ₁	0.23 a*	0.39 a	0.06 a
	S ₁	0.12 a	0.33 a	0.02 a
Badger Ballhead	P ₁	1.79 a	1.24 a	0.42 a
	S ₁	1.59 a	1.15 a	0.37 a
P.I. 215514	P ₁	2.35 a	2.17 a	2.03 a
	S ₁	3.68 b	2.17 a	2.15 a
Red Danish	P ₁	1.83 a	1.36 a	0.60 a
	S ₁	3.07 b	1.18 a	0.86 a
Chieftain Savoy	P ₁	2.59 a	1.18 a	0.64 a
	S ₁	2.45 a	1.32 a	0.62 a

*Mean separation, within columns and cultivars, by Duncan's
Multiple Range Test at the 5% level.

incomplete dominance for total non-wrapper leaf weight. Reciprocal differences between F_1 population means were noted in the 1975L planting (Tables 11-13). Powers *et al.* (23) partitioning tests were applied to these distributions to determine the number of genes controlling total non-wrapper leaf weight and to define the boundary between small and large total non-wrapper leaf weight classes. Powers *et al.* (23) formula (F_2/P_1) was applied sequentially from the recessive ends of both the F_2 and P_1 distributions. Using the 1975E F_2 planting of Baby Head x Badger Ballhead (Table 55) as an example recessive frequencies of 6.0/4.8 or 1.25 for the 0.2 kg class, 12.0/23.8 or 0.50 for the 0.3 kg class, 21.5/61.9 or 0.35 for the 0.4 kg class, 31.8/88.1 or 0.36 for the 0.5 kg class, 46.1/95.2 or 0.48 for the 0.6 kg class and 67.3/100 or 0.67 for the 0.8 kg class were produced (Table 55). The increase in frequency between the 0.6 kg and 0.8 kg classes suggested a dividing point of 0.6 kg. Further, the mean of all values less than 1 for classes 0.2 to 0.6 kg was equal to 0.42, which closely resembles a 0.44 frequency expected from a 7:9 model. Due to overlap of the parental distributions a weighting procedure was used to adjust the expected genetic ratio to account for misclassified plants. The 1975E Baby Head x Badger Ballhead cross required a weighting procedure which was calculated in the following manner. The net overlap around the 0.6 kg dividing point was $2.6+2.6-4.8=0.4$. The expected number of plants in the deficient class was $((100-0.4)/100)(0.5625)(252)) = 141.23$. By subtraction a weighted expected ratio of 110.77:141.23 was produced (Table 57). The weighted expected ratio for the 1975E reciprocal planting was calculated in the following manner from a 0.5 kg dividing point (23). The expected number of plants in the deficient class was $((100-9.3)/100)$

Table 55. Parent, F₁, F₂ and backcross total non-wrapper leaf weight distributions in percent for the 1975E planting of the cross Baby Head x Badger Ballhead.

	No. of Plants	Total Non-wrapper Leaf Weight in Kilograms											Mean
		0.1	0.2	0.3	0.4	0.5	0.6	0.8	1.0	1.2	1.4	3.8	
Baby Head (P ₁)	42		4.8	19.0	38.1	26.2	7.1	4.8					0.4 ± 0.1
Badger Ballhead (P ₂)	39				2.6		2.6	17.9	17.9	10.2	12.8	36.0	1.2 ± 0.5
(P ₁ × P ₂)	83				3.6	7.3	13.2	45.8	12.0	9.7	4.8	3.6	0.8 ± 0.3
(P ₂ × P ₁)	89				1.1	11.3	20.2	34.9	24.7	5.6	1.1	1.1	0.7 ± 0.2
(P ₁ × P ₂) F ₂	252	0.8	5.2	6.0	9.5	10.3	14.3	21.2	14.7	5.6	4.4	8.0	0.7 ± 0.5
(P ₂ × P ₁) F ₂	248	2.0	9.7	15.3	13.3	12.1	15.7	13.4	9.3	4.4	1.6	3.2	0.6 ± 0.4
(P ₂ × P ₁) × P ₂	33		6.1	3.0	6.1	3.0	6.1	18.2	24.2	18.2	9.1	6.0	0.8 ± 0.4

Table 56. Parent, F₁ and F₂ total non-wrapper leaf weight distributions in percent for the 1975L planting of the cross Baby Head x Badger Ballhead.

Total Non-wrapper Leaf Weight in Kilograms												
		Upper Limit of Class										
No. of Plants		0.2	0.3	0.4	0.5	0.6	0.8	1.0	1.2	1.4	1.8	Mean
Baby Head (P_1)	53	100.0										0.1 ± 0.04
Badger Ballhead (P_2)	49	20.4	14.3	8.2	20.4	14.3	18.4	2.0		2.0		0.4 ± 0.2
($P_1 \times P_2$)	38	44.8	28.9		7.9	2.6	5.3	2.6	5.3	2.6		0.3 ± 0.4
($P_2 \times P_1$)	77	83.1	10.4	3.9	1.3	1.3						0.1 ± 0.1
($P_1 \times P_2$) F_2	130	73.8	9.2	6.9	3.9	2.3	2.3		0.8		0.8	0.2 ± 0.2
($P_2 \times P_1$) F_2	211	76.3	11.4	4.3	1.4	2.8	1.4	0.6		0.9	0.9	0.2 ± 0.2

Table 57. Chi-square test for goodness of fit to the postulated model for total non-wrapper leaf weight in the F_2 generation (1975E planting).

Cross	Observed	Expected	Model	χ^2	P
Baby Head x Badger Ballhead					
F_2	109:143	110.77:141.23*	7: 9	0.0504	0.82
RF_2	130:118	126.47:121.53*	9: 7	0.2010	0.65
Baby Head x P.I. 215514					
F_2	201: 58	194.25: 64.75	3: 1	0.9383	0.33
RF_2	331:120	338.25:112.75	3: 1	0.6216	0.43
Baby Head x Chieftain Savoy					
F_2	110: 82	103.10: 93.90*	7: 9	0.7073	0.40
RF_2	109: 88	100.49: 91.51*	7: 9	1.8893	0.17
Pooled	219:170	203.59:185.41*	7: 9	2.4466	0.12
Red Danish x Badger Ballhead					
F_2	70:139	80.85:128.15*	7: 9	2.3761	0.12
RF_2	59: 95	59.58: 94.42*	7: 9	0.0091	0.92
Pooled	129:234	140.43:222.57*	7: 9	1.5173	0.22
Red Danish x P.I. 215514					
F_2	110:201	115.14:195.86*	1: 3	2.3649	0.54
Red Danish x Chieftain Savoy					
F_2	10: 97	8.59: 98.41*	1:15	0.2516	0.64
RF_2	10: 92	8.19: 93.81*	1:15	0.4349	0.51
Pooled	20:189	16.78:192.21*	1:15	0.6718	0.44

* = Weighted

$(0.5625)(248) = 126.47$. The expected ratio was 126.47:121.53. The 1975E reciprocal F_2 population produced a different model and division point. The distribution was bimodal with inflection points at 0.3 kg and 0.6 kg. The 0.5 kg class, with the fewest members between 2 inflection points was selected as a division point. As in the previous example (23) the formula (F_2/P_2) suggested frequencies 3.2/32.0 or 0.08 for the 3.8 kg class, 4.8/48.8 or 0.10 for the 1.4 kg class, 9.2/59.0 or 0.16 for 1.2 kg class, 18.5/76.9 or 0.24 for the 1.0 kg class, 31.9/94.8 or 0.34 for the 0.8 kg class, 47.6/97.4 or 0.49 for the 0.6 kg class, 59.7/97.4 or 0.61 for the 0.5 kg class and 73.0/100 or 0.73 for the 0.4 kg class (Table 55). Since the mean of classes 3.8 and 1.4 was 0.089 which compares favorably with an expected 0.06 frequency expected from a digenic model a 2 gene model was postulated. The data also suggest division points (23) between classes 1.4 and 1.2 kg and also between classes 0.6 and 0.5 kg. An evaluation of the data suggested a 9:6:1 model might be appropriate. A multiple allelic 2 locus model was postulated as the simplest model available to insure digenic control of total non-wrapper leaf weight. To account for cultivar differences each locus in the model was given 5 alleles. The loci, E and G , produce the cultivar and F_1 genotypes noted in Tables 16 and 17. For the 1975E planting of green cabbage crosses, E_3 and E_5 were dominant to E , and E was dominant to e_4 . Alleles at the G locus were inherited in a similar manner. Red x green cabbage crosses suggest an allelic dominance pattern where E_3 and E_4 were dominant to E_2 , and E_2 was dominant to e_5 . A similar pattern was noted for the G locus. In the late planting E was dominant to e_3 , e_4 and e_5 ; E_2 was dominant to e_3 and e_5 . Similar patterns were noted for the G locus. Chi-square homogeneity tests suggest both

1975E F_2 populations of Baby Head x Badger Ballhead should not be pooled (Table 55). Using a dividing point of 0.6 kg an F_2 segregation ratio of 109 small non-wrapper leaf weight leaves to 142 large non-wrapper leaf weight leaves showed good fit ($P=0.82$) to a 7:9 weighted theoretical ratio of 11:141 (Table 57). A single dominant allele at each locus was required to produce a large total non-wrapper leaf weight. Dominant alleles, E_3 and G_3 , were contributed by Badger Ballhead, while recessive alleles, e and g , were produced by Baby Head. The reciprocal F_2 population produced a segregation ratio of 130:106:12 which fit ($P=0.43$) a 9:6:1 weighted expected ratio of 126.47:104.17:17.36. Data from a backcross between the reciprocal F_1 and Badger Ballhead produced an observed ratio of 6:27 which fit ($P=0.92$) an expected 1:3 ratio of 8.25:24.75. A single dominant allele at each locus conditioned small total non-wrapper leaf weight. Medium non-wrapper leaf weight was produced by a single dominant locus genotype. Large total non-wrapper leaf weight was produced by a homozygous recessive genotype. Dominant alleles, E and G were produced by Baby Head and recessive alleles, e_3 and g_3 , were contributed by Badger Ballhead. The reciprocal F_2 data support a 9:7 weighted theoretical ratio for total non-wrapper leaf weight inheritance (Table 57). The 96:34 F_2 ratio observed from the Baby Head x Badger Ballhead 1975L planting fit ($P=0.07$) a 3:1 weighted expected ratio of 104:26. A 0.2 kg division point was used. The reciprocal F_2 population produced a segregation ratio of 169:42 using a 0.2 kg division point. The ratio fit ($P=0.17$) an expected ratio of 169:42 produced by a 3:1 weighted theoretical ratio (Table 58). The presence of E conditioned a small leaf weight while the recessive genotype e_3e_3 conditioned a large leaf weight. Dominant alleles E and G

Table 58. Chi-square test for goodness of fit to the postulated model for total non-wrapper leaf weight in the F_2 generation (1975L planting).

Cross	Observed	Expected	Model	χ^2	P
Baby Head x Badger Ballhead					
F_2	96: 34	104.13: 25.87*	3: 1	3.1921	0.07
RF_2	161: 50	169.01: 41.98*	3: 1	1.9103	0.17
Pooled	257: 87	273.15: 67.85*	3: 1	4.7976	0.03
Baby Head x P.I. 215514					
F_2	128: 40	126.00: 42.00	3: 1	0.1269	0.72
RF_2	195: 49	183.00: 61.00	3: 1	3.1478	0.08
Pooled	323: 89	309.00: 103.00	3: 1	2.5372	0.11
Baby Head x Chieftain Savoy					
F_2	165: 50	168.75: 46.25*	3: 1	0.3873	0.53
RF_2	139: 39	139.71: 38.29*	3: 1	0.0167	0.90
Pooled	304: 89	308.46: 84.54*	3: 1	0.2997	0.58
Red Danish x Badger Ballhead					
F_2	55: 236	49.37: 241.63*	1: 3	0.7744	0.38
RF_2	14: 16	5.09: 24.91*	1: 3	18.7889	<0.01
Red Danish x Chieftain Savoy					
F_2	51: 148	51.48: 147.51*	1: 3	0.0062	0.94
RF_2	49: 175	57.95: 166.05*	1: 3	1.8661	0.17
Pooled	100: 323	109.44: 313.56*	1: 3	3.5405	0.06

* = Weighted

were contributed by Baby Head while the recessive alleles e_3 and g_3 were produced by Badger Ballhead (Table 56).

F_1 population means for Baby Head x P.I. 215514 suggest total non-wrapper leaf weight inheritance ranged from incomplete dominance for small total weight in the 1975E and 1975L plantings to additive inheritance in the 1974L planting (Tables 11-13). Both 1975E F_2 populations of Baby Head x P.I. 215514 fit 3:1 models. The genotype $E_G_$ produced a dominant small non-wrapper leaf weight phenotype (Table 59). Using a division point of 1.1 kg an observed ratio of 201:58 was produced which fit ($P=0.33$) a 3:1 model of 194.25:64.75. The reciprocal F_2 population, using a 1.3 kg dividing point, produced an observed ratio of 331:120 which fit ($P=0.43$) a 3:1 model of 338.25:112.75 (Table 57). Baby Head x P.I. 215514 F_2 populations grown in the 1975L planting were pooled. Using a division point of 0.5 kg an observed ratio of 323:89 was produced (Table 60). The ratio fit ($P=0.53$) a 3:1 model of 309:103 (Table 58). The genotype $e_4e_4g_4g_4$ conditioned a recessive large total non-wrapper leaf weight phenotype. Dominant alleles E and G were contributed by Baby Head.

Baby Head x Chieftain Savoy F_1 populations suggest total non-wrapper leaf weight was inherited in an additive manner. Both the 1974L and 1975E F_1 population means were larger than the midparent mean. F_1 means for the 1975L planting suggest incomplete dominance for small total non-wrapper leaf weight (Tables 11-13). Baby Head x Chieftain Savoy F_2 distributions within the 1975E and 1975L plantings were pooled. The 1975E F_2 segregation ratio of 219:170 was compared ($P=0.12$) to a 7:9 weighted theoretical ratio of 204:185 (Table 57). The division point was 0.7 kg (Table 61). One dominant allele at each loci conditioned

Table 59. Parent, F₁ and F₂ total non-wrapper leaf weight distributions in percent for the 1975E planting of the cross Baby Head x P.I. 215514.

	No. of Plants	Total Non-wrapper Leaf Weight in Kilograms Upper Limit of Class											Mean
		0.1	0.3	0.5	0.7	0.9	1.1	1.3	1.5	1.7	1.9	4.2	
Baby Head (P ₁)	42		23.8	64.3	9.5	2.4							0.4 ± 0.1
P.I. 215514 (P ₃)	18								11.1	5.6	22.2	61.1	2.2 ± 0.6
(P ₁ x P ₃)	86	3.5		3.5	4.6	23.2	26.8	19.8	8.1	8.1	1.2	1.2	1.0 ± 0.4
(P ₃ x P ₁)	70			1.4	10.2	11.4	25.4	22.8	10.2	14.3	4.3		1.1 ± 0.3
(P ₁ x P ₃) F ₂	259	1.5	14.3	17.0	17.8	15.0	12.0	7.7	5.8	3.9	2.3	2.7	0.8 ± 0.5
(P ₃ x P ₁) F ₂	451	1.3	7.1	14.0	12.6	13.5	14.6	10.2	9.8	5.1	2.9	8.9	1.0 ± 0.6

Table 60. Parent, F₁ and F₂ total non-wrapper leaf weight distributions in percent for the 1975L planting of the cross Baby Head x P.I. 215514.

	No. of Plants	Total Non-wrapper Leaf Weight in Kilograms											
		0.2	0.3	0.4	0.5	0.6	0.8	1.0	1.2	1.4	1.8	3.8	Mean
Baby Head (P ₁)	53	100.0											0.1 ± 0.04
P.I. 215514 (P ₃)	13							7.7	7.7	15.4	23.0	46.2	2.0 ± 0.7
(P ₁ x P ₃)	73	20.6	39.7	19.2	13.7	2.7	4.1						0.3 ± 0.1
(P ₃ x P ₁)	81	16.0	23.4	17.3	22.2	12.3	7.4	1.4					0.4 ± 0.2
(P ₁ x P ₃) F ₂	168	38.1	15.4	13.1	9.5	7.2	8.3	3.0	1.8	1.2	2.4		0.4 ± 0.3
(P ₃ x P ₁) F ₂	244	39.3	16.8	10.2	13.5	4.5	9.4	2.3	2.4	0.4	0.8	0.4	0.3 ± 0.3

Table 61. Parent, F_1 , F_2 , and backcross total non-wrapper leaf weight distributions in percent for the 1975E planting of the cross Baby Head x Chieftain Savoy.

Total Non-wrapper Leaf Weight in Kilograms													
		Upper Limit of Class											
No. of Plants	0.1	0.3	0.5	0.7	0.9	1.1	1.3	1.5	1.7	1.9	3.8	Mean	
Baby Head (P_1)	42	23.8	64.3	9.5	2.4							0.4 ± 0.1	
Chieftain Savoy (P_5)	34	5.9	8.8	3.0	23.5	14.7	8.8	3.0	8.8	14.7	8.8	1.2 ± 0.7	
(P_1 × P_5)	52	5.8	15.4	30.8	15.4	15.4	9.6	3.8	1.9		1.9	0.8 ± 0.4	
(P_5 × P_1)	83	2.4	4.8	13.2	31.3	15.7	9.6	6.2	4.8	2.4	4.8	0.8 ± 0.5	
(P_1 × P_5) F_2	192	1.6	15.1	18.2	22.4	14.6	9.4	7.4	5.7	3.6	1.5	0.7 ± 0.4	
(P_5 × P_1) F_2	197	1.5	12.2	20.8	20.8	14.7	12.7	5.2	6.6	2.5	3.0	0.7 ± 0.4	
(P_1 × P_5) × P_5	32		3.1	6.2	6.2	18.8	15.7	15.7	12.5	9.4	6.2	1.1 ± 0.5	
(P_5 × P_1) × P_5	15		20.0		6.7	20.0		6.7	13.3	6.7	13.3	1.2 ± 0.9	
(P_5 × P_1) × P_1	55	9.1	29.2	20.0	14.5	7.3	7.3	3.6	5.4	1.8		0.5 ± 0.4	

large leaf weight. A homozygous recessive locus in the genotype conditioned small total non-wrapper leaf weight. Dominant alleles, E_5 and G_5 , were contributed by Chieftain Savoy. Recessive alleles e and g were contributed by Baby Head. Backcrossing the reciprocal F_1 to the recessive cultivar, Baby Head, produced a segregation ratio of 42:13 (Table 61). This data fit ($P=0.84$) a 3:1 model expected on backcrossing to a 7:9 model. Both backcrosses to Chieftain Savoy suggest the absence of complete dominance. Backcrossing to the F_1 produced a 5:27 ratio while backcrossing to the reciprocal F_1 produced a 5:10 ratio. Ratios of 0:32 and 0:15 were expected to support the 7:9 model. Data from the pooled 1975L F_2 population suggest the genotype E_{---} was dominant for small non-wrapper leaf weight under these growing conditions (Table 62). Using a dividing point of 0.4 kg the pooled 1975L F_2 population produced a segregation ratio of 304:89 which fit ($P=0.53$) a 3:1 weighted theoretical ratio of 308:85 (Table 58). A single dominant gene controlled small total non-wrapper leaf weight in this cross. The recessive genotype $e_5e_5g_5g_5$ conditioned large total non-wrapper leaf weight in this planting.

Red x green cabbage crosses exhibit a different direction of dominance and inheritance pattern for total non-wrapper leaf weight. Although 1975L F_1 plantings of Red Danish x Badger Ballhead and Red Danish x P.I. 215514 produce population means approximating the midparent mean, suggesting additive gene action, the remaining crosses in the 1974L, 1975E and 1975L plantings exhibited dominance or overdominance for increased total non-wrapper leaf weight (Tables 11-13). The pooled 1975E F_2 population of Red Danish x Badger Ballhead produced a segregation ratio of 129:234 using a division point of 1.2 kg (Table 63). This ratio fit ($P=0.22$) a 7:9 weighted theoretical ratio of 140:223 (Table 57).

Table 62. Parent, F_1 and F_2 total non-wrapper leaf weight distributions in percent for the 1975L planting of the cross Baby Head x Chieftain Savoy.

Total Non-wrapper Leaf Weight in Kilograms												
		Upper Limit of Class										
	No. of Plants	0.2	0.3	0.4	0.5	0.6	0.8	1.0	1.2	1.4	1.8	Mean
Baby Head (P_1)	53	100.0										0.1 ± 0.04
Chieftain Savoy (P_5)	43	9.3	4.6		9.3	28.1	23.2	14.0	4.6	2.3	4.6	0.6 ± 0.3
(P_1 x P_5)	20	10.0	30.0	15.0	10.0	30.0	5.0					0.4 ± 0.1
(P_5 x P_1)	59	44.1	20.3	16.9	8.5	6.8	3.4					0.2 ± 0.2
(P_1 x P_5) F_2	215	50.7	15.3	10.6	8.4	4.2	7.9	1.9	0.5	0.5		0.3 ± 0.2
(P_5 x P_1) F_2	178	52.2	15.2	10.7	8.4	3.4	5.0	3.4	1.1		0.6	0.3 ± 0.3

Table 63. Parent, F_1 , F_2 , and backcross total non-wrapper leaf weight distributions in percent for the 1975E planting of the cross Red Danish x Badger Ballhead.

Total Non-wrapper Leaf Weight in Kilograms Upper Limit of Class													
No. of Plants	0.8	1.0	1.2	1.4	1.6	1.8	2.0	2.2	2.4	3.0	3.6	Mean	
Red Danish (P_4)	35	17.2	2.8	17.1	14.6	22.8	2.8	5.7	2.8	8.6	5.6	1.4 ± 0.7	
Badger Ballhead (P_2)	39	23.1	17.9	10.2	12.8	12.8	10.2	5.2	2.6		5.2	1.2 ± 0.5	
(P_4 × P_2)	96	1.0	1.0	10.5	14.6	19.8	18.8	10.5	12.5	5.2	5.1	1.0	1.7 ± 0.4
(P_2 × P_4)	90	1.1	5.6	6.7	11.1	20.0	22.2	15.6	3.3	6.7	5.5	2.2	1.7 ± 0.5
(P_4 × P_2) F_2	209	7.6	15.8	10.0	13.9	15.4	11.0	11.0	7.2	4.3	2.8	1.0	1.4 ± 0.5
(P_2 × P_4) F_2	154	9.1	11.7	17.5	9.7	16.9	9.7	10.8	3.2	6.5	3.1	1.8	1.4 ± 0.6
(P_4 × P_2) × P_2	12			16.7	16.7	33.4	8.3	8.3			8.3	8.3	1.7 ± 0.6
(P_2 × P_4) × P_4	47			2.1	4.2	8.5	10.6	21.5	10.6	8.5	31.9	2.1	2.1 ± 0.5

Data from the backcross F_1 x Badger Ballhead suggest a poor fit ($P < 0.005$) to the expected 3:1 model. Data from the backcross F_1 x Red Danish produced an observed ratio of 1:46. A 0.47 ratio was expected (Table 63). The data support the postulated 7:9 model. Genes contributed by Red Danish, E_2 and G_2 , were dominant for increased total non-wrapper leaf weight (Table 16). The presence of a homozygous recessive e_3 or g_3 locus conditioned small total non-wrapper leaf weight. The same genes appear to be dominant in the 1975L planting. The Red Danish x Badger Ballhead F_2 population produced 55 small total non-wrapper leaf weight phenotypes and 236 large total non-wrapper leaf weight phenotypes. A 1:3 weighted expected ratio of 49:242 was compared ($P = 0.38$) to the observed segregation ratio (Table 58). A division point of 0.4 kg was used to separate the F_2 data into classes (Table 64). The genotype E_2 was dominant for large total non-wrapper leaf weight (Table 64). The recessive genotype $e_3e_3g_3g_3$ conditioned small total non-wrapper leaf weight. The e_3 and g_3 alleles were contributed by Badger Ballhead.

Although data from the 1975L F_1 planting of Red Danish x P.I. 215514 suggest incomplete dominance for small total non-wrapper leaf weight, data from both the 1974L and 1975E F_1 plantings suggest over-dominance for large total non-wrapper leaf weight (Tables 11-13). The dominant E_4 allele donated by P.I. 215514 produced a large total non-wrapper leaf weight phenotype when compared to the e_2 allele (Tables 16, 65). Using a dividing point of 1.8 kg the 1975E planting of Red Danish x P.I. 215514 produced an F_2 segregation ratio of 110:201. The data fit ($P = 0.54$) a 1:3 weighted expected ratio of 115:196 suggesting the E_4 allele was dominant (Table 57). No F_2 populations of this cross were planted in the 1975L planting (Table 66).

Table 64. Parent, F_1 and F_2 total non-wrapper leaf weight distributions in percent for the 1975L planting of the cross Red Danish x Badger Ballhead.

Total Non-wrapper Leaf Weight in Kilograms													
Upper Limit of Class													
No. of Plants	0.2	0.3	0.4	0.5	0.6	0.8	1.0	1.2	1.4	1.8	3.8	Mean	
Red Danish (P_4)	32	21.9	3.1	12.5	12.5	21.9	15.6	3.1	6.3	3.1		0.6 ± 0.3	
Badger Ballhead (P_2)	49	20.4	14.3	8.2	20.4	14.3	18.4	2.0	2.0			0.4 ± 0.2	
($P_4 \times P_2$)	23		21.7	30.4	13.0	30.4	4.3					0.5 ± 0.2	
($P_2 \times P_4$)	19		21.0	21.0	26.4	31.6						0.5 ± 0.1	
($P_4 \times P_2$) F_2	291	3.1	5.5	10.3	12.1	16.8	25.9	14.4	7.2	2.7	1.0	0.6 ± 0.3	
($P_2 \times P_4$) F_2	30	26.7	3.3	16.7	13.4	6.7	13.4	3.3	3.3	3.3	6.6	0.7 ± 0.9	

Table 65. Parent, F₁ and F₂ total non-wrapper leaf weight distributions in percent for the 1975E planting of the cross Red Danish x P.I. 215514.

	No. of Plants	Total Non-wrapper Leaf Weight in Kilograms Upper Limit of Class											Mean
		0.8	1.0	1.2	1.4	1.6	1.8	2.0	2.2	2.4	3.0	5.0	
Red Danish (P ₄)	35	17.2	2.8	17.1	14.6	22.8	2.8	5.7	2.8	8.6	5.6	1.4 ± 0.7	
P.I. 215514 (P ₃)	18					11.1	27.8	11.1	11.1	5.6	22.2	11.1	2.2 ± 0.6
(P ₄ x P ₃)	85		1.2	1.2	1.2	3.5	3.5	14.0	14.0	11.8	27.1	22.5	2.5 ± 0.7
(P ₃ x P ₄)	89	1.1		2.2	3.4	9.0	11.2	5.8	16.8	14.6	28.1	7.8	2.2 ± 0.6
(P ₄ x P ₃) F ₂	311	3.1	2.9	4.8	6.4	9.0	9.0	9.6	9.6	11.7	21.8	12.1	2.1 ± 0.8

Table 66. Parent and F₁ total non-wrapper leaf weight distributions in percent for the 1975L planting of the cross Red Danish x P.I. 215514.

	No. of Plants	Total Non-wrapper Leaf Weight in Kilograms											Mean
		0.2	0.3	0.4	0.5	0.6	0.8	1.0	1.2	1.4	1.8	3.8	
Red Danish (P ₄)	32		21.9	3.1	12.5	12.5	21.9	15.7	3.1	6.2	3.1		0.6 ± 0.3
P.I. 215514 (P ₃)	13							7.7	7.7	15.4	23.0	46.2	2.0 ± 0.7
(P ₄ x P ₃)	44			2.3		4.5	22.7	15.9	22.7	11.4	9.1	11.4	1.1 ± 0.5
(P ₃ x P ₄)	14	14.3		7.1			21.6	7.1	35.7	7.1	7.1		0.8 ± 0.4

F_1 data from the 3 plantings, 1974L, 1975E and 1975L, of Red Danish x Chieftain Savoy suggest overdominance for large total non-wrapper leaf weight (Tables 11-13). F_2 populations within each planting were pooled based on chi-square homogeneity test results (Tables 67, 68). Using a dividing point of 1.2 kg the pooled 1975E F_2 populations produced a segregation ratio of 20:189 which fit ($P=0.44$) a 1:15 weighted expected ratio of 17:192 (Table 57). Both the F_1 and reciprocal F_1 plants were backcrossed to the dominant cultivar Red Danish. Ratios of 0:18 and 8:29 were observed. Ratios of 0:18 and 0:37 were expected on backcrossing to a 1:15 ratio (Table 67). Results from crossing the reciprocal F_1 to Red Danish suggest dominance may be incomplete. A single dominant gene at either or both loci conditioned large total non-wrapper leaf weight. The recessive genotype $e_5e_5g_5g_5$ conditioned small total non-wrapper leaf weight. Recessive alleles e_5 and g_5 were contributed by Chieftain Savoy. Using a 0.6 kg dividing point the pooled 1975L F_2 population produced a segregation ratio of 100:323. The data fit ($P=0.06$) a 1:3 weighted expected ratio of 109:314 (Table 58). Red Danish was the source of dominant genes for large total non-wrapper leaf weight in this population (Table 68). The presence of a dominant E_2 allele in the genotype conditioned a large total non-wrapper leaf weight phenotype regardless of the G locus genotype. F_2 segregation ratios support dominance patterns noted in the F_1 generation, i.e., dominance for small total non-wrapper leaf weight in green cabbage crosses and dominance for large total non-wrapper leaf weight in red x green cabbage crosses.

Heritability estimates of total non-wrapper leaf weight for green cabbage crosses were as follows: 4 of the 6 heritability estimates were

Table 67. Parent, F₁, F₂, and backcross total non-wrapper leaf weight distributions in percent for the 1975E planting of the cross Red Danish x Chieftain Savoy.

Total Non-wrapper Leaf Weight in Kilograms Upper Limit of Class													
No. of Plants	0.8	1.0	1.2	1.4	1.6	1.8	2.0	2.2	2.4	3.0	4.8	Mean	
Red Danish (P_4)	35	17.2	2.8	17.1	14.6	22.8	2.8	5.7	2.8	8.6	5.6	1.4 + 0.7	
Chieftain Savoy (P_5)	34	32.5	14.7	14.7	5.9	5.9	14.7	2.9	2.9	2.9	2.9	1.2 + 0.7	
($P_4 \times P_5$)	33		3.0	3.0		6.1	6.1	15.2	12.1	6.1	36.3	12.1	2.2 + 0.6
($P_5 \times P_4$)	80	1.2	2.5	3.8	3.8	8.8	7.5	11.2	11.2	17.7	24.9	7.4	2.2 + 0.6
($P_4 \times P_5$) F_2	107	3.7	4.7	0.9	2.8	15.9	13.1	13.1	15.1	6.5	19.5	4.7	2.0 + 0.7
($P_5 \times P_4$) F_2	102	4.0	2.0	3.9	4.9	5.9	4.9	9.8	15.4	6.9	24.5	17.8	2.3 + 0.9
($P_4 \times P_5$) $\times P_4$	18				5.6	5.6	11.0	22.2	22.2	16.7		16.7	2.2 + 0.7
($P_5 \times P_4$) $\times P_4$	37	5.4	5.4	10.8	24.3	21.7	5.4	5.4	8.1	5.4	8.1	8.1	1.6 + 0.7

Table 68. Parent, F₁ and F₂ total non-wrapper leaf weight distributions in percent for the 1975L planting of the cross Red Danish x Chieftain Savoy.

	No. of Plants	Total Non-wrapper Weight in Kilograms Upper Limit of Class												Mean
		0.2	0.3	0.4	0.5	0.6	0.8	1.0	1.2	1.4	1.8	3.8		
Red Danish (P ₄)	32		21.9	3.1	12.5	12.5	21.9	15.6	3.1	6.3	3.1			0.6 ± 0.3
Chieftain Savoy (P ₅)	43	9.3	4.6		9.3	28.1	23.2	14.0	4.6	2.3	4.6			0.6 ± 0.3
(P ₄ x P ₅)	28		7.1	3.6	3.6	10.7	14.3	17.9	21.4	7.1	10.7	3.6		0.9 ± 0.4
(P ₅ x P ₄)	30		10.0	6.7	3.3	10.0	10.0	20.0	16.7	13.3	6.7	3.3		0.9 ± 0.4
(P ₄ x P ₅) F ₂	199	2.5	5.5	4.5	5.0	8.0	22.2	16.2	18.6	9.0	6.0	2.5		0.8 ± 0.4
(P ₅ x P ₄) F ₂	224	4.0	2.2	3.6	5.4	6.7	21.6	18.8	13.8	7.6	12.0	4.3		0.9 ± 0.5

greater than 1. One of the 6 estimates was negative (Table 30). The 1975E planting provided a heritability estimate of 0.54 ± 0.54 , suggesting that at least half of the variation in the F_1 population was additive. The $\bar{h}_x^2$ estimate was 0.75 ± 0.39 . F_1 red x green cabbage populations produced 4 heritability estimates greater than 1 and 2 estimates within the range of 0 to 1. The estimates were 0.17 for the 1974L planting and 0.88 for the 1975L planting. The 71% difference between the 2 estimates suggests that a large number of estimates are needed to obtain a reliable heritability estimate. The mean heritability estimate for red x green cabbage crosses was 0.36 ± 0.37 and $\bar{h}_x = 0.60 \pm 0.29$ (Table 30).

Green cabbage cross genetic correlation estimates between total non-wrapper leaf weight and stalk size range from 0.16 to 0.96 (Table 69). The $\bar{r}_g$ value for this pair of variables was 0.93 ± 0.26 . The mean genetic correlation between total non-wrapper leaf weight and non-wrapper leaf number was 0.33 ± 0.11 and ranged from -0.96 to 0.98. The green cabbage mean genetic correlation between total non-wrapper leaf weight and non-wrapper leaf size was 0.90 ± 0.37 with r_g estimates ranging from 0.51 to 0.95. The r_{gx} value was 0.63 ± 0.29 . Red x green cabbage crosses exhibit a mean genetic correlation of 1.00 ± 0.04 for total non-wrapper leaf weight and stalk size. Selection for reduced total non-wrapper leaf weight might also reduce stalk size. Estimates for this correlation ranged from 0.22 to 1.00. For red x green cabbage crosses the mean genetic correlation between total non-wrapper leaf weight and non-wrapper leaf number was 0.22 ± 0.85 with a range of -0.39 to 0.53 (Table 69). The mean genetic correlation between total non-wrapper leaf weight and non-wrapper leaf size was 0.34 ± 0.93 . Only 1 r_g estimate between -1

Table 69. Genetic correlation between total non-wrapper leaf weight and three other traits in cabbage.

Traits	Plantings	Green Crosses		Red Crosses	
			R *		R *
Total Non-wrapper Leaf Weight x Stalk Size	1974L	0.96	0.84	0.57	0.69
	1975E	0.16	0.52	1.00	A
	1975L	0.74	A	0.22	0.96
Total Non-wrapper Leaf Weight x Non-wrapper Leaf Number	1974L	0.85	0.82	A	-0.39
	1975E	0.12	-0.34	A	A
	1975L	-0.96	0.98	A	0.53
Total Non-wrapper Leaf Weight x Non-wrapper Leaf Size	1974L	0.88	0.85	A	A
	1975E	0.51	0.95	A	A
	1975L	B	A	A	0.34

*Reciprocal cross

A = Correlation estimates greater than 1.0

B = Correlation estimates less than -1.0

and 1 was observed for this correlation. The r_{gx} values for these relationships were 0.97 ± 0.38 and 1.00 ± 0.18 respectively (Table 69).

Stalk size

Significant differences for stalk size exist between cultivar means and between interaction means for cultivar x inbreeding and cultivar x plantings (Table 70). Since there were no differences due to inbreeding or plantings, stalk size appears to be genetically fixed in the cultivars selected and unaffected by the environment. Similar results could be obtained if dominant genetic systems were absent. Baby Head, Badger Ballhead, P.I. 215514 and Red Danish each were significantly different for stalk size. Chieftain Savoy was not different from Badger Ballhead or Red Danish but was different from Baby Head and P.I. 215514 (Table 71). Due to an increase in the stalk size of Red Danish after 1 generation of inbreeding the cultivar x inbreeding interaction was significant. The other cultivars showed no difference in stalk size due to inbreeding (Table 71). The significance of the cultivar x plantings interaction was due to a decrease in stalk size between the 1974L and 1975L plantings for Red Danish. During this period the other 4 cultivars showed no difference in stalk size (Table 72).

The inheritance of stalk size has not been previously reported. Small stalk size appears to be incompletely dominant in green cabbage crosses. F_1 population means of Baby Head x Badger Ballhead also suggest incomplete dominance for small stalk size (Tables 11-13). Tables 73 and 74 show frequency distributions in percent for populations involved in the cross Baby Head x Badger Ballhead. Powers *et al.* (23) partitioning tests were applied to these distributions to determine the number of genes controlling stalk size and to define the boundary between small and

Table 70. Analysis of variance table for stalk size in kilograms.

Source of Variance	DF	Mean Square	F*
Replication (R)	2	0.01	1.15
Cultivar (C)	4	0.76	84.49**
Inbreeding (I)	1	0.01	0.24
C x I	4	0.02	2.56*
Plantings (P)	2	0.02	1.94
C x P	8	0.02	2.22*
I x P	2	0.01	0.86
C x I x P	8	0.01	0.88
Residual Error	58	0.01	

F test significant at the 5%, or 1%** level.

Table 71. Cultivar x inbreeding interaction means for stalk size in kilograms.

Cultivar	Inbreeding		Cultivar Means
	P ₁	S ₁	
Baby Head	0.08 a*	0.06 a	0.07 W
Badger Ballhead	0.25 a	0.22 a	0.24 X
P.I. 215514	0.65 a	0.61 a	0.63 Z
Red Danish	0.27 a	0.40 b	0.34 Y
Chieftain Savoy	0.29 a	0.30 a	0.30 XY
Inbreeding Means	0.31 A	0.32 A	

*Mean separation, within rows, by Duncan's Multiple Range Test at the 5% level.

Table 72. Cultivar x planting interaction means for stalk size in kilograms.

Cultivar	1974L	Plantings 1975E	1975L	Cultivar Means
Baby Head	0.06 a*	0.09 a	0.06 a	0.07 W
Badger Ballhead	0.27 a	0.24 a	0.19 a	0.24 X
P.I. 215514	0.59 a	0.60 a	0.70 a	0.63 Z
Red Danish	0.41 b	0.34 ab	0.26 a	0.34 Y
Chieftain Savoy	0.34 a	0.32 a	0.23 a	0.30 XY
Planting Means	0.34 A	0.32 A	0.29 A	

*Mean separation, within rows, by Duncan's Multiple Range Test at the 5% level.

Table 73. Parent, F_1 , F_2 and backcross stalk size distributions in percent for the 1975E planting of the cross Baby Head x Badger Ballhead

	No. of Plants	Stalk Size in Grams Upper Limit of Class											Mean
		80	120	160	190	240	280	320	360	400	440	900+	
Baby Head (P_1)	42	33.3	45.2	21.5									90.3 ± 28.4
Badger Ballhead (P_2)	39		2.6	15.4	20.5	12.8	15.4	10.2	2.6	7.7	5.0	7.8	260.9 ± 120.1
(P_1 × P_2)	83	8.4	36.2	28.9	13.2	6.1	3.6	1.2	1.2			1.2	138.9 ± 66.6
(P_2 × P_1)	89	13.5	43.8	29.2	9.0	3.4	1.1						115.9 ± 42.1
(P_1 × P_2) F_2	252	4.4	25.0	32.5	11.9	10.2	3.6	3.2	1.6	2.0	0.8	4.8	185.5 ± 181.4
(P_2 × P_1) F_2	248	22.2	32.3	23.0	5.6	8.9	3.6	0.8	0.4	0.8		2.4	134.7 ± 106.4
(P_2 × P_1) × P_2	33	3.0	9.1	30.3	15.2	27.3	9.1	3.0	3.0				183.2 ± 61.8

Table 74. Parent, F₁ and F₂ stalk size distributions in percent for the 1975L planting of the cross Baby Head x Badger Ballhead.

	No. of Plants	Stalk Size in Grams Upper Limit of Class											Mean
		80	140	160	190	220	260	270	320	360	460	900+	
Baby Head (P ₁)	53	58.5	39.6		1.9								70.9 + 31.6
Badger Ballhead (P ₂)	49	2.0	14.3	8.2	20.4	12.2	22.4	8.2	4.1	4.1	4.1		208.6 + 75.4
(P ₁ x P ₂)	38	21.0	60.5	5.4		2.6	7.9	2.6					113.1 + 52.7
(P ₂ x P ₁)	77	13.0	64.9	10.4	1.3	2.6			3.9	1.3	1.3	1.3	149.0 + 254.3
(P ₁ x P ₂) F ₂	130	26.9	41.5	4.6	10.0	6.2	6.9		2.3		0.8	0.8	126.8 + 77.3
(P ₂ x P ₁) F ₂	211	23.2	57.3	7.1	3.8	1.9	1.4	1.4	1.4	1.0	1.0	0.5	114.5 + 81.9

large stalk size classes. Powers et al. (23) formula, (F_2/P_2) , was applied sequentially from the recessive ends of both the F_2 and P_2 distributions. Using the 1975E planting of Baby Head x Badger Ballhead as an example recessive frequencies of 4.8/7.8 or 0.62 for the 900+ gm class, 5.6/12.8 or 0.44 for the 440 gm class, 7.6/20.5 or 0.37 for the 400 gm class, 0.2/23.1 or 0.40 for the 360 gm class, 12.4/33.3 or 0.37 for the 320 gm class, 16.0/48.7 or 0.33 for the 280 gm class, 26.2/61.5 or 0.43 for the 240 gm class, 38.1/82.0 or 0.46 for the 200 gm class and 70.6/97.4 or 0.72 for the 160 gm class were produced. The large increase in frequency between the 200 gm class and the 160 gm class suggests a dividing point of 160 gm might be used to separate F_2 data into phenotypic classes. The mean of frequency estimates between the 200 gm and 900+ gm classes was 0.43. This frequency compared favorably to a 7/16 frequency of 0.44. A 2 gene 9:7 model with a dividing point of 160 gm seems appropriate. The reciprocal F_2 population of this cross produced the same estimate of 160 gm as a dividing point but produced a lower frequency estimate for the recessive class. The mean of recessive class frequency estimates was 0.21 which suggests a monogenic 3:1 model with a 160 gm division point. Since the distribution of both parents, Baby Head and Badger Ballhead, overlapped, a weighting procedure was used to account for misclassifications in F_2 segregation ratios. For the 1975E planting of Baby Head x Badger Ballhead the net overlap around the 160 gm class was 18.0% (Table 73). The expected number of recessive plants in the F_2 population can be calculated as $((100-18)/100)(0.4375)(252) = 90.4$. The expected ratio was 161.6:90.4. The expected number of recessive plants in the reciprocal F_2 population was $((100-18)/100)(0.25)(248) = 50.84$. The expected ratio was 197.16:50.84 (Table 75). Similar results for other crosses suggested stalk size might be controlled by 2 loci. The simplest system available

to insure digenic inheritance and explain differences between the cultivars was a 2 locus system with 5 alleles per loci. The loci were designated H and I since the small stalk size of the base cultivar, Baby Head, was dominant in most cases (Tables 11-13). The genotypes of each cultivar and F_1 in this study are shown in Tables 16 and 17. Data from 1975E green cabbage crosses suggest H_5 was dominant to H and H was dominant to h_3 and h_4 . Inheritance of the I locus was similar. Red x green cabbage data suggest H_5 and H_4 were dominant to H_2 and H_2 was dominant to h_3 . The I locus exhibited a similar inheritance pattern. Allelic inheritance patterns for both 1975L green and red x green cabbage crosses suggest that H was dominant to h_3 , h_4 and h_5 , while H_3 was dominant to H_2 and H_2 was dominant to h_5 . The I locus was inherited in a similar manner for both sets of crosses. Chi-square homogeneity tests suggest that 1975E reciprocal F_2 distributions of Baby Head x Badger Ballhead were significantly different for stalk size (Table 73). The populations were not pooled. The F_2 segregation ratio of 186 small stalk size:66 large stalk size produced using a 160 gm dividing point, fit ($P=0.47$) a 9:7 weighted expected ratio of 161.6:90.4. Homozygous recessive genotypes at either loci conditioned the same phenotype, large stalk size, while 1 dominant allele, H or I , at each locus conditioned small stalk size. Recessive alleles, h_3 and i_3 , were contributed by Badger Ballhead. The reciprocal F_2 segregation ratio of 192:56 fit ($P=0.44$) a 3:1 weighted expected ratio of 197.2:50.8 (Table 75). Small stalk size was conditioned by 1 dominant H allele regardless of the I locus genotype. The recessive genotype, $h_3h_3i_3i_3$, from Badger Ballhead conditioned a large stalk size phenotype (Tables 16-17). Backcrossing the reciprocal F_1 to Badger Ballhead produced a segregation ratio of 14:19.

Table 75. Chi-square test for goodness of fit to the postulated model for stalk size in the F_2 generation (1975E planting).

Cross	Observed	Expected	Model	χ^2	P
Baby Head x Badger Ballhead					
F_2	156: 96	161.60: 90.40*	9: 7	0.5400	0.47
RF_2	192: 56	197.16: 50.87*	3: 1	0.6587	0.44
Baby Head x P.I. 215514					
F_2	152:107	145.69:113.31	9: 7	0.6252	0.43
RF_2	254:197	253.69:197.31	9: 7	0.0009	0.98
Baby Head x Chieftain Savoy					
F_2	59:133	61.71:130.28*	1: 3	0.1759	0.67
RF_2	63:134	63.32:133.68*	1: 3	0.0024	0.96
Pooled	122:267	125.03:263.96*	1: 3	0.1086	0.74
Red Danish x Badger Ballhead					
F_2	45:164	53.74:155.26*	1: 3	1.9146	0.17
RF_2	36:118	39.60:114.40*	1: 3	0.4406	0.51
Pooled	81:282	93.32:269.66*	1: 3	2.1971	0.14
Red Danish x P.I. 215514					
F_2	126:185	136.06:174.94*	7: 9	1.3230	0.25
Red Danish x Chieftain Savoy					
F_2	6:101	14.31: 92.69*	1:15	0.0754	0.79
RF_2	6: 96	13.64: 88.36*	1:15	0.0235	0.88
Pooled	12:197	13.06:195.94*	1:15	0.0922	0.77

* = Weighted

Backcrossing to a 3:1 model should produce an expected ratio of 16.5:16.5. The data fit ($P=0.41$) the expected 1:1 model. The 9:7 segregation ratio for the 1975L F_2 population suggests that 1 dominant allele at each locus is required to condition a small stalk size phenotype. The ratio also requires that the homozygous recessive condition at either loci produce the same, large stalk weight, phenotype. Using a division point of 140 gm, the 1975L F_2 population, produced a segregation ratio of 89:41 (Table 74). The data fit ($P=0.16$) a weighted segregation ratio of 81.3:48.7 (Table 76). The 1975L reciprocal F_2 population produced a 170:41 segregation ratio. The data were compared ($P=0.49$) to a 3:1 weighted expected ratio of 165.9:45.1 (Table 76). The action of 1 dominant gene, H , conditioned a small stalk size phenotype in this planting. The recessive genotype $h_3h_3i_3i_3$ produced a large stalk size phenotype (Tables 16-17). Dominant alleles, H and I , were contributed by Baby Head.

Baby Head x P.I. 215514 F_1 data from 3 plantings, 1974L, 1975E, and 1975L, suggest incomplete dominance for small stalk size (Tables 11-13). F_2 data from both the 1975E and 1975L plantings also suggest small stalk size was dominant (Tables 77-78). The 1975E Baby Head x P.I. 215514 F_2 population with a division point of 190 gm produced a segregation ratio of 192:56. A 9:7 weighted expected ratio of 181:67 was compared ($P=0.12$) to the observed data (Table 75). Homozygous recessive alleles at either loci conditioned a large stalk weight phenotype. One dominant allele at each loci, $H_I_$, was required for a small stalk weight phenotype. Chi-square homogeneity tests suggest that the 1975L F_2 populations could be pooled. The pooled F_2 segregation ratio was 327:85. A division point of 260 gm was used. The data fit ($P=0.33$) a 13:3 model of 335:77

Table 76. Chi-square test for goodness of fit to the postulated model for stalk size in the F_2 generation (1975L planting).

Cross	Observed	Expected	Model	χ^2	P
Baby Head x Badger Ballhead					
F_2	89: 41	81.34: 48.66*	9: 7	1.9283	0.16
RF_2	170: 41	165.87: 45.13*	3: 1	0.4815	0.49
Baby Head x P.I. 215514					
F_2	130: 38	136.50: 31.50	13: 3	1.6508	0.20
RF_2	197: 47	198.25: 45.75	13: 3	0.0421	0.34
Pooled	327: 85	334.75: 77.25	13: 3	0.9569	0.33
Baby Head x Chieftain Savoy					
F_2	120: 95	127.91: 87.09*	9: 7	1.2085	0.27
RF_2	116: 62	105.90: 72.10*	9: 7	2.3782	0.12
Pooled	236:157	233.81:159.19*	9: 7	0.0506	0.82
Red Danish x Badger Ballhead					
F_2	92:199	104.62:186.38*	1: 3	2.3784	0.12
RF_2	11: 19	10.79: 19.21*	1: 3	0.0066	0.94
Pooled	103:218	115.41:205.59*	1: 3	2.0838	0.15
Red Danish x Chieftain Savoy					
F_2	39:160	35.08:163.92*	1:15	0.5318	0.46
RF_2	42:182	39.49:184.51*	1:15	0.1941	0.66
Pooled	81:342	74.57:348.43*	1:15	0.6738	0.41

* = Weighted

Table 77. Parent, F₁ and F₂ stalk size distributions in percent for the 1975E planting of the cross Baby Head x P.I. 215514.

	No. of Plants	Stalk Size in Grams Upper Limit of Class											Mean
		80	140	160	190	220	260	270	320	360	460	900+	
Baby Head (P ₁)	42	33.3	64.3	2.4									90.3 ± 28.4
P.I. 215514 (P ₃)	18								5.6	11.1	11.1	72.2	606.6 ± 276.1
(P ₁ x P ₃)	86	2.3	3.5	4.6	10.5	19.8	31.4	5.8	14.0	4.6	2.3	1.2	234.9 ± 94.5
(P ₃ x P ₁)	70	1.4	8.6	8.6	11.4	7.2	24.3	7.2	22.8	2.8	5.7		233.1 ± 72.9
(P ₁ x P ₃) F ₂	259	4.6	25.9	10.4	9.6	8.1	11.6	2.3	13.5	3.9	6.6	3.5	220.4 ± 205.3
(P ₃ x P ₁) F ₂	451	0.7	14.0	5.1	12.6	7.1	14.6	2.2	15.3	7.5	13.5	7.4	269.4 ± 142.2

Table 78. Parent, F₁ and F₂ stalk size distributions in percent for the 1975L planting of the cross Baby Head x P.I. 215514.

	No. of Plants	Stalk Size in Grams Upper Limit of Class											Mean
		80	140	160	190	220	260	270	320	360	460	900+	
Baby Head (P ₁)	53	58.5	39.6		1.9								70.9 ± 31.6
P.I. 215514 (P ₃)	13								7.7		23.1	69.2	687.7 ± 295.1
(P ₁ x P ₃)	73		20.5	12.3	19.3	13.7	11.0	2.7	9.6	2.7	5.5	2.7	212.3 ± 104.4
(P ₃ x P ₁)	81		8.6	6.2	9.9	16.2	22.2	8.6	14.8	4.9	3.7	4.9	246.8 ± 103.0
(P ₁ x P ₃) F ₂	168	7.7	29.2	10.7	13.1	8.3	8.3	1.2	8.9	4.2	6.0	2.4	194.9 ± 122.1
(P ₃ x P ₁) F ₂	244	2.9	32.8	11.9	13.2	8.2	11.9	1.6	9.4	2.0	4.9	1.2	191.0 ± 117.2

(Table 76). A 13:3 ratio was produced when a dominant genotype at 1 locus and the recessive genotype at the other each produce the same, small stalk weight, phenotype. The recessive genotype h_4h_4ii conditioned a large stalk weight phenotype. Recessive alleles h_4 and i_4 were contributed by P.I. 215514.

All 3 plantings of the F_1 population, Baby Head x Chieftain Savoy, suggest incomplete dominance for large stalk size. Both F_2 populations of Baby Head x Chieftain Savoy grown in each planting period, 1975E and 1975L, were pooled as suggested by chi-square homogeneity tests. A division point of 160 gm was used to separate the F_2 data into classes. Pooled F_2 data from the early planting suggest a 1:3 weighted expected ratio of 125:264 should be compared ($P=0.74$) to an observed ratio of 122:267 (Table 75). Large stalk size was controlled by a single dominant gene, H_5 . The genotype H_5--- conditioned large stalk size while recessive small stalk size was produced by the genotype $hhii$. Recessive alleles were contributed by Baby Head while alleles from Chieftain Savoy were dominant. A segregation ratio of 26:29 was produced by backcrossing the reciprocal F_1 to the recessive cultivar Baby Head. The data showed good fit ($P=0.70$) to the expected ratio of 27.5:27.5. Backcrossing the F_1 and reciprocal F_1 to Chieftain Savoy produced segregation ratios of 4:28 and 2:13 (Table 79). Ratios of 0:33 and 0:15 were expected. F_2 data from the late planting show dominance can be effected by planting time. The observed ratio of 236:157 fit ($P=0.82$) a weighted expected ratio of 234:159 derived from a 9:7 model (Table 76). Phenotypic classes were divided using a 140 gm division point. Small stalk size was controlled by the presence of 2 dominant alleles at different loci. Large stalk size was controlled by the presence of

Table 79. Parent, F₁, F₂ and backcross stalk size distributions in percent for the 1975E planting of the cross Baby Head x Chieftain Savoy.

Stalk Size in Grams Upper Limit of Class													
No. of Plants	80	140	160	190	220	260	270	320	360	460	900+	Mean	
Baby Head (P_1)	42	33.3	64.3	2.4								90.3 ± 28.4	
Chieftain Savoy (P_5)	34		8.8	2.9	8.8	14.7	14.7	14.7	2.9	20.6	11.9	322.1 ± 188.0	
($P_1 \times P_5$)	52		19.2	3.8	7.7	11.5	13.4	3.8	19.2	7.7	11.5	2.2	244.7 ± 100.0
($P_5 \times P_1$)	83		2.4	3.8	15.7	9.6	26.5	4.8	12.0	7.2	6.0	12.0	284.6 ± 131.2
($P_1 \times P_5$) F_2	192		1.6	17.7	11.4	15.6	9.4	22.9	2.6	7.8	2.6	5.7	215.1 ± 97.2
($P_5 \times P_1$) F_2	197		0.5	22.8	8.6	16.8	10.2	13.2	4.6	7.1	3.0	8.1	232.7 ± 147.7
($P_1 \times P_5$) $\times P_5$	32			9.4	3.2	6.2	6.2	6.2	3.2	34.4	6.2	18.8	293.0 ± 111.3
($P_5 \times P_1$) $\times P_5$	15			6.7	6.7	13.3		6.7	33.2	6.7	20.0	6.7	307.8 ± 123.2
($P_5 \times P_1$) $\times P_1$	55		5.4	36.4	5.4	10.9	7.3	12.7	7.3	9.2		5.4	193.8 ± 120.4

a single homozygous recessive genotype at either loci. Dominant alleles, H and I , were contributed by Baby Head. The difference in dominance direction noted between these 2 plantings suggest a 30 day difference in planting cabbage might expose the F_2 population to conditions that change the phenotypic expression of certain genotypes (Table 80).

Red Danish x Badger Ballhead F_1 data from the 1974L, 1975E and 1975L plantings suggest overdominance for large stalk size (Tables 11-13). Chi-square homogeneity tests suggest that F_2 populations of this cross can be pooled within each planting. The pooled 1975E F_2 population produced a segregation ratio of 81:282 using a dividing point of 290 gm (Table 81). The data fit ($P=0.14$) a weighted expected ratio of 93:270 from a 1:3 model (Table 75). Large stalk size was controlled by the presence of a single dominant gene, H_2 . The recessive genotype $h_3h_3i_3i_3$ conditioned small stalk size. The dominant allele H_2 was contributed by Red Danish (Table 81). Backcrossing the F_1 to the recessive cultivar Badger Ballhead produced a segregation ratio of 3:9. An expected ratio of 6:6 was compared ($P=0.09$) to the observed data. Backcrossing the reciprocal F_1 to Red Danish produced a segregation ratio of 0:47. The data support an F_2 model of 1:3. An observed segregation ratio of 103:218 produced by the pooled 1975L F_2 population fit ($P=0.15$) a 1:3 weighted expected ratio of 115:206 (Table 76). A division point of 200 gm was used. Large stalk genes from Badger Ballhead were dominant. Large stalk size was controlled by the presence of 1 dominant H_3 allele. The recessive genotype $h_2h_2i_2i_2$ conditioned small stalk size. Recessive alleles were contributed by Red Danish (Table 82).

Table 80. Parent, F₁ and F₂ stalk size distributions in percent for the 1975L planting of the cross Baby Head x Chieftain Savoy.

	No. of Plants	Stalk Size in Grams Upper Limit of Class											Mean
		80	140	160	190	220	260	270	320	360	460	900+	
Baby Head (P ₁)	53	58.5	39.6		1.9								70.9 ± 31.6
Chieftain Savoy (P ₅)	43		9.3	16.3	7.0	20.9	18.6	2.3	11.6	4.6	9.3		228.4 ± 82.5
(P ₁ x P ₅)	20		25.0	20.0	20.0	20.0			15.0				181.0 ± 54.8
(P ₅ x P ₁)	59	8.4	42.4	8.5	22.0	6.8	5.1	1.7	1.7			3.4	157.4 ± 109.3
(P ₁ x P ₅) F ₂	215	10.7	45.1	7.4	7.9	10.2	6.2		5.1	2.3	3.2	1.9	160.1 ± 99.4
(P ₅ x P ₁) F ₂	178	21.3	43.8	9.0	8.4	6.2	4.8		2.8	2.2	0.5	1.0	134.7 ± 80.5

Table 81. Parent, F₁, F₂ and backcross stalk size distributions in percent for the 1975E planting of the cross Red Danish x Badger Ballhead.

	No. of Plants	Stalk Size in Grams Upper Limit of Class											Mean
		160	200	240	290	320	400	500	600	700	800	900+	
Red Danish (P ₄)	35	20.0	2.8	5.7	5.7	8.6	14.4	20.0	8.6	2.8	5.7	5.7	377.5 ± 228.0
Badger Ballhead (P ₂)	39	17.9	20.5	12.8	15.4	10.2	10.2	7.8	2.6	2.6			260.9 ± 120.0
(P ₄ x P ₂)	96		1.0	15.6	16.7	21.9	19.8	17.7	4.2		1.0	2.1	344.6 ± 120.2
(P ₂ x P ₄)	90		2.2	4.4	3.3	8.9	28.9	31.3	14.4	3.3	2.2	1.1	418.5 ± 122.4
(P ₄ x P ₂) F ₂	209	1.0	3.8	3.3	13.4	4.8	13.9	25.4	15.8	10.0	2.9	5.7	454.1 ± 184.8
(P ₂ x P ₄) F ₂	154	1.0	2.6	11.7	8.4	6.2	27.9	19.5	6.5	6.5	1.9	7.8	413.7 ± 163.1
(P ₄ x P ₂) x P ₂	12			8.3	16.8	8.3	25.0	25.0	8.3			8.3	415.4 ± 181.8
(P ₂ x P ₄) x P ₄	47					4.2	8.6	25.5	14.9	12.8	34.0		722.9 ± 217.8

Table 82. Parent, F₁ and F₂ stalk size distributions in percent for the 1975L planting of the cross Red Danish x Badger Ballhead.

	No. of Plants	Stalk Size in Grams Upper Limit of Class										Mean	
		160	200	240	290	320	400	500	600	700	800		900+
Red Danish (P_4)	32	37.5	28.4	12.5	18.8		3.1						186.4 $\pm$ 62.4
Badger Ballhead (P_2)	49	24.5	24.5	20.4	18.4	4.1	6.1	2.0					208.6 $\pm$ 75.4
($P_4 \times P_2$)	23	17.4	13.0		34.8	8.7	21.8	4.3					261.3 $\pm$ 86.9
($P_2 \times P_4$)	19	5.3	31.6	31.6	10.5	10.5	10.5						233.9 $\pm$ 68.8
($P_4 \times P_2$) F_2	291	16.2	15.5	19.6	20.0	8.6	12.0	5.2	1.0	1.0	0.7	0.3	257.5 $\pm$ 109.7
($P_2 \times P_4$) F_2	30	26.7	10.0	3.3	16.7	3.3	16.7	10.0	10.0			3.3	319.8 $\pm$ 296.1

1974L and 1975E plantings of Red Danish x P.I. 215514 F_1 suggest overdominance for large stalk size (Tables 11-13). Data from the 1975L planting show stalk size to be inherited in an additive manner (Table 84). Only the F_2 population of Red Danish x P.I. 215514 was grown in the 1975E planting. Although both cultivar distributions were nearly identical the F_2 data showed transgressive segregation for large stalk size. The data were compared to a 7:9 model which assumed that H_2 was dominant to h_4 and I_4 was dominant to i_2 . Using a division point of 600 gm an F_2 segregation ratio of 126:185 was produced (Table 83). This ratio was compared ($P=0.25$) to an expected ratio of 136:175 (Table 75). Large stalk size was controlled by the presence of H_2 and I_4 . Homozygous recessive genotypes at either loci conditioned a small stalk size phenotype.

All plantings of Red Danish x Chieftain Savoy F_1 suggested overdominance for large stalk size (Tables 11-13). Chi-square homogeneity tests suggested pooling F_2 populations of Red Danish x Chieftain Savoy within each planting. Transgressive segregation for large stalk size was noted in the 1975E planting (Table 85). Using a 320 gm division point the F_2 distribution produced an observed segregation ratio of 12:197. The data show good fit ($P=0.77$) to a 1:15 model (Table 75). The presence of either dominant allele conditioned large stalk size while the recessive genotype $h_5h_5i_5i_5$ conditioned small stalk size. Backcross segregation ratios suggest differences between reciprocal F_1 's. The dominant cultivar, Red Danish, was crossed to reciprocal F_1 plants and produced segregation ratios of 0:18 (F_1) and 28:9 (RF_1). Ratios of 0:18 and 0:37 were expected. The difference between the observed RF_1 backcross ratio and its expected ratio suggest differences

Table 83. Parent, F₁ and F₂ stalk size distributions in percent for the 1975E planting of the cross Red Danish x P.I. 215514.

Stalk Size in Grams Upper Limit of Class													
No. of Plants	160	200	240	290	320	400	500	600	700	800	900+	Mean	
Red Danish (P_4)	35	20.0	2.8	5.7	5.7	8.6	14.4	20.0	8.6	2.8	5.7	5.7	377.5 + 228.0
P.I. 215514 (P_3)	18					5.6	11.0	27.8	27.8		5.6	22.2	606.6 + 276.1
($P_4 \times P_3$)	85		1.2				5.8	20.0	11.8	16.5	16.5	28.2	684.7 + 229.3
($P_3 \times P_4$)	89		1.1		2.2	1.1	3.6	16.8	28.1	20.2	11.2	15.7	625.1 + 193.6
($P_4 \times P_3$) F_2	311	0.6	0.6	0.3	2.6	1.2	5.8	11.2	18.3	12.5	11.9	35.0	694.8 + 254.2
													143

Table 84. Parent and F₁ stalk size distributions in percent for the 1975L planting of the cross Red Danish x P.I. 215514.

	No. of Plants	Stalk Size in Grams Upper Limit of Class											Mean
		160	200	240	290	320	400	500	600	700	800	900+	
Red Danish (P_4)	32	37.5	28.4	12.5	18.8		3.1						186.4 ± 62.4
P.I. 215514 (P_3)	13					7.7	7.7	30.7		7.7	7.7	38.5	687.7 ± 295.1
($P_4 \times P_3$)	44	2.3	9.1	6.8	13.6	9.1	29.5	15.9	9.1		2.3	2.3	367.8 ± 145.8
($P_3 \times P_4$)	14	14.3				14.3	7.1	28.7	7.1	21.4		7.1	472.1 ± 222.7

Table 85. Parent, F₁, F₂ and backcross stalk size distributions in percent for the 1975L planting of the cross Red Danish x Chieftain Savoy.

	No. of Plants	Stalk Size in Grams Upper Limit of Class											Mean
		160	200	240	290	320	400	500	600	700	800	900+	
Red Danish (P ₄)	35	20.0	2.8	5.7	5.7	8.6	14.4	20.0	8.6	2.8	5.7	5.7	377.5 ± 228.0
Chieftain Savoy (P ₅)	34	11.8	17.6	11.8	11.8	11.8	5.9	17.6	5.9			5.8	322.1 ± 188.0
(P ₄ x P ₅)	33		3.0				6.1	12.1	21.2	27.3	18.2	12.1	623.1 ± 172.0
(P ₅ x P ₄)	80		1.2		3.8	2.5	6.2	18.8	20.0	17.5	16.2	13.8	596.4 ± 185.4
(P ₄ x P ₅) F ₂	107	0.9	1.1	2.8	0.9	0.9	8.4	14.0	21.5	21.5	8.4	19.6	585.6 ± 161.8
(P ₅ x P ₄) F ₂	102			1.0	1.0	3.9	3.9	20.6	24.5	10.8	16.7	17.6	677.1 ± 305.4
(P ₄ x P ₅) x P ₄	18						5.6		11.1	22.2	22.2	38.9	788.2 ± 211.7
(P ₅ x P ₄) x P ₄	37	13.5	21.6	29.8	10.8		2.7					21.6	370.2 ± 329.3

between F_1 and RF_1 gametic transmission. Pooled F_2 data for the 1975L planting suggest Chieftain Savoy contributed dominant genes for large stalk size (Table 86). A 1:15 weighted theoretical ratio of 75:348 was compared ($P=0.43$) to an observed segregation ratio of 81:342. A division point of 200 gm was used to separate F_2 data into phenotypic classes. The model suggests that the genotype $h_2h_2^i i_2^i i_2^i$ was recessive for small stalk weight while all other gene combinations produced large stalk size (Table 16).

Green cabbage cross stalk size heritability estimates between 0 and one ranged from 0.28 to 0.96. The mean heritability estimate was 0.36 ± 0.24 . The data show a 50% difference in reciprocal cross heritability estimates for the 1975L planting. This difference may be due to maternal influences rather than to environmental causes. The $\bar{h}_x^2$ estimate was 0.40 ± 0.23 . Only 1 red x green cabbage heritability estimate fell within the 0 to 1 heritability range. That heritability estimate was 0.57 ± 0.60 . The $\bar{h}_x^2$ estimate for red x green cabbage crosses was 0.81 ± 0.40 (Table 30).

Genetic correlations between stalk size and non-wrapper leaf number and non-wrapper leaf size exhibited a wide range of estimates. Green cabbage F_1 estimates of genetic correlation between stalk size and non-wrapper leaf number ranged from 0.37 to 0.67 with a mean of 0.60 ± 0.55 (Table 87). The $\bar{r}_{gx}$ estimate for the relationship was -0.58 ± 0.42 . The mean genetic correlation between green cabbage F_1 stalk size and non-wrapper leaf size was 0.93 ± 0.32 . Estimates for this genetic correlation ranged from 0.21 to 0.98 and produced an $\bar{r}_{gx}$ estimate of 1.00 ± 0.04 (Table 87). Red x green cabbage F_1 mean genetic correlations between stalk size and non-wrapper leaf number and non-wrapper leaf size

Table 86. Parent, F₁ and F₂ stalk size distributions in percent for the 1975L planting of the cross Red Danish x Chieftain Savoy.

	No. of Plants	Stalk Size in Grams Upper Limit of Class											Mean
		160	200	240	290	320	400	500	600	700	800	900+	
Red Danish (P ₄)	32	37.5	28.4	12.5	18.8		3.1						186.4 ± 62.4
Chieftain Savoy (P ₅)	43	25.6	20.9	9.3	20.9	9.3	9.3	4.7					228.4 ± 82.5
(P ₄ x P ₅)	28	32.2		7.1	21.4	14.3	10.7	14.3					261.1 ± 115.8
(P ₅ x P ₄)	30	16.7	6.7	6.7	26.6	3.3	36.7	3.3					265.5 ± 89.6
(P ₄ x P ₅) F ₂	199	9.5	10.0	9.5	14.1	6.0	21.6	15.6	9.5	3.5		0.5	331.1 ± 135.1
(P ₅ x P ₄) F ₂	224	10.7	8.0	10.7	14.7	10.7	21.2	13.8	6.2	0.9	1.8	1.3	328.4 ± 174.6

Table 87. Genetic correlations between stalk size, non-wrapper leaf number, efficiency index and non-wrapper leaf size in cabbage.

Traits	Plantings	Green Crosses		Red Crosses	
			R*		R*
Stalk Size x Non-wrapper Leaf Number	1974L	0.63	0.37	-0.12	0.08
	1974E	B	B	A	0.96
	1975L	0.67	A	-0.74	0.89
Stalk Size x Non-wrapper Leaf Size	1974L	A	A	0.33	0.84
	1975E	0.98	0.88	0.99	A
	1975L	0.21	A	-0.27	-0.09
Non-wrapper Leaf Number x Efficiency Index	1974L	A	0.96	B	B
	1975E	0.93	A	0.96	0.80
	1975L	B	-0.02	B	A
Non-wrapper Leaf Number x Non-wrapper Leaf Size	1974L	0.49	0.40	A	-0.80
	1975E	-0.84	-0.65	A	A
	1975L	-0.96	0.98	0.78	-0.65

*Reciprocal cross

A = Correlation estimate greater than 1.0

B = Correlation estimate less than -1.0

were 0.88 ± 0.44 and 0.91 ± 0.43 respectively. The ranges associated with these r_g values were -0.74 to 0.96 and -0.27 to 0.99. $\bar{R}_{gx}$ estimates for these relationships were 0.89 ± 0.42 and 0.94 ± 0.37 respectively. Both green and red x green cabbage crosses produced a wide range of genetic correlation estimates. Differences between estimates may be a function of maternal inheritance as shown in red x green cabbage F_1 correlations between stalk size and non-wrapper leaf number estimated during the 1975L planting or a function of environment as shown in red x green cabbage F_1 correlation estimates between stalk size and non-wrapper leaf size for the 3 plantings (Table 87).

Non-Wrapper Leaf Number

Analysis of the results for 1 generation of inbreeding for non-wrapper leaf number suggests significant differences exist between cultivars, inbreeding and plantings. Significant interactions also exist for cultivar x inbreeding, cultivar x plantings and inbreeding x plantings (Table 88). Four cultivars, Baby Head, Badger Ballhead, P.I. 215514 and Chieftain Savoy were each significantly different for non-wrapper leaf number. Red Danish was not different from Badger Ballhead or Chieftain Savoy but was significantly different from the other 2 cultivars (Table 89). The S_1 plants produced an increase of 1 non-wrapper leaf (Table 89). Although this increase was significant and suggests that non-wrapper leaf number may not be genetically fixed in these cultivars the small increase in non-wrapper leaf number may not justify time spent in added inbreeding for this trait prior to use in a genetic study. A comparison of both the 1974L and 1975E plantings shows no difference in non-wrapper leaf number, however, the 1975L planting showed a significant decrease in non-wrapper leaf number when

Table 88. Analysis of variance table for non-wrapper leaf number.

Source of Variance	DF	Mean Square	F*
Replication (R)	2	0.74	0.22
Cultivar (C)	4	512.02	152.10**
Inbreeding (I)	1	19.19	5.70*
C x I	4	28.07	8.34**
Plantings (P)	2	230.52	68.48**
C x P	8	30.13	8.95**
I x P	2	16.36	4.86**
C x I x P	8	6.33	1.88
Residual Error	58	3.37	

F test significant at the 5%, or 1%** level.

Table 89. Cultivar x inbreeding interaction means for non-wrapper leaf number.

Cultivar	Inbreeding		Cultivar Means
	P ₁	S ₁	
Baby Head	8.54 b*	6.47 a	7.50 W
Badger Ballhead	14.71 a	16.67 b	15.69 X
P.I. 215514	21.90 a	22.76 a	22.33 Z
Red Danish	14.08 a	18.56 b	16.32 XY
Chieftain Savoy	17.51 a	16.91 a	17.21 Y
Inbreeding Means	15.35 A	16.27 B	

*Mean separation, within rows, by Duncan's Multiple Range Test at the 5% level.

compared to the previous plantings (Table 90). Cultivar response to inbreeding in this study can be divided into 3 groups:

- (1) Baby Head, showing a reduction in non-wrapper leaf number due to 1 generation of inbreeding.
- (2) Badger Ballhead and Red Danish, showing an increase in non-wrapper leaf number due to 1 generation of inbreeding.
- (3) P.I. 215514 and Chieftain Savoy unaffected by 1 generation of inbreeding (Table 89).

The significant cultivar x plantings interaction suggests that these cultivars responded differently during the 3 planting periods. Baby Head's non-wrapper leaf number increased between the 1974L and 1975E plantings and decreased between the 1975E and 1975L plantings. Both Badger Ballhead and P.I. 215514 showed no difference in non-wrapper leaf number between the 1974L and 1975E plantings but showed a reduction in non-wrapper leaf number between the 1975E and 1975L plantings. Red Danish and Chieftain Savoy both produced significantly less non-wrapper leaves between the 1974L and 1975E plantings and showed no change between the 1975E and 1975L plantings (Table 90). The significance of the inbreeding x plantings interaction was due to a significant increase in non-wrapper leaf number due to inbreeding in the 1975L planting. No differences were shown for other plantings (Table 91).

In 1934 Pearson (20) reported that in cabbage few non-wrapper leaves were dominant to many leaves. He also reported on several modifying factors. The 1974L F_1 planting of Baby Head x Badger Ballhead supports Pearson's (20) conclusions. The data show an incomplete

Table 90. Cultivar x planting interaction means for non-wrapper leaf number.

Cultivar	1974L	Plantings 1975E	1975L	Cultivar Means
Baby Head	7.16 b*	12.86 c	2.49 a	7.50 W
Badger Ballhead	18.57 b	17.10 b	11.40 a	15.69 X
P.I. 215514	23.72 b	23.48 b	19.80 a	22.33 Z
Red Danish	18.26 b	15.90 a	14.81 a	16.32 XY
Chieftain Savoy	20.57 b	16.44 a	14.62 a	17.21 Y
Planting Means	17.66 B	17.16 B	12.62 A	

*Mean separation, within rows, by Duncan's Multiple Range Test at the 5% level.

Table 91. Inbreeding x plantings interaction means for non-wrapper leaf number.

Inbreeding	1974L	Plantings 1975E	1975L	Inbreeding Means
P ₁	17.12 a*	17.47 a	11.46 a	15.35 Y
S ₁	18.19 a	16.84 a	13.78 b	16.27 Z
Planting Means	17.66 B	17.16 B	12.62 A	

*Mean separation, within columns, by Duncan's Multiple Range Test at the 5% level level.

dominance for non-wrapper leaves. Data for the 1975E and 1975L F_1 plantings of this cross do not agree with Pearson's (20) conclusions. The data suggest that for the 1975E planting many non-wrapper leaves were overdominant. However, in the 1975L planting the F_1 population showed incomplete dominance for many leaves and the reciprocal F_1 population showed incomplete dominance for few non-wrapper leaves (Tables 11-13). In contrast, all of the F_2 populations of green cabbage crosses showed dominance for few non-wrapper leaves (Tables 94-95). Tables 92 and 93 show frequency distributions in percent for populations involved in this cross. Powers *et al.* (23) partitioning tests were applied to these distributions to determine the number of genes controlling non-wrapper leaf number and to define the boundary between few and many non-wrapper leaves. Powers *et al.* (23) formula (F_2/P_2) was applied sequentially from the recessive ends of both the F_2 and P_2 distributions. Using the 1975E Baby Head x Badger Ballhead F_2 population (Table 92) as an example recessive frequencies of 5.2/30.8 or 0.49 for the 21 leaf class, 23.5/43.6 or 0.54 for the 19 leaf class, 40.9/69.2 or 0.59 for the 17 leaf class and 56.7/79.5 or 0.71 for the 15 leaf class were produced. The rapid increase in frequency between the 17 and 15 leaf classes suggested a dividing point of 15 leaves would be appropriate to separate the F_2 data into 2 classes, few (0-15) and many (16+) leaves. A mean estimate of 0.54 was produced by classes 17-21. The 1975E reciprocal F_2 population produced the same dividing point, 15 leaves, and produced a mean frequency estimate of 0.53. The data from both populations suggest a 9:7 model could fit the data, however, due to a large amount of cultivar overlap a weighted 3:1 model was used to explain the segregation patterns observed. A 3:1 model was chosen since the bimodal distribution pattern

Table 92. Parent, F_1 , F_2 and backcross non-wrapper leaf number distributions in percent for the 1975E planting of the cross Baby Head x Badger Ballhead.

	No. of Plants	Non-wrapper Leaf Number Upper Limit of Class											Mean
		5	7	9	11	13	15	17	19	21	23	25	
Baby Head (P_1)	42			2.4	4.8	16.7	30.9	30.9	7.1	4.8	2.4		14 ± 3
Badger Ballhead (P_2)	39			5.1	5.1	10.3	10.3	25.6	12.8	23.1	2.6	5.1	16 ± 4
($P_1 \times P_2$)	83				3.6	2.4	28.9	19.3	20.5	7.3	9.6	8.4	17 ± 4
($P_2 \times P_1$)	89				2.2	7.9	15.7	31.5	24.7	12.3	4.5	1.2	16 ± 3
($P_1 \times P_2$) F_2	252	2.8	3.6	7.5	14.3	15.1	15.8	17.4	8.3	6.0	4.0	5.2	14 ± 6
($P_2 \times P_1$) F_2	248	3.2	6.0	6.9	12.1	20.6	19.4	12.1	8.5	4.8	3.6	2.8	13 ± 5
($P_2 \times P_1$) $\times P_2$	33	9.1	3.0	9.1	3.0	6.1	27.3	21.2	12.1	3.0	6.1		13 ± 5

Table 93. Parent, F₁ and F₂ non-wrapper leaf number distributions in percent for the 1975L planting of the cross Baby Head x Badger Ballhead.

	No. of Plants	Non-wrapper Leaf Number Upper Limit of Class												Mean
		3	5	7	9	11	13	14	17	19	21	58		
Baby Head (P_1)	53	52.8	28.3	11.3	5.7			1.9						3 + 2
Badger Ballhead (P_2)	49	4.1	6.1	10.2	12.2	20.4	12.2	8.2	24.5	2.0				10 + 4
($P_1 \times P_2$)	38	5.3	7.9	13.2	13.2	28.9	10.5	2.6	7.9	2.6	5.3	2.6		10 + 5
($P_2 \times P_1$)	77	32.5	42.8	10.4	7.8	3.9	1.3		1.3					4 + 2
($P_1 \times P_2$) F_2	130	18.5	30.0	13.8	13.8	14.7	2.3	2.3	3.8	0.8				6 + 4
($P_2 \times P_1$) F_2	211	13.7	31.8	17.2	18.0	8.0	4.3	1.4	3.3	0.9	1.4			6 + 4

Table 94. Chi-square test for goodness of fit to the postulated model for non-wrapper leaf number in the F_2 generation (1975E planting).

Cross	Observed	Expected	Model	χ^2	P
Baby Head x Badger Ballhead					
F_2	149:103	161.78: 90.22*	3: 1	2.8199	0.10
RF_2	169: 79	159.22: 88.78*	3: 1	1.6781	0.19
Baby Head x P.I. 215514					
F_2	181: 78	180.38: 78.62*	13: 3	0.0072	0.93
RF_2	328:123	314.09:136.91*	13: 3	2.0295	0.15
Pooled	509:201	494.46:215.54*	13: 3	1.4076	0.24
Baby Head x Chieftain Savoy					
F_2	146: 46	150.66: 41.34*	3: 1	0.6681	0.41
RF_2	116: 81	122.76: 74.24*	9: 7	0.9887	0.32
Red Danish x Badger Ballhead					
F_2	59:150	69.02:139.98*	1: 3	2.1702	0.14
RF_2	43:111	50.85:103.15*	1: 3	1.8109	0.18
Pooled	102:261	119.87:243.13*	1: 3	3.9774	0.05
Red Danish x P.I. 215514					
F_2	62:249	73.86:237.14*	7: 9	2.4985	0.11
Red Danish x Chieftain Savoy					
F_2	26: 81	26.32: 80.68	1: 3	0.0053	0.94
RF_2	17: 85	25.09: 76.91	1: 3	3.4616	0.06
Pooled	43:166	51.42:157.58	1: 3	1.8269	0.18

* = Weighted

Table 95. Chi-square test for goodness of fit to the postulated model for non-wrapper leaf number in the F_2 generation (1975L planting).

Cross	Observed	Expected	Model	χ^2	P
Baby Head x Badger Ballhead					
F_2	99: 31	107.50: 22.50*	3: 1	3.8821	0.05
RF_2	170: 41	174.48: 36.52*	3: 1	0.6644	0.42
Pooled	269: 72	281.98: 59.02*	3: 1	3.4511	0.06
Baby Head x P.I. 215514					
F_2	123: 45	129.23: 38.77*	3: 1	1.3018	0.25
RF_2	189: 55	186.54: 57.46*	3: 1	0.1376	0.71
Baby Head x Chieftain Savoy					
F_2	126: 89	126.14: 88.86*	9: 7	0.0004	0.98
RF_2	92: 86	104.43: 73.57*	9: 7	3.5799	0.06
Pooled	218:175	230.57:162.43*	9: 7	1.6576	0.20
Red Danish x Badger Ballhead					
F_2	37:254	44.30:246.70	3:13	1.4179	0.23
RF_2	11: 19	10.66: 19.34	7: 9	0.0172	0.90
Red Danish x Chieftain Savoy					
F_2	31:168	38.20:160.80*	1:15	1.6787	0.20
RF_2	33:191	43.00:181.00*	1:15	2.8766	0.09

* = Weighted

expected for a 2 gene model was absent in the F_2 data (Table 92). The expected weighted ratio was calculated as follows. The net overlap around the 15 leaf class was $(30.9 + 7.1 + 4.8 + 2.4 - 5.1 - 5.1 - 10.3 - 10.3) = 14.4$. The number of dominant plants expected was $((100-14.4)/100)(0.75)(252) = 161.78$. The expected ratio was 161.78:90.22. Substituting the number 248 for 252 in the previous equation produced the expected ratio for the 1975E reciprocal F_2 population. The ratio was 159.22:88.78 (Table 94). The results of similar tests on other F_2 populations suggest digenic control of non-wrapper leaf number. The simplest gene system available to insure digenic control and account for phenotypic differences between cultivars was a 2 locus system with 5 alleles per loci. The postulated loci J and x produced cultivar genotypes as noted in Table 16. F_2 data from each of the crosses suggest J was dominant to j_3 , j_4 and j_5 . The x alleles were inherited in a similar manner. Red x green cabbage crosses in the 1975E planting suggest J_5 and J_4 were dominant to J_2 and J_2 was dominant to j_3 . The 1975L planting of red x green cabbage crosses suggest J_5 was dominant to J_2 and J_2 was dominant to j_3 . In both plantings the dominance relationships of the x locus were similar to those of the J locus (Tables 16-17). For both the 1975E and 1975L F_2 plantings of Baby Head x Badger Ballhead few non-wrapper leaves were dominant. 1975E F_2 populations of this cross were not pooled. The F_2 population, using a 15 leaf dividing point, produced a segregation ratio of 149:103 which fit ($P=0.10$) a weighted theoretical ratio of 161.78:90.22 (Table 94). The reciprocal F_2 planting, using the same dividing point, produced an observed ratio of 169:79. A 3:1 weighted expected ratio of 159.22:88.78 was compared ($P=0.19$) to the observed ratio (Table 94). Crossing the reciprocal F_1 to the recessive cultivar,

Badger Ballhead, produced a segregation ratio of 19:14. This ratio fit ($P=0.41$) an expected 1:1 model of 16.5:16.5. The pooled F_2 data for the 1975L planting of this cross showed a segregation ratio of 269:72. The data fit ($P=0.06$) a 3:1 weighted expected ratio of 282:59 (Table 95). A dividing point of 9 leaves was used to separate the phenotypic classes (Table 93). Few non-wrapper leaves were produced when a single dominant gene, J , was present in the genotype. Many non-wrapper leaves were produced by the recessive genotype $j_3j_3k_3k_3$. Dominant alleles were contributed by Baby Head (Table 16).

All 3 plantings, 1974L, 1975E and 1975L, of Baby Head x P.I. 215514 F_1 suggest incomplete to complete dominance for few non-wrapper leaves (Tables 11-13). The results of a chi-square homogeneity test suggest that both the 1975E F_2 and 1975E reciprocal F_2 populations of Baby Head x P.I. 215514 could be pooled (Table 96). Using a dividing point of 17 leaves the pooled F_2 population produced a ratio of 509:201 which fit ($P=0.24$) a 13:3 weighted expected ratio of 494.46:215.54 (Table 94). Few non-wrapper leaves were produced when the dominant genotype at 1 locus, J , or the recessive genotype at the other locus, k_4k_4 , were present in the total plant genotype. Many non-wrapper leaves were produced by the genotype $j_4j_4K_4K_4$. Dominant alleles, J and K , were provided by Baby Head while recessive alleles j_4 and k_4 were produced by P.I. 215514. F_2 populations from the 1975L planting were different statistically and were not pooled. Using a dividing point of 14 leaves, the 1975L F_2 population produced a segregation ratio of 123:45 while the reciprocal F_2 population, using a dividing point of 13 leaves, produced a ratio of 189:55 (Table 97). Both populations fit ($P=0.25$ and 0.71) 3:1 weighted expected ratios of 129:38 and 187:57

Table 96. Parent, F₁ and F₂ non-wrapper leaf number distributions in percent for the 1975E planting of the cross Baby Head x P.I. 215514.

	No. of Plants	Non-wrapper Leaf Number Upper Limit of Class											Mean
		9	11	13	15	17	19	21	23	25	30	58	
Baby Head (P ₁)	42	2.3	4.8	16.7	31.0	31.0	7.1	4.8	2.3				14 ± 3
P.I. 215514 (P ₃)	18						5.6	16.7	16.7	16.7	33.3	11.0	24 ± 4
(P ₁ x P ₃)	86	4.7	4.7	11.6	34.9	23.2	12.8	4.6	2.3		1.2		14 ± 4
(P ₃ x P ₁)	70	2.8	14.3	14.3	27.1	20.0	12.8	5.7	1.5	1.5			14 ± 3
(P ₁ x P ₃) F ₂	259	22.4	12.7	13.9	13.1	7.7	8.1	8.9	7.3	2.7	1.6	1.6	13 ± 6
(P ₃ x P ₁) F ₂	451	19.5	8.6	16.6	13.7	14.2	13.5	6.4	3.2	2.0	1.6	0.7	13 ± 5

Table 97. Parent, F₁ and F₂ non-wrapper leaf number distributions in percent for the 1975L planting of the cross Baby Head x P.I. 215514.

	No. of Plants	Non-wrapper Leaf Number Upper Limit of Class											Mean
		3	5	7	9	11	13	14	17	19	21	58	
Baby Head (P ₁)	53	52.8	28.3	11.3	5.7			1.9					3 + 2
P.I. 215514 (P ₃)	13						7.7		15.4		46.1	30.8	19 + 3
(P ₁ x P ₃)	73	4.1	11.0	21.9	24.6	19.1	11.0	1.4	4.1	1.4	1.4		8 + 3
(P ₃ x P ₁)	81		16.0	8.6	23.6	29.6	13.6	3.7	4.9				8 + 3
(P ₁ x P ₃) F ₂	168	9.5	14.3	12.5	10.7	8.9	10.7	6.5	11.3	4.8	4.8	6.0	10 + 6
(P ₃ x P ₁) F ₂	244	6.1	16.3	17.6	13.9	14.3	9.4	5.7	8.6	5.3	1.6	1.2	9 + 5

respectively (Table 95). Few non-wrapper leaves were controlled by the presence of 1 dominant gene, J , provided by Baby Head. The recessive genotype $j_4j_4k_4k_4$ conditioned many non-leaves (Tables 96-97).

Both the 1974L and 1975L plantings of Baby Head x Chieftain Savoy F_1 suggest incomplete dominance for many non-wrapper leaves, however, the 1975E planting of this F_1 population showed incomplete dominance for few non-wrapper leaves (Tables 11-13). The data suggest non-wrapper leaf number may be affected by planting time. The 1975E planting of Baby Head x Chieftain Savoy F_2 produced a segregation ratio of 146:46. The data fit ($P=0.41$) a 3:1 weighted expected ratio. The presence of a single gene, J , from Baby Head was dominant for few non-wrapper leaves. The recessive genotype $j_5j_5k_5k_5$ from Chieftain Savoy produced many non-wrapper leaves. The reciprocal F_2 population of this cross produced 116 plants with few leaves and 81 plants with many leaves (Table 94). A dividing point of 16 leaves was used for both populations (Table 98). The reciprocal F_2 data fit ($P=0.32$) a 9:7 weighted theoretical ratio (Table 94). A single dominant allele was required at each locus, $J_L_$, to produce few non-wrapper leaves. Homozygous recessive genotypes at each locus produced many non-wrapper leaves. Baby Head contributed dominant alleles for few leaves while Chieftain Savoy contributed recessive alleles for many leaves. An 8:7 ratio was produced by crossing the reciprocal F_1 of this cross to the recessive cultivar Chieftain Savoy. The data produced a poor fit ($P=0.01$) to the 3.75:11.25 ratio expected. In contrast, the same cross using the F_1 rather than reciprocal F_1 produced better agreement ($P=0.08$) to a 16:16 expected ratio. Backcrossing the reciprocal F_1 to the dominant cultivar Baby Head produced a ratio of 50:5. A ratio

Table 98. Parent, F_1 , F_2 and backcross non-wrapper leaf number distributions in percent for the 1975E planting of the cross Baby Head x Chieftain Savoy.

	No. of Plants	Non-wrapper Leaf Number Upper Limit of Class											Mean
		10	12	14	16	18	20	22	24	26	31	58	
Baby Head (P_1)	42	2.4	7.1	28.6	40.5	11.9	7.1	2.4					14 ± 3
Chieftain Savoy (P_5)	34	17.6		8.8	8.8	14.7	17.6	14.7	8.8	3.0	3.0	3.0	17 ± 7
($P_1 \times P_5$)	52	32.7	13.5	13.5	11.5	9.6	5.8	3.8	5.8		3.8		13 ± 6
($P_5 \times P_1$)	83	36.1	22.9	9.6	15.7	6.0	2.4	2.4	1.3	3.6			12 ± 5
($P_1 \times P_5$) F_2	192	42.2	9.9	13.5	10.5	8.8	7.3	3.1	2.1	2.1		0.5	12 ± 6
($P_5 \times P_1$) F_2	197	24.4	8.6	9.6	16.2	11.2	9.1	9.1	4.1	2.1	4.1	1.5	15 ± 6
($P_1 \times P_5$) $\times P_5$	32	12.5	15.6	18.8	18.8	21.9	9.4	3.1					14 ± 4
($P_5 \times P_1$) $\times P_5$	15	20.0	13.3	6.7	13.3	6.7	13.3	6.7	13.3	6.7			15 ± 6
($P_5 \times P_1$) $\times P_1$	55	47.3	14.5	23.6	5.4	9.2							10 ± 4

of 55:0 was expected. The data support the 3:1 and 9:7 models postulated for non-wrapper leaf number inheritance in the cross Baby Head x Chieftain Savoy. F_2 segregation data were pooled for the late planting (Table 99). Using a dividing point of 8 leaves a pooled segregation ratio of 218:175 was observed. The data fit ($P=0.20$) a 9:7 weighted expected ratio of 231:162 (Table 95). Chieftain Savoy contributed recessive genes for many leaves while Baby Head contributed genes for few non-wrapper leaves. A homozygous recessive genotype at either locus conditioned many non-wrapper leaves (Table 99).

F_1 crosses between red and green cabbage show dominance for many leaves (Tables 11-13). All 3 plantings, 1974L, 1975E and 1975L, of Red Danish x Badger Ballhead F_1 suggest overdominance for many non-wrapper leaves. A comparison of cultivar distributions suggest Red Danish produced a greater number of non-wrapper leaves than did Badger Ballhead (Tables 100-101). Pooled Red Danish x Badger Ballhead F_2 segregation data from the early planting also show many non-wrapper leaves to be dominant (102:261) (Table 94). The pooled data fit ($P=0.05$) a weighted expected ratio of 120:243 (Table 94). A dividing point of 17 leaves was used. Red Danish contributed a single dominant gene, J_2 , for many non-wrapper leaves. The recessive genotype, $j_3j_3k_3k_3$, from Badger Ballhead produced few non-wrapper leaves. Crossing the F_1 to the dominant cultivar Red Danish did not produce a close fit to the expected 0:47 ratio. A ratio of 14:33 was observed (Table 100). Many non-wrapper leaves were also dominant in the late planting. The observed 37:254 segregation ratio for the 1975L F_2 population of Red Danish x Badger Ballhead fit ($P=0.23$) a 3:13 weighted expected ratio of 44:247 (Table 95). Many non-wrapper leaves were

Table 99. Parent, F₁ and F₂ non-wrapper leaf number distributions in percent for the 1975L planting of the cross Baby Head x Chieftain Savoy.

	No. of Plants	Non-wrapper Leaf Number Upper Limit of Class											Mean
		3	5	7	9	11	13	14	17	19	21	58	
Baby Head (P ₁)	53	52.8	28.3	11.3	5.7			1.9					3 ± 2
Chieftain Savoy (P ₅)	43		4.6	4.6	2.3	4.6	16.3	7.0	11.7	27.9	9.3	11.7	15 ± 5
(P ₁ × P ₅)	20		5.0	5.0	30.0	25.0	5.0	10.0	20.0				10 ± 3
(P ₅ × P ₁)	59	13.6	16.9	20.3	13.6	16.9	5.1		11.9	1.7			7 ± 4
(P ₁ × P ₅) F ₂	215	7.4	27.9	15.8	16.7	8.9	8.9	2.3	6.0	3.8	0.9	1.4	7 ± 5
(P ₅ × P ₁) F ₂	178	14.0	17.4	12.9	12.9	11.3	7.9	3.4	7.9	3.4	2.2	6.7	9 ± 6

Table 100. Parent, F₁, F₂ and backcross non-wrapper leaf number distributions in percent for the 1975E planting of the cross Red Danish x Badger Ballhead.

Non-wrapper Leaf Number Upper Limit of Class													
No. of Plants	9	11	13	15	17	19	21	23	25	30	58	Mean	
Red Danish (P_4)	35		11.4	14.3	28.7	25.7	8.6	5.7	2.8	2.8			16 + 3
Badger Ballhead (P_2)	39	5.1	5.1	10.2	10.2	25.6	12.8	23.1	2.6	5.1			16 + 4
($P_4 \times P_2$)	96		4.2	15.6	22.9	28.1	15.6	9.4	2.1	2.1			17 + 3
($P_2 \times P_4$)	90			10.0	16.7	30.0	21.1	14.4	5.6	2.2			18 + 3
($P_4 \times P_2$) F_2	209		1.4	2.4	9.1	15.3	21.0	19.6	10.2	9.6	8.1	3.3	19 + 5
($P_2 \times P_4$) F_2	154	0.6	1.4	2.6	8.4	14.9	18.2	24.0	12.3	7.8	8.4	1.4	19 + 5
($P_4 \times P_2$) $\times P_2$	12		8.3	16.8	8.3	25.0	33.3	8.3					17 + 3
($P_2 \times P_4$) $\times P_4$	47		2.1	6.4	21.3	10.6	23.4	12.8	19.2	4.2			19 + 4

Table 101. Parent, F_1 and F_2 non-wrapper leaf number distributions in percent for the 1975L planting of the cross Red Danish x Badger Ballhead.

	No. of Plants	Non-wrapper Leaf Number Upper Limit of Class											Mean
		5	7	9	11	13	15	17	19	21	23	58	
Red Danish (P_4)	32			18.8	9.4	53.1	12.5	6.2					11 ± 2
Badger Ballhead (P_2)	49	10.2	10.2	12.2	20.4	12.2	18.4	14.3	2.1				10 ± 4
($P_4 \times P_2$)	23		4.3	4.3	8.7	17.4	47.9	17.4					13 ± 3
($P_2 \times P_4$)	19			5.3	5.3	26.3	26.3	21.0	15.8				13 ± 3
($P_4 \times P_2$) F_2	291	0.7	1.7	2.7	7.6	21.3	22.3	16.2	13.7	6.2	4.5	3.1	14 ± 4
($P_2 \times P_4$) F_2	30	13.3	3.3	10.0	10.0	10.0	16.7	16.7		3.3		16.7	14 ± 8

produced when the dominant genotype at 1 locus, J_{2-} , or the recessive genotype at the other locus, k_3k_3 , were present. The genotype $j_3j_3k_2k_2$ conditioned few non-wrapper leaves. The reciprocal F_2 population was small. The observed segregation ratio of 11:19 fit ($P=0.90$) a 7:9 weighted expected ratio (Table 95). The dominant genotype $J_{2-}K_{2-}$ conditioned many non-wrapper leaves. Few non-wrapper leaves were produced when homozygous recessive genotypes at either loci were present. Red Danish contributed dominant genes for many leaves while Badger Ballhead produced recessive alleles for few leaves (Tables 16, 100). In both the F_2 and reciprocal F_2 populations a dividing point of 11 leaves was used (Table 101).

Data from the 1974L and 1975L F_1 populations of Red Danish x P.I. 215514 suggest incomplete dominance for few non-wrapper leaves. Data from the 1975E planting of this population suggest an additive inheritance for non-wrapper leaf number (Tables 11-13). The trend toward dominance for many non-wrapper leaves in red x green cabbage F_2 populations was further noted in Red Danish x P.I. 215514 F_2 populations. Phenotypic classes for the 1975L F_2 population were produced using a 17 leaf dividing point. An observed ratio of 62 plants with few leaves to 249 plants with many leaves was produced (Table 102). The data fit ($P=0.11$) a 7:9 weighted theoretical ratio of 74:237 (Table 94). A single dominant allele at each locus, $J_{4-}K_{4-}$, produced many non-wrapper leaves. P.I. 215514 contributed dominant alleles for many non-wrapper leaves. Few non-wrapper leaves were produced when homozygous recessive genotypes at either locus were present. Red Danish produced recessive genes for few non-wrapper leaves (Tables 95, 103).

Table 102. Parent, F₁ and F₂ non-wrapper leaf number distributions in percent for the 1975E planting of the cross Red Danish x P.I. 215514.

	No. of Plants	Non-wrapper Leaf Number Upper Limit of Class											Mean
		9	11	13	15	17	19	21	23	25	30	58	
Red Danish (P ₄)	35			11.4	14.3	28.7	25.7	8.6	5.7	2.8	2.8		16 ± 3
P.I. 215514 (P ₃)	18						5.6	16.7	16.7	16.7	33.3	11.0	24 ± 4
(P ₄ x P ₃)	85					4.7	18.8	25.9	21.2	14.1	14.1	1.2	21 ± 3
(P ₃ x P ₄)	89			2.2	3.4	7.9	29.2	23.6	11.2	12.4	9.0	1.1	20 ± 4
(P ₄ x P ₃) F ₂	311	0.6	0.6	1.9	6.2	10.6	12.5	14.8	14.5	13.2	15.8	9.3	21 ± 6

Table 103. Parent and F₁ non-wrapper leaf number distributions in percent for the 1975L planting of the cross Red Danish x P.I. 215514.

	No. of Plants	Non-wrapper Leaf Number Upper Limit of Class										Mean		
		5	7	9	11	13	15	17	19	21	23		58	
Red Danish (P_4)	32			18.8	9.4	53.1	12.5	6.2						11 + 2
P.I. 215514 (P_3)	13					7.7		15.4		46.1	15.4	15.4		19 + 3
($P_4 \times P_3$)	44			2.3				4.5	25.0	20.4	18.3	29.5		20 + 4
($P_3 \times P_4$)	14		14.4	7.1		7.1	14.4	7.1		21.4	21.4	7.1		15 + 7

Both the 1974L and 1975E F_1 plantings of Red Danish x Chieftain Savoy suggest overdominance for many non-wrapper leaves. However, the 1975L F_1 planting of this cross suggests an overdominance for few non-wrapper leaves (Tables 11-13). Non-wrapper leaf number may be affected by environmental conditions. 1975E F_2 plantings of Red Danish x Chieftain Savoy suggest Red Danish contributed recessive alleles for few non-wrapper leaves (Tables 104-105). The pooled 1975E F_2 population of Red Danish x Chieftain Savoy fit ($P=0.18$) a 1:3 model with an expected ratio of 52:157 (Table 94). A dividing point of 17 leaves was used to separate the F_2 data into phenotypic classes. Many non-wrapper leaves were controlled by the presence of 1 dominant gene, J_5 , contributed by Chieftain Savoy. The recessive genotype, $j_2j_2k_2k_2$, produced few non-wrapper leaves. Both the F_1 and reciprocal F_1 were backcrossed to the recessive cultivar Red Danish. The segregation ratios, 8:10 and 14:23 fit ($P=0.67, 0.16$) an expected 1:1 model. The data support the 1:3 model for non-wrapper leaf weight inheritance in the cross Red Danish x Chieftain Savoy (Table 94). Both 1975L F_2 populations of this cross were compared to 1:15 weighted theoretical ratios since the parental cultivars overlapped. Powers *et al.* (23) test suggested a division point of 13 leaves should be used. The 1975L F_2 population produced a segregation ratio of 31:168 while the reciprocal population was composed of 33 plants with few non-wrapper leaves and 191 plants with many leaves (Table 105). Both populations fit ($P=0.20, 0.09$) 1:15 weighted expected ratios (Table 95). The recessive genotype, $j_2j_2k_2k_2$ contributed by Red Danish, produced few non-wrapper leaves. Many non-wrapper leaves were produced by genotypes with 1 or more dominant alleles per loci. Chieftain Savoy, $J_5J_5K_5K_5$, contributed

Table 104. Parent, F₁, F₂ and backcross non-wrapper leaf number distributions in percent for the 1975E planting of the cross Red Danish x Chieftain Savoy.

	No. of Plants	Non-wrapper Leaf Number Upper Limit of Class											Mean
		9	11	13	15	17	19	21	23	25	30	58	
Red Danish (P ₄)	35			11.4	14.3	28.7	25.7	8.6	5.7	2.8	2.8		16 + 3
Chieftain Savoy (P ₅)	34	14.7	2.9	5.9	11.9	8.8	17.6	14.7	8.8	5.9	5.9	2.9	17 + 7
(P ₄ x P ₅)	33				3.0	6.1	36.4	30.3	18.2	3.0	3.0		19 + 3
(P ₅ x P ₄)	80			3.8	3.8	8.8	23.8	27.5	10.0	13.8	7.5	1.0	20 + 4
(P ₄ x P ₅) F ₂	107	0.9	0.9	2.8	3.7	15.9	15.9	15.9	17.8	12.2	9.3	4.7	20 + 5
(P ₅ x P ₄) F ₂	102	1.0	2.0	1.0	3.9	8.8	10.8	19.6	16.7	9.8	18.6	7.8	21 + 6
(P ₄ x P ₅) x P ₄	18				11.1	33.3	27.8	11.1	11.1		5.6		18 + 4
(P ₅ x P ₄) x P ₄	37		2.7	8.1	8.1	18.9	24.3	18.9	13.6	2.7		2.7	18 + 4

Table 105. Parent, F_1 and F_2 non-wrapper leaf number distributions in percent for the 1975L planting of the cross Red Danish x Chieftain Savoy.

	No. of Plants	Non-wrapper Leaf Number Upper Limit of Class											Mean
		5	7	9	11	13	15	17	19	21	23	58	
Red Danish (P_4)	32			18.8	9.4	53.1	12.5	6.2					11 ± 2
Chieftain Savoy (P_5)	43	4.6	4.6	2.3	4.6	16.3	9.3	9.3	27.9	9.3	7.0	4.6	15 ± 5
(P_4 x P_5)	28		7.1	28.6	35.8	21.4	7.1						9 ± 2
(P_5 x P_4)	30	3.3	10.0	30.0	36.7	20.0							9 ± 2
(P_4 x P_5) F_2	199	2.0	0.5	4.0	3.0	6.0	13.1	11.6	15.1	18.1	11.0	15.6	18 ± 6
(P_5 x P_4) F_2	224	1.8	0.9	3.6	3.1	5.4	10.7	12.5	15.6	11.2	12.9	22.3	18 ± 6

dominant alleles for many non-wrapper leaves. A comparison between F_2 data from green cabbage crosses and red x green cabbage crosses shows a striking difference in dominance direction for non-wrapper leaf number. Further experiments are needed to determine whether this difference was due to the use of red cabbage in these crosses or whether an interaction of the green and red germplasm produced this difference.

Heritability estimates for non-wrapper leaf number have been shown by Chiang (3) and Swarup (30) to be 0.35 and 0.52 respectively. Heritability estimates for green cabbage crosses included a negative estimate and 4 estimates greater than 1. The only estimate within the established 0 to 1 heritability range was 0.67 ± 0.88 . The $\bar{h}_x^2$ estimate was 0.90 ± 0.48 . It appears that 67% of the variation in the F_1 population may be additive. Heritability estimates from red x green cabbage F_1 populations included 3 negative estimates and 1 estimate greater than 1. Two estimates fell within the established 0 to 1 heritability range. They were 0.42 and 0.37. The mean heritability estimate was 0.50 ± 0.33 with an $\bar{h}_x^2$ estimate of 0.51 ± 0.33 . Additive genetic control for non-wrapper leaf number may be greater in green cabbage F_1 's than in red x green cabbage F_1 populations (Table 30).

It appears from the data that there is a better genetic correlation between non-wrapper leaf number and efficiency index than between non-wrapper leaf number and non-wrapper leaf size. The F_1 mean genetic correlations between non-wrapper leaf number and efficiency index or non-wrapper leaf size for crosses involving green cabbage cultivars were 0.94 ± 0.27 and -0.18 ± 0.59 , while the same $\bar{r}_g$ values for red x

green cabbage F_1 's were 0.85 ± 0.90 and -0.56 ± 0.93 . Correlation estimates between non-wrapper leaf number and efficiency index ranged from -0.02 to 0.96 , while genetic correlations between non-wrapper leaf number and non-wrapper leaf size ranged from -0.96 to 0.98 for crosses between green cabbage cultivars. $\bar{r}_{gx}$ estimates were 0.92 ± 0.10 and -0.18 ± 0.59 respectively. Red x green cabbage F_1 genetic correlations between non-wrapper leaf number and efficiency index ranged from 0.79 to 0.96 and for correlations between non-wrapper leaf number and non-wrapper leaf size ranged between -0.80 and 0.78 . $\bar{r}_{gx}$ estimates were 1.00 ± 0.10 and 0.34 ± 0.92 respectively (Table 87).

Efficiency Index

Efficiency index is a ratio of total non-wrapper leaf weight and stalk size (weight) to head weight. Efficient plants, those that produce a head weight equal to or greater than the sum of total non-wrapper leaf weight and stalk size, produce efficiency index readings that are equal to or less than 1. Analysis of the inbreeding data showed significant differences exist between cultivars, inbreeding and plantings. The interactions, cultivar x inbreeding, cultivar x plantings, inbreeding x plantings and cultivar x inbreeding x plantings were also significant (Table 106). Although Chieftain Savoy did not differ from P.I. 215514, all of the other cultivars were significantly different from each other. Between cultivars, efficiency index estimates ranged from 0.36 units of unsalable plant parts per unit of cabbage head to 2.02 units of unsalable plant parts per unit of cabbage head (Table 107). The difference of 0.5 units due to inbreeding was significant. It appears that 1 generation of inbreeding a randomly selected parent plant reduced plant efficiency to 50%

Table 106. Analysis of variance table for efficiency index
(non-wrapper leaf weight + stalk size (weight)/head
weight).

Source of Variance	DF	Mean Square	F*
Replication (R)	2	0.07	0.38
Cultivar (C)	4	7.07	38.99**
Inbreeding (I)	1	5.41	29.85**
C x P	4	1.71	9.43**
Plantings (P)	2	10.45	57.62**
C x P	8	2.45	13.50**
I x P	2	1.52	8.40**
C x I x P	8	0.90	4.99**
Residual Error	58	0.18	

F test significant at the 5%, or 1%** level.

Table 107. Cultivar x inbreeding interaction means for efficiency index.

Cultivar	Inbreeding		Cultivar Means
	P ₁	S ₁	
Baby Head	0.41 a*	0.32 a	0.36 W
Badger Ballhead	0.68 a	0.99 a	0.83 X
P.I. 215514	1.16 a	1.47 a	1.31 Y
Red Danish	1.26 a	2.80 b	2.03 Z
Chieftain Savoy	1.21 a	1.60 a	1.40 Y
Inbreeding Means	0.94 A	1.43 B	

*Mean separation, within rows, by Duncan's Multiple Range Test at the 5% level.

(Table 107). The selection of only 1 plant from an open-pollinated line may also have contributed to reduced plant efficiency. The data show environmental effects modified efficiency index. Each planting was significantly different. A comparison between the 1974L and 1975L plantings show that efficiency estimates can double due to environmental effects (Table 108). The significance of the cultivar x inbreeding interaction was due to a difference in plant efficiency between inbreeding levels for Red Danish (Table 107). Plant efficiency for Baby Head was not effected by different plantings, however, Red Danish showed a significant increase in efficiency from the 1974L planting to the 1975E planting and a significant decrease in efficiency from the 1957E to 1975L planting. Badger Ballhead, P.I. 215514 and Chieftain Savoy all showed a significant increase in plant efficiency between the 1974L and 1975E plantings and remained unchanged between the 1975E and 1975L plantings (Table 108). While plant efficiency decreased due to 1 generation of inbreeding in both the 1974L and 1975L plantings, the 1975E planting showed no change in plant efficiency due to inbreeding (Table 109). The second order interaction, cultivar x inbreeding x plantings was significant due to a decrease in plant efficiency between inbreeding levels of the 1975L planting of Red Danish. Other cultivars showed no change in efficiency due to inbreeding for either the 1975E or 1975L plantings. Differences in cultivar, inbreeding response during the 1974L planting contributed to a significant interaction. For the 1974L planting both Baby Head and Badger Ballhead showed no difference in plant efficiency due to inbreeding while the other 3 cultivars each showed a significant decrease in plant efficiency after 1 generation of inbreeding (Table 110).

Table 108. Cultivar x planting interaction means for efficiency index.

Cultivar	1974L	Plantings 1975E	1975L	Cultivar Means
Baby Head	0.26 ab*	0.69 b	0.15 a	0.36 W
Badger Ballhead	1.25 b	0.66 a	0.59 a	0.83 X
P.I. 215514	2.12 b	0.95 a	0.87 a	1.31 Y
Red Danish	2.87 b	0.77 a	2.45 b	2.03 Z
Chieftain Savoy	2.78 b	0.59 a	0.84 a	1.40 Y
Planting Means	1.85 C	0.73 A	0.98 B	

*Mean separation, within rows, by Duncan's Multiple Range Test at the 5% level.

Table 109. Inbreeding x plantings interaction means for efficiency index.

Inbreeding	1974L	Plantings 1975E	1975L	Inbreeding Means
P_1	1.46 a*	0.74 a	0.62 a	0.94 Y
S_1	2.24 b	0.72 a	1.34 b	1.43 Z
Planting Means	1.85 C	0.73 A	0.98 B	

*Mean separation, within columns, by Duncan's Multiple Range Test at the 5% level.

Table 110. Cultivar x inbreeding x planting interaction means for efficiency index.

Cultivar	Inbreeding	1974L	Plantings 1975E	1975L
Baby Head	P ₁	0.32 a*	0.73 a	0.17 a
	S ₁	0.19 a	0.64 a	0.12 a
Badger Ballhead	P ₁	1.11 a	0.60 a	0.34 a
	S ₁	1.40 a	0.73 a	0.83 a
P.I. 215514	P ₁	1.68 a	0.96 a	0.84 a
	S ₁	2.56 b	0.93 a	0.90 a
Red Danish	P ₁	2.00 a	0.86 a	0.90 a
	S ₁	3.73 b	0.67 a	4.00 b
Chieftain Savoy	P ₁	2.21 a	0.58 a	0.84 a
	S ₁	3.34 b	0.60 a	0.84 a

*Mean separation, within columns and cultivars, by Duncan's Multiple Range Test at the 5% level.

No study has previously reported on the inheritance of a cabbage efficiency index. F_1 means of green cabbage crosses suggest incomplete dominance to overdominance for increased plant efficiency. On the other hand all red x green cabbage crosses, with the exception of the 1975L F_1 mean of Red Danish x Chieftain Savoy, show reduced plant efficiency to be dominant. The 1974 F_1 planting of Baby Head x Badger Ballhead suggests that increased plant efficiency was completely dominant, however, both the 1975E and 1975L F_1 plantings of this cross suggest complete dominance to overdominance for reduced plant efficiency (Tables 11-13). Tables 111 and 112 show frequency distributions in percent for populations involved in the cross Baby Head x Badger Ballhead. Powers *et al.* (23) partitioning tests were applied to these distributions to determine the number of genes controlling plant efficiency and to define the boundary between efficient and inefficient classes. Powers *et al.* (23) formula (F_2/P_1) was applied sequentially from the recessive ends of both the F_2 and P_1 distributions. Using the 1975E planting of Baby Head x Badger Ballhead as an example recessive frequencies of 3.6/9.6 or 0.38 for the 3.50+ class, 5.6/12.0 or 0.47 for the 1.09 class, 6.8/21.5 or 0.32 for the 0.99 class, 10.0/33.4 or 0.30 for the 0.89 class, 13.6/45.3 or 0.30 for the 0.79 class, 20.3/61.9 or 0.33 for the 0.69 class and 31.4/80.9 or 0.39 for the 0.59 class were produced (Table 111). The change in frequency between the 0.69 and 0.59 classes suggest a dividing point of 0.59 could separate the phenotypic classes. Frequency estimates were close to the 0.25 frequency expected from a 3:1 model. The 1975E reciprocal population also suggests dominance for increased plant efficiency. Applying the same formula (F_2/P_1) to the recessive end of the Baby Head distribution, frequencies of 6.8/9.6 or 0.71 for the 3.50+ class,

Table 111. Parent, F₁, F₂ and backcross efficiency index distributions in percent for the 1975E planting of the cross Baby Head x Badger Ballhead.

	No. of Plants	Efficiency Index X 100 Upper Limit of Class										Mean
		29	39	49	59	69	79	89	99	109	350+	
Baby Head (P ₁)	42	2.4	2.4	14.3	19.0	16.6	11.9	11.9	9.5	2.4	9.6	71.1 ± 25.4
Badger Ballhead (P ₂)	39	7.7	20.5	20.5	23.1	10.1	7.7			2.6	7.8	58.6 ± 39.7
(P ₁ x P ₂)	83		7.2	12.0	13.2	14.6	12.0	15.8	8.4	6.0	10.8	73.9 ± 26.0
(P ₂ x P ₁)	89	1.1	6.7	16.8	23.7	12.4	19.1	10.1	1.1	3.4	5.6	64.6 ± 21.7
(P ₁ x P ₂) F ₂	252	5.6	13.9	25.8	23.3	11.1	6.7	3.6	3.2	1.2	2.0	50.8 ± 71.8
(P ₂ x P ₁) F ₂	248	3.6	11.3	17.7	19.4	13.9	12.5	5.6	4.4	2.8	2.0	55.9 ± 35.6
(P ₂ x P ₁) x P ₂	33	9.1	12.1	21.2	12.1	30.4	9.1	3.0		3.0		44.7 ± 18.8

Table 112. Parent, F_1 and F_2 efficiency index distributions in percent for the 1975L planting of the cross Baby Head x Badger Ballhead.

		Efficiency Index X 100 Upper Limit of Class													
		No. of Plants	19	29	39	49	59	69	79	89	99	109	350+	Mean	
Baby Head (P_1)		53	71.7	24.5										17.4 ±	10.6
Badger Ballhead (P_2)		49	24.5	12.2	24.6	26.6	6.1			2.0	2.0	2.0		35.2 ±	19.0
(P_1 x P_2)		38	31.5	26.4	15.8	7.9	2.6	5.3	7.9				2.6	33.0 ±	23.2
(P_2 x P_1)		77	74.0	11.7	7.8	3.9		1.3					1.3	35.4 ±	148.1
(P_1 x P_2) F_2		130	43.1	20.8	16.2	10.6	1.5	4.6	0.8	0.8	0.8		0.8	27.0 ±	19.4
(P_2 x P_1) F_2		211	29.8	37.4	14.8	8.0	3.8	2.4	0.9	1.4		0.5	1.0	29.0 ±	23.2

8.8/12.0 or 0.73 for the 1.09 class, 11.6/21.5 or 0.54 for the 0.99 class, 16.0/33.4 or 0.48 for the 0.89 class, 21.6/45.3 or 0.48 for the 0.79 class, 34.1/61.9 or 0.55 for the 0.69 class and 48.0/80.9 or 0.59 for the 0.59 class were produced (Table 112). The frequencies suggest a dividing point between the 0.69 and 0.59 classes. The observed mean frequency of 0.58 was higher than the 0.43 expected from a 9:7 model, however, the data fit ($P=0.10$) the model (Table 114). In both the F_2 and reciprocal F_2 populations weighted theoretical ratios were used to explain the data since the distributions of the parental cultivars overlapped. The weighted ratio was obtained by the following method: first the net overlap around the dividing point was subtracted from 100 and divided by 100. This number was multiplied by the total number of plants in the sample and the expected frequency of the deficient class. For example the 1975E Baby Head x Badger Ball-head F_2 3:1 weighted expected ratio was calculated in the following manner (Table 113). The net overlap $(38.1-28.2) = 9.9$ subtracted from 100 and divided by 100 = (0.901) , was multiplied by 252 and by the frequency of the deficient class, 0.25, to provide the number of recessive plants (56.76). The expected ratio was found by subtracting this number from 252 to produce a ratio of 195.24:56.76 (Table 113). The weighted expected ratio of the 1975E reciprocal F_2 population was calculated in a similar manner. For example $((100-9.9)/100)(0.4375)(248) = 97.76$. The expected ratio was 150.24:97.76 (Table 114). Powers et al. (23) tests on other F_2 populations suggest a maximum of 2 genes control this trait. Genes for components of this trait may be linked since such a complex trait should be controlled by a large number of genes. In order to explain the differences between cultivars and provide a simplified gene system a 2 locus 5 allele per locus model was

Table 113. Chi-square test for goodness of fit to the postulated model for efficiency index in the F_2 generation (1975E planting).

Cross	Observed	Expected	Model	χ^2	P
Baby Head x Badger Ballhead					
F_2	201: 51	195.24: 56.76*	3: 1	0.7552	0.41
RF_2	163: 85	150.24: 97.76*	9: 7	2.7485	0.10
Baby Head x P.I. 215514					
F_2	245: 14	242.81: 16.19	15: 1	0.3153	0.57
RF_2	424: 27	422.81: 28.19	15: 1	0.0533	0.82
Pooled	669: 41	665.62: 44.38	15: 1	0.2738	0.60
Baby Head x Chieftain Savoy					
F_2	181: 11	180.00: 12.00	15: 1	0.0889	0.76
RF_2	187: 10	184.69: 12.31	15: 1	0.4633	0.30
Red Danish x Badger Ballhead					
F_2	35:174	43.48:165.52*	1: 3	2.0903	0.15
RF_2	27:127	32.04:121.96*	1: 3	1.0015	0.32
Pooled	62:301	75.52:287.47*	1: 3	3.0585	0.08
Red Danish x P.I. 215514					
F_2	18:293	19.44:291.56	1:15	0.1134	0.74
Red Danish x Chieftain Savoy					
F_2	8: 99	5.54:101.46*	1:15	1.1508	0.28
RF_2	7: 97	5.28: 96.72*	1:15	0.5892	0.44
Pooled	15:194	10.82:198.18*	1:15	1.6999	0.19

* = Weighted

Table 114. Chi-square test for goodness of fit to the postulated model for efficiency index in the F_2 generation (1975L planting).

Cross	Observed	Expected	Model	χ^2	P
Baby Head x Badger Ballhead					
F_2	83: 47	91.87: 38.13*	9: 7	2.9209	0.09
RF_2	142: 69	149.11: 61.88*	9: 7	1.1574	0.28
Pooled	225:116	240.95:100.01*	9: 7	3.6158	0.06
Baby Head x P.I. 215514					
F_2	130: 38	138.92: 29.08*	3: 1	3.3114	0.07
RF_2	183: 61	185.39: 58.61*	3: 1	0.1283	0.72
Baby Head x Chieftain Savoy					
F_2	171: 44	167.97: 47.03*	3: 1	0.2496	0.62
RF_2	128: 50	139.06: 38.94*	3: 1	4.0249	0.04
Pooled	299: 94	307.04: 85.96*	3: 1	0.9617	0.33
Red Danish x Badger Ballhead					
F_2	15:276	11.70:279.30*	1:15	0.9673	0.32
Red Danish x Chieftain Savoy					
F_2	15:184	12.44:186.56	1:15	0.5632	0.45
RF_2	12:212	14.00:210.00	1:15	0.3523	0.55
Pooled	27:396	26.44:396.56	1:15	0.0128	0.91

* = Weighted

postulated. The loci were designated L and M . Tables 16 and 17 show the cultivar and F_1 genotypes under this system. A comparison of cultivar distribution patterns and postulated models for segregation data suggest that in both 15:1 and 1:15 models transgressive segregation occurred. These observations suggest that parental homozygous loci were in repulsion for crosses producing these ratios. Green cabbage crosses in the early planting suggest L was dominant to L_3 , L_4 and L_5 and m was recessive to M_e , M_4 and M_5 . Red x green cabbage crosses in the early planting suggest L_2 was dominant to L_3 , L_4 and L_5 while m_5 and m_3 were recessive to M_2 , and M_2 was recessive to M_4 . 1975L F_2 distributions suggest L was dominant to L_3 , L_4 and L_5 . Similar inheritance patterns were noted for the M locus. Red x green cabbage crosses grown in the late planting suggest L_2 was dominant to L_3 and L_5 while m_3 was recessive to M_2 and M_2 was recessive to M_5 (Tables 16-17). 1975E Baby Head x Badger Ballhead F_2 data, using the 0.59 class as a dividing point, produced a segregation ratio of 201:51. The data fit ($P=0.41$) a 3:1 weighted expected ratio of 195.24:56.76 (Table 113). Efficient plants were dominant and controlled by the presence of a single gene L_3 . The recessive genotype $llmm$ produced inefficient plants. Baby Head was the source of recessive alleles in this cross. Reciprocal F_2 data for the same planting, showed a segregation ratio of 163 efficient plants to 22 inefficient plants. Again a dividing point of 0.59 was used to separate the phenotypic classes. This data fit ($P=0.10$) a 9:7 weighted expected ratio of 150.24:97.76 (Table 113). Inefficient plants were produced when 1 or more homozygous recessive loci occurred in the plant genotype. The genotype L_3-M_3- conditioned efficient plants. Dominant alleles for efficiency were

provided by Badger Ballhead (Table 111). The reciprocal F_1 was crossed to the dominant cultivar Badger Ballhead. This cross produced a segregation ratio of 32:1. A ratio of 33:0 was expected. The data support the 9:7 model with Badger Ballhead contributing dominant alleles for increased cabbage plant efficiency. F_2 data from the 1975L planting of Baby Head x Badger Ballhead was pooled to produce a segregation ratio of 225:116. A division point of 0.29 was used to separate the data into classes. The data fit ($P=0.06$) a 9:7 weighted expected ratio of 241:100 (Table 114). Homozygous recessive genotypes at either locus produced inefficient plants. Recessive alleles l_3 and m_3 were contributed by Badger Ballhead.

Both the 1974L and 1975L plantings of Baby Head x P.I. 215514 F_1 suggest incomplete dominance for efficiency while the 1975E planting suggests overdominance for efficiency (Tables 11-13). Both the 1975E F_2 and reciprocal F_2 populations of Baby Head x P.I. 215514 were pooled. The pooled data suggest efficiency was dominant (Table 115). Of the 710 F_2 plants sampled 669 were classed as efficient and 41 were classed as less efficient. A dividing point of 0.89 was used. The data showed good fit ($P=0.60$) to the 15:1 model (Table 113). Efficient plants were produced when either L or M_4 were present in the genotype. Inefficient plants were produced by the genotype $l_4 l_4^{mm}$. Baby Head contributed L and m alleles while P.I. 215514 contributed l_4 and M_4 alleles. Each cultivar contributed 1 dominant and 1 recessive allele to the F_1 plant. F_2 populations in the 1975L planting were not pooled. The F_2 population, using a dividing point of 0.69, produced a segregation ratio of 130:38 (Table 114). The data fit ($P=0.07$) a 3:1 weighted expected ratio of 139:29 (Table 114). The 1975L reciprocal F_2 population of this cross, with an observed ratio of 183:61, also fit

Table 115. Parent, F_1 and F_2 efficiency index distributions in percent for the 1975E planting of the cross Baby Head x P.I. 215514.

Efficiency Index X 100 Upper Limit of Class													
No. of Plants	19	29	39	49	59	69	79	89	99	109	350+	Mean	
Baby Head (P_1)	42	2.4	2.4	14.3	19.0	16.6	11.9	11.9	9.5	2.4	9.6	71.1 ± 25.4	
P.I. 215514 (P_3)	18				5.6	11.1	22.2	22.2		16.6	22.3	96.0 ± 32.1	
(P_1 x P_3)	86	2.3	9.3	32.6	27.8	14.0	4.6	2.3	1.2	2.3	2.4	45.6 ± 20.6	
(P_3 x P_1)	70		8.6	32.8	35.7	15.9	1.4	1.4	1.4		1.4	43.4 ± 16.2	
(P_1 x P_3) F_2	259	3.1	15.4	24.3	19.3	13.5	7.7	6.9	4.2	0.8	4.0	49.0 ± 27.4	
(P_3 x P_1) F_2	451	5.3	13.1	22.8	21.7	14.6	8.9	4.6	3.1	4.0	0.9	47.3 ± 24.6	



($P=0.72$) a 3:1 weighted theoretical ratio (Table 114). The presence of a single dominant gene, L , from Baby Head conditioned efficient plant production. The recessive genotype, $l_4l_4m_4m_4$, produced inefficient plants (Table 116).

F_1 populations of Baby Head x Chieftain Savoy produced the same results as F_1 populations of Baby Head x P.I. 215514. 1974L and 1975L F_1 plantings showed incomplete dominance for efficiency while the 1975E planting showed overdominance (Tables 11-13). Baby Head x Chieftain Savoy F_2 data from the early planting were not pooled. Using a dividing point of 0.69 the F_2 population produced a segregation ratio of 181:11 and fit ($P=0.76$) a 15:1 model (Table 113). The recessive genotype $l_5l_5m_5m_5$ conditioned poor efficiency (Table 117). The reciprocal F_2 population produced a ratio of 187:10 which fit ($P=0.30$) a 15:1 model (Table 113). A dividing point of 0.89 was used to separate phenotypic classes. Dominant efficient plants were produced when a dominant allele at either loci, L or M_5 , was present in the plant genotype. The recessive genotype $l_5l_5m_5m_5$ conditioned inefficient plants. Chieftain Savoy contributed 1 dominant allele L_5 and 1 recessive allele m_5 to the gene pool while Baby Head produced both a dominant allele M and a recessive allele l . Crossing both the F_1 and reciprocal F_1 plants to Chieftain Savoy produced ratios of 26:6 and 15:0. Ratios of 32:0 and 15:0 were expected. The reciprocal F_1 was also backcrossed to Baby Head. A ratio of 55:0 was produced. A 55:0 ratio was expected. The backcross data support the 15:1 F_2 model for Baby Head x Chieftain Savoy efficiency index inheritance. F_2 data from the late planting were pooled. The segregation ratio of 299:94 suggests that efficiency was dominant (Table 118). A dividing point of 0.39 was used to separate

Table 116. Parent, F_1 and F_2 efficiency index distributions in percent for the 1975L planting of the cross Baby Head x P.I. 215514.

Efficiency Index X 100 Upper Limit of Class												
No. of Plants	19	29	39	49	59	69	79	89	99	109	350+	Mean
Baby Head (P_1)	53	71.7	24.5			3.8						17.4 ± 10.6
P.I. 215514 (P_3)	13			7.7	7.7	15.4	23.0	7.7	15.4		23.1	87.5 ± 34.0
($P_1 \times P_3$)	73	9.6	42.5	31.4	11.0	1.4	1.4	2.7				30.2 ± 11.9
($P_3 \times P_1$)	81	4.9	39.5	37.0	11.2	6.2	1.2					32.0 ± 10.0
($P_1 \times P_3$) F_2	168	6.6	16.1	25.0	12.5	11.3	6.0	4.8	2.1	1.2	14.4	65.9 ± 73.9
($P_3 \times P_1$) F_2	244	17.6	23.8	21.5	12.3	10.2	6.1	3.7	2.4	1.2	1.2	44.6 ± 83.7



Table 117. Parent, F₁, F₂ and backcross efficiency index distributions in percent for the 1975E planting of the cross Baby Head x Chieftain Savoy.

	No. of Plants	Efficiency Index X 100 Upper Limit of Class											Mean
		19	29	39	49	59	69	79	89	99	109	350+	
Baby Head (P ₁)	42		2.4	2.4	14.3	19.0	16.6	11.9	11.9	9.5	2.4	9.6	71.1 ± 25.4
Chieftain Savoy (P ₅)	34	2.9	8.8	20.6	14.7	17.6	20.8	5.9		2.9		5.8	56.4 ± 38.1
(P ₁ x P ₅)	52	15.3	21.4	13.5	11.5	11.5	11.5	5.8			3.8	5.7	47.5 ± 36.6
(P ₅ x P ₁)	83	7.2	43.4	22.9	8.5	7.2	6.0		1.2	1.2	1.2	1.2	35.6 ± 21.0
(P ₁ x P ₅) F ₂	192	10.4	19.8	31.3	18.8	8.3	5.7	2.6	1.0	1.6	0.5		37.8 ± 17.5
(P ₅ x P ₁) F ₂	197	10.1	18.3	19.4	14.2	15.7	7.6	5.1	4.6	2.5		2.5	45.0 ± 24.3
(P ₁ x P ₅) x P ₅	32	3.1	6.2	28.1	18.9	6.2	18.8	9.4	3.1		3.1	3.1	51.7 ± 24.3
(P ₅ x P ₁) x P ₅	15	20.0	20.0	13.3	33.3	6.7		6.7					36.9 ± 15.7
(P ₅ x P ₁) x P ₁	55	34.5	20.0	9.2	14.5	14.5	7.3						32.4 ± 17.5

Table 118. Parent, F₁ and F₂ efficiency index distributions in percent for the 1975L planting of the cross Baby Head x Chieftain Savoy.

Efficiency Index X 100 Upper Limit of Class														
No. of Plants		19	29	39	49	59	69	79	89	99	109	350+	Mean	
Baby Head (P_1)		53	71.7	24.5			3.8							17.4 + 10.6
Chieftain Savoy (P_5)		43		4.6	11.6	9.4	11.6	9.4	2.3	14.0	9.4	4.6	23.1	83.6 + 46.5
($P_1 \times P_5$)		20	40.0	20.0	5.0	5.0	10.0	20.0						32.3 + 21.2
($P_5 \times P_1$)		59	54.2	20.3	6.8	3.4	5.1	8.5	1.7					24.4 + 17.5
($P_1 \times P_5$) F_2		215	32.1	26.6	20.9	7.4	6.0	2.3	0.9	0.9	1.4	0.5		30.3 + 23.3
($P_5 \times P_1$) F_2		178	36.0	23.0	12.9	10.1	1.6	2.8	3.9	0.6	0.6	8.5		41.0 + 48.8

the F_2 classes. The data fit ($P=0.33$) a 3:1 weighted expected ratio of 307:86 (Table 114). Efficient plants were produced by the presence of a dominant L allele from Baby Head. Inefficient plants were produced by the $l_5 l_5 m_5 m_5$ genotype of Chieftain Savoy.

All 3 plantings, 1974L, 1975E and 1975L, of Red Danish x Badger Ballhead F_1 suggest poor efficiency was dominant to overdominant when compared to efficiency (Tables 11-13). F_2 data from the 1975E planting of Red Danish x Badger Ballhead were pooled as suggested by chi-square homogeneity tests. A population of 363 plants was sampled for efficiency index (Table 119). Using a dividing point of 0.59, data from the pooled F_2 population produced a ratio of 62:301. This ratio fit ($P=0.08$) a 1:3 weighted theoretical ratio of 76:287 (Table 113). Inefficient plants were produced when a single dominant allele, L_2 , was present in the plant genotype. Efficient plants were conditioned by the recessive genotype $l_3 l_3 m_3 m_3$. Badger Ballhead contributed genes for efficiency while Red Danish contributed genes for inefficiency. A ratio of 7:5 was obtained from the backcross between the F_1 and the recessive cultivar Badger Ballhead. The data fit ($P=0.59$) an expected 6:6 ratio. Data from a cross between the reciprocal F_1 and Red Danish suggest a segregation ratio of 2:45. A ratio of 0:47 was expected. Data from the 1975L F_2 planting of this cross produced a ratio of 15:276 (Table 120). A dividing point of 0.39 was used to separate the F_2 data into classes. The observed ratio fit ($P=0.32$) a 1:15 weighted expected ratio (Table 114). Inefficient plants were controlled by 2 dominant genes. The presence of a dominant allele, L_2 or M_2 , at either locus conditioned an inefficient plant. The homozygous recessive genotype $l_3 l_3 m_3 m_3$ from Badger Ballhead produced an efficient plant phenotype.

Table 119. Parent, F_1 , F_2 and backcross efficiency index distributions in percent for the 1975E planting of the cross Red Danish x Badger Ballhead.

	No. of Plants	Efficiency Index X 100 Upper Limit of Class											Mean
		19	29	39	49	59	69	79	89	99	109	350+	
Red Danish (P_4)	35			2.8		8.6	28.6	14.5	8.6	8.6	5.7	22.6	89.8 ± 43.4
Badger Ballhead (P_2)	39		7.7	20.5	20.5	23.1	10.1	7.7			2.6	7.8	58.6 ± 39.7
(P_4 x P_2)	96			1.0	15.6	14.6	14.6	12.6	9.4	9.4	6.2	16.6	79.5 ± 32.2
(P_2 x P_4)	90					3.3	14.4	15.6	16.7	11.1	8.9	30.0	99.7 ± 44.8
(P_4 x P_2) F_2	209		0.5	1.4	2.4	12.4	12.0	17.6	16.3	12.4	5.7	19.3	91.4 ± 56.3
(P_2 x P_4) F_2	154		2.6	1.3	6.5	7.1	11.0	11.7	12.6	13.6	5.8	27.8	95.8 ± 56.3
(P_4 x P_2) x P_2	12			8.3	16.8	33.3	33.3	8.3					56.3 ± 11.0
(P_2 x P_4) x P_4	47					4.2	4.2	2.1	6.4	8.5	10.7	63.9	138.4 ± 64.8

Table 120. Parent, F₁ and F₂ efficiency index distributions in percent for the 1975L planting of the cross Red Danish x Badger Ballhead.

Efficiency Index X 100 Upper Limit of Class													
No. of Plants	19	29	39	49	59	69	79	89	99	109	350+	Mean	
Red Danish (P ₄)	32		3.1	9.4	12.5	18.8	21.9	3.1	6.3		24.9	89.5 ±	49.8
Badger Ballhead (P ₂)	49	24.5	12.2	24.6	26.6	6.1		2.0	2.0	2.0		35.2 ±	19.0
(P ₄ x P ₂)	23		13.0	17.4	4.3	4.3	13.2	8.9	13.0	4.3		84.1 ±	60.2
(P ₂ x P ₄)	19		5.3	10.5		15.7		10.5	21.0		37.0	108.7 ±	62.7
(P ₄ x P ₂) F ₂	291	1.0	1.4	2.7	4.5	6.5	10.0	10.0	6.9	8.6	5.2	129.1 ±	104.3
(P ₂ x P ₄) F ₂	30	6.7	6.7	3.3	13.3	6.7	3.3	6.7	10.2	3.3	3.3	104.1 ±	83.9

F_1 populations of Red Danish x P.I. 215514 grown in the 1974L, 1975E and 1975L plantings suggest poor cabbage plant efficiency was overdominant (Tables 11-13). Due to poor seed production, F_2 populations of Red Danish x P.I. 215514 were grown only in the early planting (Table 122). Of the 311 plants sampled, 18 were classified as efficient while 293 were less efficient (Table 121). The data produced a good fit ($P=0.74$) to a 1:15 model (Table 113). A dividing point of 0.49 was used to separate the F_2 data. Inefficient plants were produced when either of the dominant L_2 or M_4 alleles were present in the plant genotype. Efficient plants were produced by the $l_4^1 l_4^1 m_2^m m_2^m$ genotype. Red Danish produced a dominant L_2 allele while P.I. 215514 produced a dominant M_4 allele.

1975L and 1975E F_1 plantings of Red Danish x Chieftain Savoy suggest overdominance and complete dominance for reduced plant efficiency. The 1975L F_1 planting suggests incomplete dominance for increased plant efficiency (Tables 11-13). Environmental conditions affect changes in plant efficiency. Red Danish x Chieftain Savoy F_2 data were pooled within each planting based on the results of chi-square homogeneity tests. Pooled F_2 data from each planting were compared to 1:15 weighted theoretical ratios. F_2 data from the early planting produced a ratio of 15:194 (Table 123). This ratio fit ($P=0.10$) an expected 11:198 ratio (Table 113). A division point of 0.59 was used to divide F_2 data into classes. Inefficient plants were produced by genotypes with either a dominant L_2 or M_2 allele. The recessive genotype $l_5^1 l_5^1 m_5^m m_5^m$ from Chieftain Savoy conditioned an efficient plant phenotype. F_1 plants backcrossed to Red Danish produced a ratio of 1:17. A 0:18 ratio was expected. However, the 20:17 ratio produced

Table 121. Parent, F₁ and F₂ efficiency index distributions in percent for the 1975E planting of the cross Red Danish x P.I. 215514.

Efficiency Index X 100 Upper Limit of Class												
No. of Plants	19	29	39	49	59	69	79	89	99	109	350+	Mean
Red Danish (P ₄)	35		2.8		8.6	28.6	14.5	8.6	8.6	5.7	22.6	89.8 ± 43.4
P.I. 215514 (P ₃)	18				5.6	11.1	22.2	22.2		16.6	22.3	96.0 ± 32.1
(P ₄ x P ₃)	85	11.8	8.1	14.1	11.7	9.4	11.7	4.7	5.9	1.2	20.2	126.8 ± 49.3
(P ₃ x P ₄)	89			1.1	7.9	11.2	10.1	7.9	12.6	10.1	39.1	112.3 ± 55.8
(P ₄ x P ₃) F ₂	311		1.0	1.9	2.9	6.9	9.3	9.3	6.9	6.1	5.8	133.8 ± 82.6

Table 122. Parent and F_1 efficiency index distributions in percent for the 1975L planting of the cross Red Danish x P.I. 215514.

Efficiency Index X 100 Upper Limit of Class													202
No. of Plants	19	29	39	49	59	69	79	89	99	109	350+	Mean	
Red Danish (P_4)	32		3.1	9.4	12.5	18.8	21.9	3.1	6.3		24.9	89.5 + 49.8	
P.I. 215514 (P_3)	13			7.7	7.7	15.4	23.0	7.7	15.4		23.1	87.5 + 34.0	
($P_4 \times P_3$)	44	2.3							4.5		93.2	197.9 + 100.0	
($P_3 \times P_4$)	14		14.4	14.4	7.1	7.1				7.1	49.9	133.6 + 93.9	

Table 123. Parent, F₁, F₂ and backcross efficiency index distributions in percent for the 1975E planting of the cross Red Danish x Chieftain Savoy.

	No. of Plants	Efficiency Index X 100 Upper Limit of Class											Mean
		19	29	39	49	59	69	79	89	99	109	350+	
Red Danish (P ₄)	35			2.8		8.6	28.6	14.5	8.6	8.6	5.7	22.6	89.8 ± 43.4
Chieftain Savoy (P ₅)	34	2.9	8.8	20.6	14.7	17.6	20.8	5.9		2.9		5.8	56.4 ± 38.1
(P ₄ x P ₅)	33					12.1	24.2	21.3	15.2	9.1	3.0	15.1	89.7 ± 43.4
(P ₅ x P ₄)	80				1.2	3.8	16.2	22.5	25.2	11.2	1.2	18.7	91.4 ± 42.1
(P ₄ x P ₅) F ₂	107	0.9			2.8	3.7	7.5	15.9	12.1	9.3	10.3	37.1	108.3 ± 55.2
(P ₅ x P ₄) F ₂	102			1.0	2.0	3.9	4.9	7.8	8.8	10.6	5.9	55.1	146.9 ± 126.1
(P ₄ x P ₅) x P ₄	18				5.6		5.6		27.8	16.4	11.1	33.5	106.4 ± 39.4
(P ₅ x P ₄) x P ₄	37				21.6	32.4	10.9	5.4	5.4	5.4		18.9	104.5 ± 126.5

from the reciprocal F_1 x Red Danish backcross did not agree with the 0:37 expected ratio. Differences in F_1 and RF_1 gametic transmission are suggested. Data from the 1975L planting of Red Danish x Chieftain Savoy F_2 show an observed segregation ratio of 27:396 (Table 124). The data show good fit ($P=0.91$) to a 1:15 model (Table 114). A division point of 0.39 was used. Since Red Danish and Chieftain Savoy were both inefficient in the 1975L planting (Table 124) the presence of efficient plants suggest transgressive segregation. Transgressive segregation could occur when 2 recessive loci recombine to produce a homozygous recessive phenotype. The recessive genotype $l_5l_5m_5m_5$ conditioned an efficient phenotype. Dominant inefficient plants were produced when either of the dominant L_2 or M_5 alleles were present in the plant phenotype. Red Danish contributed L_2 and m_2 alleles while Chieftain Savoy contributed l_5 and M_5 alleles.

F_1 green cabbage cross heritability estimates for efficiency index range from 0.18 to 0.96. The mean heritability estimate was 0.75 ± 0.62 . Two heritability estimates were negative, 2 were greater than 1 and 2 estimates were within the 0 to 1 heritability range. The $\bar{h}_x^2$ estimate was 0.86 ± 0.45 . Red x green cabbage F_1 heritability estimates for efficiency index ranged from 0.15 to 0.56. The mean heritability was 0.35 ± 0.34 with an $\bar{h}_x^2$ estimate of 0.58 ± 0.27 . Again 2 estimates were negative, 2 were greater than 1 and 2 were within the 0 to 1 heritability range (Table 30).

Non-Wrapper Leaf Size

Non-wrapper leaf size is the ratio between total non-wrapper leaf weight and non-wrapper leaf number. Small numbers suggest leaf size (weight) was small while larger numbers suggest larger leaf size.

Table 124. Parent, F₁ and F₂ efficiency index distributions in percent for the 1975L planting of the cross Red Danish x Chieftain Savoy.

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Efficiency Index X 100
Upper Limit of Class

	No. of Plants	19	29	39	49	59	69	79	89	99	109	350+	Mean
Red Danish (P_4)	32			3.1	9.4	12.5	18.8	21.9	3.1	6.3		24.9	89.5 + 49.8
Chieftain Savoy (P_5)	43		4.6	11.6	9.4	11.6	9.4	2.3	14.0	9.4	4.6	23.1	83.6 + 46.5
($P_4 \times P_5$)	28	3.6	3.6	3.6	10.7	10.7	7.1	17.8	14.3	3.6		21.4	84.0 + 55.2
($P_5 \times P_4$)	30		10.0	10.0	10.0	10.0	6.7	16.7	23.3			13.3	70.1 + 32.4
($P_4 \times P_5$) F_2	199	1.5	4.0	2.0	3.5	4.0	5.1	4.5	4.0	5.1	5.6	60.7	153.7 + 117.1
($P_5 \times P_4$) F_2	224	1.3	2.2	1.8	3.6	1.8	5.4	5.8	6.7	4.9	3.1	63.4	173.1 + 128.1

Analysis of inbreeding data for non-wrapper leaf size showed significant differences exist between cultivar and planting means. No difference due to inbreeding was noted (Table 125). However, this result may also occur when dominance is absent. Non-wrapper leaf size ranged from 0.02 kg for Baby Head to 0.11 kg for P.I. 215514. No difference was observed between Red Danish and Chieftain Savoy, however, these cultivars differed from each of the other cultivars (Table 106). Each planting was significantly different for non-wrapper leaf size (Table 126). The significance of the cultivar x plantings interaction was due to different cultivar responses to the 3 plantings. Baby Head showed no difference in non-wrapper leaf size for the 3 plantings, however, Badger Ballhead, Red Danish and Chieftain Savoy showed significant reductions in non-wrapper leaf size for the 3 plantings. P.I. 215514 showed a significant reduction in non-wrapper leaf size between the 1974L and 1975E plantings and then showed no change between the 1975E and 1975L plantings (Table 126). The second order interaction, cultivar x inbreeding x plantings was significant due to cultivar x plantings responses and also due to the effect of P.I. 215514 and its inbred grown in the 1974 planting. P.I. 215514 showed a significant increase in non-wrapper leaf size after 1 generation of inbreeding in the 1974L planting. Cultivars grown in the 1975E and 1975L plantings produced no difference in non-wrapper leaf size after an added generation of inbreeding (Table 127).

Baby Head x Badger Ballhead F_1 plantings in 1974L and 1975L suggest non-wrapper leaf size was inherited in an additive manner. The 1975E F_1 planting of this cross suggested incomplete dominance for small non-wrapper leaf size (Tables 11-13). Tables 128 and 129 show

Table 125. Analysis of variance table for non-wrapper leaf size in kilograms.

Source of Variance	DF	Mean Square	F*
Replication (R)	2	0.0003	1.48
Cultivar (C)	4	0.0193	89.94**
Inbreeding (I)	1	0.00001	0.03
C x I	4	0.0005	2.43*
Plantings (P)	2	0.0178	83.01**
C x P	8	0.0021	9.78**
I x P	2	0.0007	3.12*
C x I x P	8	0.0006	2.75**
Residual Error	58	0.0002	

F test significant at the 5%, or 1%** level.

Table 126. Cultivar x planting interaction means in kilograms for non-wrapper leaf size.

Cultivar	1974L	Plantings 1975E	1975L	Cultivar Means
Baby Head	0.02 a*	0.03 a	0.02 a	0.02 W
Badger Ballhead	0.09 c	0.07 b	0.04 a	0.07 X
P.I. 215514	0.13 b	0.10 a	0.11 a	0.11 Z
Red Danish	0.13 c	0.08 b	0.05 a	0.09 Y
Chieftain Savoy	0.12 c	0.08 b	0.04 a	0.08 Y
Planting Means	0.10 C	0.07 B	0.05 A	

*Mean separation, within rows, by Duncan's Multiple Range Test at the 5% level.

Table 127. Cultivar x inbreeding x planting interaction means in kilograms for non-wrapper leaf size.

Cultivar	Inbreeding	1974L	Plantings 1975E	1975L
Baby Head	P ₁	0.03 a*	0.03 a	0.02 a
	S ₁	0.02 a	0.03 a	0.01 a
Badger Ballhead	P ₁	0.10 a	0.08 a	0.04 a
	S ₁	0.08 a	0.07 a	0.03 a
P.I. 215514	P ₁	0.10 a	0.09 a	0.12 a
	S ₁	0.16 b	0.10 a	0.10 a
Red Danish	P ₁	0.12 a	0.08 a	0.05 a
	S ₁	0.14 a	0.08 a	0.05 a
Chieftain Savoy	P ₁	0.13 a	0.07 a	0.04 a
	S ₁	0.12 a	0.08 a	0.04 a

*Mean separation, within columns and cultivars, by Duncan's Multiple Range Test at the 5% level.

Table 128. Parent, F₁, F₂ and backcross non-wrapper leaf size distributions in percent for the 1975E planting of the cross Baby Head x Badger Ballhead.

Non-wrapper Leaf Size in Grams Upper Limit of Class													
No. of Plants	19	29	39	49	59	69	79	89	99	109	169	Mean	
Baby Head (P_1)	42	7.1	64.3	23.8	2.4	2.4							26.5 + 7.1
Badger Ballhead (P_2)	39			5.1	12.8	12.8	15.6	12.8	5.1	5.1	10.2	20.5	79.2 + 30.9
($P_1 \times P_2$)	83	2.4	4.8	21.7	32.5	20.6	10.8	3.6	1.2		2.4		46.9 + 15.6
($P_2 \times P_1$)	89		14.6	20.2	28.3	21.3	11.2	2.2	2.2				44.9 + 13.6
($P_1 \times P_2$) F_2	252	3.2	9.5	19.8	22.2	15.1	13.8	4.8	4.0	1.2	0.8	5.6	52.8 + 26.8
($P_2 \times P_1$) F_2	248	12.1	15.7	23.4	19.0	13.7	6.1	3.6	2.8	0.8	0.8	2.0	42.3 + 23.0
($P_2 \times P_1$) $\times P_2$	33			6.1	21.2	21.2	18.1	12.1	9.1	6.1	6.1		62.2 + 19.2

Table 129. Parent, F₁ and F₂ non-wrapper leaf size distributions in percent for the 1975L planting of the cross Baby Head x Badger Ballhead.

	No. of Plants	Non-wrapper Leaf Size in Grams Upper Limit of Class										Mean
		9	19	34	49	59	64	79	89	99	119	
Baby Head (P ₁)	53	5.7	47.2	28.3	13.1	1.9			1.9	1.9		24.3 ± 17.6
Badger Ballhead (P ₂)	49		6.1	22.4	49.0	14.3	4.2	2.0	2.0			41.4 ± 13.2
(P ₁ x P ₂)	38		21.0	55.2	10.5	2.7		7.9	2.7			31.4 ± 17.8
(P ₂ x P ₁)	77	1.3	9.0	49.5	32.4	5.2	1.3	1.3				32.7 ± 12.8
(P ₁ x P ₂) F ₂	130	4.6	23.8	48.5	16.2	4.6	1.5			0.8		26.8 ± 14.0
(P ₂ x P ₁) F ₂	211	1.9	22.3	58.3	12.3	2.9		0.9	0.9		0.5	26.6 ± 13.6

frequency distributions in percent for populations involved in this study. Powers *et al.* (23) partitioning tests were applied to these distributions to determine the number of genes controlling non-wrapper leaf size and to define the boundary between the small and large non-wrapper leaf weight phenotypes. Powers *et al.* formula (F_2/P_2) was applied sequentially from the recessive ends of both the F_2 and P_2 distributions. Using the 1975E F_2 planting of Baby Head x Badger Ballhead (Table 128) as an example recessive frequencies of 5.6/20.5 or 0.27 for the 169 gm class, 6.4/30.7 or 0.21 for the 109 gm class, 7.6/35.8 or 0.21 for the 99 gm class, 11.6/40.9 or 0.28 for the 89 gm class, 16.4/53.7 or 0.30 for the 79 gm class and 30.2/69.3 or 0.44 for the 69 gm class were produced. The large difference in frequency between the 79 gm class and 69 gm class suggests a dividing point of 69 gm. The mean frequency of 0.25 agrees closely with a 0.25 frequency expected from a 3:1 model. A monogenic model with a dividing point between the 69 gm and 79 gm classes was postulated. The reciprocal F_2 population of this cross produced similar results. Powers *et al.* (23) formula (F_2/P_2) was again applied to produce the following recessive frequencies, 2.0/20.5 or 0.10 for the 169 gm class, 2.8/30.7 or 0.09 for the 109 gm class, 3.6/35.8 or 0.10 for the 99 gm class, 6.4/49.9 or 0.16 for the 89 gm class, 10.00/53.7 or 0.19 for the 79 gm class and 16.1/69.3 or 0.23 for the 69 gm class. The increase in frequency noted between the 69 gm and 79 gm classes suggest a dividing point of 69 gm. The mean frequency of 0.128 when doubled (23) shows close agreement to the 0.25 frequency expected from a 3:1 model. The 1975E reciprocal F_2 data of this cross were screened using 69 gm as a separation. Since the results of Powers *et al.* (23) tests suggest some F_2 populations

used a digenic system to control non-wrapper leaf size a 2 gene system was postulated. These loci were designated n and o . Each of the 5 cultivars had a different set of alleles at these loci to explain the observed differences between cultivars. The 1975E gene system suggests that n_5 and n_4 were dominant to n and n was dominant to n_3 for green cabbage crosses. The o locus was inherited in a similar fashion. 1975L data suggests that n was dominant to n_3 , n_4 and n_5 while o_5 was dominant to o and o was dominant to o_3 and o_4 . The early planting of red x green cabbage crosses suggest that n_2 was dominant to n_3 , n_4 and n_5 while o_2 was recessive to o_3 , o_4 and o_5 . The late planting suggests that n_3 was dominant to n_2 and n_2 was dominant to n_5 . Inheritance patterns at the other locus suggest that o_5 and o_3 were dominant to o_2 . Dominance for large non-wrapper leaf size was noted for all populations grown in the early planting while dominance for small non-wrapper leaf size was noted in the late planting. Parental distributions of Baby Head and Badger Ballhead overlap in the 1975E planting. A weighting factor was applied to the expected F_2 ratio to account for the misclassification of phenotypes. The 1975E F_2 planting of Baby Head x Badger Ballhead will again be used as an example (Table 128). Using a division point of 69 gm the data suggest Badger Ballhead produces only 53.7% of its plants with a large non-wrapper leaf size phenotype. Because of this overlap of 46.3% the small non-wrapper leaf size F_2 class will be larger than normally expected and the large leaf size class will be smaller than expected. In this study the net overlap, 46.3, was subtracted from 100, then divided by 100 and multiplied by both the expected probability of the deficient class and the total number of F_2 plants sampled to obtain the expected segregation

ratio. In this case the expected number of recessive large leaf size phenotypes was $((100-46.3)/100)(252)(0.25) = 33.83$. The number of dominant small leaf size phenotypes was found by subtraction $(252-33.83) = 218.17$. The observed F_2 segregation ratio of 211:42 for the 1975E planting of Baby Head x Badger Ballhead fits ($P=0.19$) a 3:1 weighted theoretical ratio of 218.17:33.83 (Table 130). The reciprocal F_2 population produced a ratio of 223:25 which fit ($P=0.13$) a 3:1 weighted expected ratio of 215:33 (Table 130). The presence of a single dominant allele, N , from Baby Head produced small non-wrapper leaf size. The cultivar Badger Ballhead provided the recessive genotype $n_3n_3o_3o_3$ for large non-wrapper leaf size. The backcross ratio of 16:17 for RF_1 x Badger Ballhead fit ($P=0.88$) an expected 1:1 model. Both the F_2 and backcross data support weighted 3:1 F_2 ratios for non-wrapper leaf size inheritance. A chi-square homogeneity test suggested pooling the 1975L F_2 data (Table 129). A dividing point of 34 gm was used to divide the F_2 data into phenotypic classes. The pooled F_2 data produced a ratio of 274:67 which fit ($P=0.20$) a 3:1 weighted expected ratio (Table 131). Small non-wrapper leaf size was controlled by a single dominant gene, N , contributed by Baby Head. The recessive genotype $n_3n_3o_3o_3$ produced a large size non-wrapper leaf.

Both the 1974L and 1975E plantings of Baby Head x P.I. 215514 suggest dominance for large non-wrapper leaf size. However, the 1975L planting of the same cross suggests incomplete dominance for small non-wrapper leaf size (Tables 11-13). The F_1 data suggests that environmental conditions can greatly affect non-wrapper leaf size phenotypes. F_2 populations of Baby Head x P.I. 215514 grown in the 1975L planting were pooled. Using a dividing point of 39 gm to separate the small and

Table 130. Chi-square test for goodness of fit to the postulated model for non-wrapper leaf size in the F_2 generation (1975E planting).

Cross	Observed	Expected	Model	χ^2	P
Baby Head x Badger Ballhead					
F_2	211: 42	218.17: 33.83*	3: 1	1.7548	0.19
RF_2	223: 25	214.71: 33.29*	3: 1	2.3897	0.13
Baby Head x P.I. 215514					
F_2	59:200	61.67:197.33*	1: 3	0.1513	0.70
RF_2	33:418	26.84:424.15*	1:15	1.5004	0.22
Baby Head x Chieftain Savoy					
F_2	68:124	68.57:123.43*	1: 3	0.0074	0.93
RF_2	119: 78	123.12: 73.88*	9: 7	0.3685	0.54
Red Danish x Badger Ballhead					
F_2	15:194	13.06:195.94	1:15	0.3066	0.58
RF_2	6:148	9.62:144.36	1:15	1.4562	0.23
Pooled	21:342	22.69:340.31	1:15	0.1339	0.71
Red Danish x P.I. 215514					
F_2	19:292	19.44:291.56	1:15	0.0107	0.92
Red Danish x Chieftain Savoy					
F_2	9: 98	6.69:100.31	1:15	0.8529	0.36
RF_2	9: 93	6.38: 95.62	1:15	1.1529	0.28
Pooled	18:191	13.06:195.94	1:15	1.3476	0.24

* = Weighted

Table 131. Chi-square test for goodness of fit to the postulated model for non-wrapper leaf size in the F_2 generation (1975L planting).

Cross	Observed	Expected	Model	χ^2	P
Baby Head x Badger Ballhead					
F_2	100: 30	100.65: 29.35*	3: 1	0.0188	0.89
RF_2	174: 37	163.37: 47.63*	3: 1	3.0647	0.08
Pooled	274: 67	264.02: 76.98*	3: 1	1.6737	0.20
Baby Head x P.I. 215514					
F_2	154: 14	157.91: 10.09*	15: 1	1.6135	0.20
RF_2	233: 11	229.35: 14.65*	15: 1	0.9686	0.32
Pooled	387: 25	387.26: 24.74*	15: 1	0.0029	0.96
Baby Head x Chieftain Savoy					
F_2	204: 11	201.56: 13.44	15: 1	0.4717	0.49
RF_2	171: 7	166.88: 11.12	15: 1	1.6315	0.20
Pooled	375: 18	368.44: 24.56	15: 1	1.8702	0.17
Red Danish x Badger Ballhead					
F_2	244: 47	248.69: 42.31*	15: 1	0.6073	0.44
RF_2	27: 3	25.64: 4.36*	15: 1	0.4978	0.48
Pooled	271: 50	274.32: 46.68*	15: 1	0.2770	0.60
Red Danish x Chieftain Savoy					
F_2	159: 40	161.69: 37.31	13: 3	0.2383	0.62
RF_2	177: 47	182.00: 42.00	13: 3	0.7326	0.39
Pooled	336: 87	343.69: 79.31	13: 3	0.9171	0.34

* = Weighted

large leaf size classes the 1975E F_2 planting showed increased non-wrapper leaf size to be dominant with a segregation ratio of 59:200 (Table 132). This ratio showed good fit ($P=0.70$) to a 1:3 weighted expected ratio of 61.67:197.33 (Table 130). Increased non-wrapper leaf size was controlled by a single dominant gene, n_4 , contributed by P.I. 215514. The recessive genotype, $nnoo$ contributed by Baby Head, produced small size non-wrapper leaves. The reciprocal F_2 population, using a 39 gm dividing point, produced a ratio of 33 plants with small leaf size to 418 plants with large non-wrapper leaf size. This ratio fit ($P=0.22$) a 1:15 weighted theoretical ratio of 27:424 (Table 130). Large non-wrapper leaf size was controlled by 2 dominant genes n_4 and o_4 . The presence of either or both of these genes in the genotype conditioned large leaf size. The genotype, $nnoo$, of Baby Head produced small leaf size. Opposite segregation patterns were observed in the 1975L planting of this cross (Table 133). A dividing point of 59 gm was used to separate the F_2 data into phenotypic classes. Pooled F_2 data from the 1975L planting showed a good fit ($P=0.96$) to a 15:1 weighted expected ratio of 387:25 (Table 131). The genotype of P.I. 215514, $n_4n_4o_4o_4$, was recessive for large non-wrapper leaf size. Small non-wrapper leaf size was produced when either or both of 2 dominant alleles, n or o , were present in the plant genotype. Baby Head contributed dominant genes for small leaf size in this planting (Tables 132-133).

The 1975L planting of Baby Head x Chieftain Savoy F_1 suggests non-wrapper leaf size was inherited in an additive manner. However, the 1974L and 1975E F_1 plantings suggest incomplete to complete dominance for large non-wrapper leaf size (Tables 11-13). Baby Head x

Table 132. Parent, F₁ and F₂ non-wrapper leaf size distributions in percent for the 1975E planting of the cross Baby Head x P.I. 215514.

Non-wrapper Leaf Size in Grams Upper Limit of Class													
	No. of Plants	19	29	39	54	59	69	79	89	99	139	179	Mean
Baby Head (P_1)	42	7.1	64.3	23.8	4.8								26.5 + 7.1
P.I. 215514 (P_3)	18					5.6	16.7		38.9	11.0	22.2	5.6	94.2 + 26.8
($P_1 \times P_3$)	86	1.2	3.5	2.3	8.1	5.8	31.3	12.8	12.8	12.8	7.0	2.4	72.3 + 23.6
($P_3 \times P_1$)	70		1.4	1.4	8.6	4.3	11.4	20.3	17.1	10.0	21.3	4.2	84.1 + 27.2
($P_1 \times P_3$) F_2	259	4.3	6.6	12.0	26.5	8.9	17.0	9.3	5.4	2.7	6.9	0.4	56.7 + 24.4
($P_3 \times P_1$) F_2	451	0.4	1.6	5.3	20.0	7.1	14.3	16.2	11.3	10.9	10.7	2.2	72.4 + 28.2

Table 133. Parent, F₁ and F₂ non-wraper leaf size distributions in percent for the 1975L planting of the cross Baby Head x P.I. 215514.

	No. of Plants	Non-wraper Leaf Size in Grams Upper Limit of Class											Mean
		9	19	34	49	59	64	79	89	99	119	159+	
Baby Head (P ₁)	53	5.7	47.2	28.3	13.1	1.9			1.9	1.9			24.3 ± 17.6
P.I. 215514 (P ₃)	13				7.7		15.4	7.7	15.4	15.4		38.4	104.4 ± 42.2
(P ₁ × P ₃)	73		4.1	32.9	50.8	6.8	2.7	2.7					37.6 ± 11.7
(P ₃ × P ₁)	81	1.3		18.5	46.9	19.8	4.7	6.2	1.3		1.3		45.0 ± 14.9
(P ₁ × P ₃) F ₂	168		13.1	45.8	23.8	8.9	2.8	3.9	1.2		1.2	0.6	35.0 ± 22.9
(P ₃ × P ₁) F ₂	244	0.8	7.4	46.3	32.4	8.6	3.3		0.4	0.4		0.4	38.3 ± 61.6

Chieftain Savoy F_2 populations grown in the early planting were not pooled because of differences in segregation patterns (Table 134). Both the F_2 and reciprocal F_2 data were phenotypically divided into classes using a 54 gm dividing point. The 1975E F_2 population produced a segregation ratio of 68:124. This ratio fit ($P=0.93$) a 1:3 weighted expected ratio of 68.57:123.43 (Table 130). Large non-wrapper leaf weight was controlled by the presence of 1 dominant gene, w_5 , donated by Chieftain Savoy. The absence of this gene in the genotype conditioned small non-wrapper leaf size. The 1975E reciprocal F_2 population showed small leaf size to be dominant with an observed segregation ratio of 119:78. This ratio fit ($P=0.54$) a 9:7 weighted theoretical ratio of 123:74 (Table 130). Small size non-wrapper leaves were produced when both the dominant w and o genes were present in the genotype. Large size non-wrapper leaves were produced by genotypes that were homozygous recessive at either loci. Backcrossing the F_1 x Chieftain Savoy gave a ratio of 5:27. A ratio of 0:32 was expected. The reciprocal F_1 was crossed to both Chieftain Savoy and Baby Head. These crosses produced observed ratios of 3:12 and 32:23 respectively. These ratios were compared ($P=0.68$) to 1:3 and 1:0 models. If the reciprocal F_2 had produced segregation ratios similar to those observed for the F_2 , then backcross data would support a 1:3 model, however, it appears that reciprocal differences exist between F_2 and RF_2 populations (Table 134). 1975L F_2 plantings of Baby Head x Chieftain Savoy were pooled as suggested by a chi-square homogeneity test. A dividing point of 59 gm was used to divide the F_2 data into phenotypic classes. The data suggest small leaf size was dominant (Table 135). An observed ratio of 375:18 fit ($P=0.17$) an expected ratio of 368:25 from a 15:1

Table 134. Parent, F₁, F₂ and backcross non-wrapper leaf size distributions in percent for the 1975E planting of the cross Baby Head x Chieftain Savoy.

Non-wrapper Leaf Size in Grams Upper Limit of Class													
No. of Plants	19	29	39	54	59	69	79	89	99	139	179	Mean	
Baby Head (P_1)	42	7.1	64.3	23.8	4.8								26.5 + 7.1
Chieftain Savoy (P_5)	34	5.9	2.9		20.6	8.8	2.9	20.7	11.8	17.6	5.9	2.9	70.1 + 27.7
($P_1 \times P_5$)	52		3.8	7.7	32.7	1.9	25.1	5.8	3.8	3.8	11.6	3.8	67.7 + 38.7
($P_5 \times P_1$)	83		1.2	1.2	20.5	12.0	15.7	12.0	9.6	13.2	13.2	1.2	73.2 + 25.9
($P_1 \times P_5$) F_2	192	1.0	3.6	9.9	25.8	9.1	14.1	14.6	12.1	4.7	3.1	2.0	63.4 + 28.6
($P_5 \times P_1$) F_2	197	2.5	12.2	17.8	27.9	9.7	10.6	11.2	4.1	2.0	2.0		50.3 + 21.0
($P_1 \times P_5$) $\times P_5$	32	3.1			12.5	9.4	15.8	6.2	12.5	12.5	24.9	3.1	85.1 + 32.7
($P_5 \times P_1$) $\times P_5$	15		6.7	13.3		6.7	13.3	13.2	20.0	6.7	13.4	6.7	74.3 + 31.4
($P_5 \times P_1$) $\times P_1$	55	14.5	12.7	14.5	16.4	5.4	5.4	9.5	5.4	3.6	9.0	3.6	55.7 + 38.1

Table 135. Parent, F_1 and F_2 non-wrapper leaf size distributions in percent for the 1975L planting of the cross Baby Head x Chieftain Savoy.

	No. of Plants	Non-wrapper Leaf Size in Grams Upper Limit of Class											Mean
		9	19	34	49	59	64	79	89	99	119	159+	
Baby Head (P_1)	53	5.7	47.2	28.3	13.1	1.9			1.9	1.9			24.3 + 17.6
Chieftain Savoy (P_5)	43		4.6	18.6	51.2	18.7	2.3	2.3				2.3	43.6 + 17.2
($P_1 \times P_5$)	20			40.0	55.0			5.0					37.4 + 10.5
($P_5 \times P_1$)	59	1.7	10.2	30.5	50.8	6.8							33.8 + 10.9
($P_1 \times P_5$) F_2	215	1.9	14.9	37.2	33.5	7.4	2.3	2.3			0.5		33.5 + 15.4
($P_5 \times P_1$) F_2	178	2.2	33.1	34.8	18.5	7.4	1.1	0.6	0.6		0.6	1.1	32.3 + 44.2

model (Table 131). Small non-wrapper leaf size was produced when n_1 or both of 2 dominant genes, n or o_5 , were present in the plant genotype. The genotype $n_5 n_5 o_5 o_5$ produced large non-wrapper leaf size. This system suggests that each cultivar contributed 1 dominant allele to the F_1 plant. Each cultivar produced small non-wrapper leaves.

Both the 1974L and 1975L plantings of Red Danish x Badger Ballhead F_1 suggest non-wrapper leaf size was additively inherited. The 1975E F_1 planting of this cross showed overdominance for large leaf size (Tables 11-13). F_2 populations of Red Danish x Badger Ballhead were pooled within each planting. Data from the 1975E planting was separated into phenotypic classes using a 44 gm division point. The data showed small leaf size to be recessive (Table 136) while data from the 1975L planting, using a 59 gm dividing point showed large leaf size to be recessive (Table 137). A pooled ratio of 21:342 was observed for the early planting while a pooled ratio of 271:50 was observed for the late planting. The 1975E data showed good fit ($P=0.71$) to a 1:15 model (Table 130) while the 1975L data fit ($P=0.60$) a 15:1 weighted expected ratio (Table 131). Both backcross populations showed perfect agreement to their expected ratios. The backcross data support a 1:15 1975E F_2 model with both cultivars contributing 1 dominant allele to the F_1 genotype. Since both cultivars produced large leaf size, the 1975E data suggest that recessive small leaf size was conditioned by the $n_3 n_3 o_2 o_2$ genotype. The presence of either n_2 or o_3 in the genotype conditioned the production of large non-wrapper leaf size. 1975L data suggest that the Red Danish genotype $n_2 n_2 o_2 o_2$ conditioned the recessive trait for large leaf size. The presence of either n_3 or o_3 in the genotype produced small leaf size.

Table 136. Parent, F₁, F₂ and backcross non-wrapper leaf size distributions in percent for the 1975E planting of the cross Red Danish x Badger Ballhead.

	No. of Plants	Non-wrapper Leaf Size in Grams Upper Limit of Class											Mean
		44	59	69	79	89	99	109	119	129	149	219	
Red Danish (P ₄)	35	14.3	2.8	11.5	14.3	8.6	14.3	5.7	11.5	8.6	5.6	2.8	88.0 + 34.6
Badger Ballhead (P ₂)	39	10.2	20.5	15.6	12.8	5.1	5.1	10.2	5.1	7.7	7.7		79.2 + 30.9
(P ₄ x P ₂)	96	1.0	5.2	6.2	11.4	14.6	9.7	16.7	11.4	12.5	8.3	3.0	99.2 + 26.0
(P ₂ x P ₄)	90	6.7	4.4	8.9	8.9	18.9	11.0	10.0	8.9	5.6	15.6	1.1	94.4 + 29.6
(P ₄ x P ₂) F ₂	209	7.3	21.5	15.3	16.3	12.0	8.4	6.7	3.8	5.3	2.4	1.0	76.4 + 26.8
(P ₂ x P ₄) F ₂	154	3.9	20.7	18.2	20.8	11.2	5.8	7.8	2.6	4.5	3.2	1.3	77.2 + 26.4
(P ₄ x P ₂) x P ₂	12		8.3		8.3	25.0	25.0	16.8			8.3	8.3	98.4 + 28.9
(P ₂ x P ₄) x P ₄	47			4.2	2.1	8.5	19.4	12.8	23.4	8.5	14.8	6.3	110.6 + 22.8

Table 137. Parent, F₁ and F₂ non-wrapper leaf size distributions in percent for the 1975L planting of the cross Red Danish x Badger Ballhead.

Non-wrapper Leaf Size in Grams Upper Limit of Class													
	No. of Plants	9	19	34	49	59	64	79	89	99	119	159+	Mean
Red Danish (P_4)	32			25.0	15.6	9.4	9.4	18.8	12.5	3.1	6.2		56.9 + 25.7
Badger Ballhead (P_2)	49		6.1	22.4	49.0	14.3	4.2	2.0	2.0				41.4 + 13.2
($P_4 \times P_2$)	23			34.8	26.1	30.5	4.3	4.3					42.3 + 12.5
($P_2 \times P_4$)	19			31.6	47.4	21.0							39.6 + 8.7
($P_4 \times P_2$) F_2	291		2.4	23.0	42.6	15.8	3.8	8.9	1.8	1.0	0.7		44.8 + 16.2
($P_2 \times P_4$) F_2	30	3.3	6.7	36.7	26.7	16.6		6.7				3.3	40.0 + 23.5

Both the 1974L and 1975E F_1 populations of Red Danish x P.I. 215514 suggest overdominance for large non-wrapper leaf size. However, the 1975L F_1 planting suggests non-wrapper leaf size was inherited in an additive manner (Tables 11-13). Environmental conditions can affect non-wrapper leaf size. Both Red Danish and P.I. 215514 produced large leaf size phenotypes in the 1975E planting (Table 138). The 1975E F_2 population of this cross produced a 19:292 segregation ratio using a dividing point of 59 gm. The observed data fit ($P=0.92$) a 1:15 model (Table 130). A genotype of $n_4n_4o_2o_2$ was suggested for small non-wrapper leaf size. The presence of either n_2 , from Red Danish, or o_4 , from P.I. 215514, in the plant genotype produced large non-wrapper leaves.

All 3 plantings, 1974L, 1975E and 1975L, of Red Danish x Chieftain Savoy F_1 suggest overdominance for large non-wrapper leaf size (Tables 11-13). Chi-square homogeneity tests suggest F_2 populations of Red Danish x Chieftain Savoy could be pooled. 1975E F_2 data suggest small non-wrapper leaf size was recessive (Table 140). Using a 59 gm dividing point to separate phenotypic classes an observed ratio of 18:191 was produced. The data fit ($P=0.24$) a 1:15 model (Table 130). Backcrossing the F_1 to Red Danish produced a ratio of 0:18 while crossing the reciprocal F_1 to Red Danish produced a 4:33 ratio. Ratios of 0:18 and 0:37 were expected. Since both parental distributions produced large non-wrapper leaf size the 1:15 model suggests that the recombinant genotype $n_5n_5o_2o_2$ conditioned small non-wrapper leaf size. The presence of either n_2 or o_5 alleles in the plant genotype conditioned the production of large non-wrapper leaves. Using a 64 gm dividing point to separate the data into phenotypic classes the pooled

Table 138. Parent, F₁ and F₂ non-wrapper leaf size distributions in percent for the 1975E planting of the cross Red Danish x P.I. 215514.

	No. of Plants	Non-wrapper Leaf Size in Grams Upper Limit of Class											Mean
		44	59	69	79	89	99	109	119	129	149	219	
Red Danish (P ₄)	35	14.3	2.8	11.5	14.3	8.6	14.3	5.7	11.5	8.6	5.6	2.8	88.0 + 34.6
P.I. 215514 (P ₃)	18		5.6	16.7		38.9	11.0		5.6	5.6	16.6		94.2 + 26.8
(P ₄ x P ₃)	85	2.3	1.2	1.2	5.9	2.4	10.7	15.1	11.8	16.5	18.8	14.1	118.4 + 29.9
(P ₃ x P ₄)	89	1.1	1.1	3.4	5.6	2.2	11.3	12.4	18.0	19.1	23.6	2.2	112.7 + 23.9
(P ₄ x P ₃) F ₂	311	2.6	3.5	7.1	11.9	11.6	12.9	12.2	12.9	9.6	13.8	1.9	99.5 + 28.4

Table 139. Parent and F₁ non-wrapper leaf size distributions in percent for the 1975L planting of the cross Red Danish x P.I. 215514.

	No. of Plants	Non-wrapper Leaf Size in Grams Upper Limit of Class										Mean
		19	34	49	59	64	79	89	99	119	159+	
Red Danish (P ₄)	32		25.0	15.6	9.4	9.4	18.8	12.5	3.1	6.2		56.9 ± 25.7
P.I. 215514 (P ₃)	13			7.7		15.4	7.7	15.4	15.4		38.4	104.4 ± 42.2
(P ₄ × P ₃)	44		15.9	31.8	18.2	6.8	15.9	2.3	4.5	2.3	2.3	55.2 ± 22.9
(P ₃ × P ₄)	14	7.1	14.3	21.4	28.7		14.3	7.1		7.1		54.2 ± 24.3

Table 140. Parent, F₁, F₂ and backcross non-wrapper leaf size distributions in percent for the 1975E planting of the cross Red Danish x Chieftain Savoy.

	No. of Plants	Non-wrapper Leaf Size in Grams Upper Limit of Class												Mean
		44	59	69	79	89	99	109	119	129	149	219		
Red Danish (P ₄)	35	14.3	2.8	11.5	14.3	8.6	14.3	5.7	11.5	8.6	5.6	2.8	88.0 ± 34.6	
Chieftain Savoy (P ₅)	34	14.7	23.5	2.9	20.7	11.8	17.6	5.9					70.1 ± 27.7	
(P ₄ x P ₅)	33		3.0	6.1	3.0	6.1	12.1	6.1	6.1	12.1	33.3	12.1	120.2 ± 32.8	
(P ₅ x P ₄)	80	2.5	2.5	3.8	7.5	3.8	12.5	8.8	18.8	16.2	15.0	8.6	110.5 ± 29.2	
(P ₄ x P ₅) F ₂	107	2.8	5.6	6.5	8.4	15.1	12.1	11.2	13.1	14.0	8.4	2.8	99.2 ± 28.6	
(P ₅ x P ₄) F ₂	102	3.9	4.9	4.9	8.8	9.8	13.8	8.8	10.8	11.8	14.7	7.8	106.5 ± 37.2	
(P ₄ x P ₅) x P ₄	18					11.1	5.6	27.6	11.1		22.3	22.3	127.8 ± 35.3	
(P ₅ x P ₄) x P ₄	37	5.4	5.4	8.1	16.2	16.2	13.6	10.8	5.4	10.8	5.4	2.7	91.4 ± 27.8	

F_2 data from the 1975L planting produced a segregation ratio of 336:87 (Table 141). This data fit ($P=0.34$) a 13:3 model (Table 131). The presence of dominant o_5 alleles or the action of homozygous recessive alleles, n_5n_5 , conditioned the production of small non-wrapper leaves. The Red Danish genotype $n_2N_2o_2O_2$ conditioned the production of large non-wrapper leaves.

Non-wrapper leaf size heritability estimates for green cabbage F_1 populations range from 0.52 to 0.84 with an $\bar{h}^2$ value of 0.68 ± 0.53 and an $\bar{h}_x^2$ value of 0.79 ± 0.43 . Three h^2 estimates were greater than 1 and 1 estimate was negative. Two estimates were within the 0 to 1 heritability range. Red x green cabbage F_1 heritability estimates range from 0.40 to 0.70 with a mean heritability estimate of 0.53 ± 0.33 and an $\bar{h}_x^2$ estimate of 0.61 ± 0.30 . Three estimates were within the 0 to 1 heritability range and 3 estimates were greater than 1. Red x green cabbage heritability estimates suggest that greater than 50% of the F_1 population variance was due to additive genetic effects that may be fixed in cabbage by inbreeding (Table 18).

Table 141. Parent, F₁ and F₂ non-wrapper leaf size distributions in percent for the 1975L planting of the cross Red Danish x Chieftain Savoy.

	No. of Plants	Non-wrapper Leaf Size in Grams Upper Limit of Class										Mean
		19	34	49	59	64	79	89	99	119	159+	
Red Danish (P ₄)	32		25.0	15.6	9.4	9.4	18.8	12.5	3.1	6.2		56.9 ± 25.7
Chieftain Savoy (P ₅)	43	4.6	18.6	51.2	18.7	2.3	2.3				2.3	43.6 ± 17.2
(P ₄ × P ₅)	28			10.7	7.1	3.6	7.1	10.8	7.1	39.3	14.3	96.4 ± 34.8
(P ₅ × P ₄)	30			6.7	3.3	6.7	10.0	13.4	6.7	26.7	26.5	101.0 ± 35.7
(P ₄ × P ₅) F ₂	199	1.0	23.6	29.6	19.6	6.1	13.6	3.0	1.5	1.5	0.5	49.7 ± 25.5
(P ₅ × P ₄) F ₂	224	2.2	17.4	31.7	16.7	11.2	15.2	3.6	0.4	0.8	0.8	51.0 ± 19.1

CONCLUSIONS

This study has shown that components of cabbage plant efficiency are heritable traits. Seven traits in cabbage: maturity, head weight, total non-wrapper leaf weight, stalk size, non-wrapper leaf number, efficiency index and non-wrapper leaf size, are each controlled by 2 loci. This type of inheritance is not unique in cabbage. The length of the longitudinal and transverse diameters of cabbage heads was found by Krauze (12) to be controlled by 2 dominant genes. Studies by Dickson (6) found cabbage core length to be controlled by 2 genes each incompletely dominant. The dominance direction was affected by the half sib related F_1 and F_2 populations using either Baby Head or Red Danish as parents. The presence of gross changes in dominance direction in cabbage may be triggered by environmental sensors that modify genotypic dominance to produce an optimum phenotype. Reversals in dominance patterns have been noted by Shifriss (28) in acorn squash. Modifications in dominance have also been shown by Russell and Srb (26) in *Neurospora*. They observed that while the bulk of their modifiers "increased" the dominance of the wild type allele, 2 modifiers "decreased" the dominance of the wild type allele. Both Russell (26) and Shifriss (24) showed modification to be dosage dependent, stronger in the heterozygous condition than in the homozygous condition. Further studies by Srb and Basil (30) show that the genotypic background of *Neurospora* can trigger a completely dominant or completely recessive phenotype when dominant Pk-4 mutants are introduced into 3 species of this organism. Dominance patterns suggest that more efficient cabbage

cultivars could be produced without sacrificing head quality or yield. Heritability estimates were greatly influenced by the environment. The wide range of estimates suggests that selection of traits with high heritability estimates, days to maturity, head weight, and leaf number, for green cabbage crosses and stalk size for red x green cabbage crosses, may increase the rate of progress especially if they are favorably correlated with low heritability traits. Heritability estimates for all traits ranged from 0.96 to 0.05. Heritability estimates were larger in green cabbage crosses than in red x green cabbage crosses. The presence of very large and very small heritability estimates between plantings provide an area for further study. Genetic correlation data suggest that components of plant efficiency are correlated and selection for a given trait may simultaneously affect other traits in cabbage. Data from this study produced genetic correlations greater than 1 and less than negative 1. These aberrant estimates may be due to sampling error or a violation of assumptions necessary for genetic correlation estimates. Estimates of this type have also been found by Sharma (27) in cabbage and Burton (2) in pearl millet.

A generation of added inbreeding produced significant changes in the following traits: head weight, total non-wrapper leaf weight, non-wrapper leaf number and efficiency index. Additional inbreeding should be applied to open-pollinated cabbage cultivars prior to undertaking genetic studies of these traits. For this sample of cultivars, maturity stalk size and non-wrapper leaf size appeared to be genetically homozygous. Genetic studies of these traits could be undertaken without added inbreeding.

More study is needed to determine whether the change in dominance pattern observed between green cabbage crosses and red x green cabbage crosses is a result of the cultivars chosen or whether all red cabbage cultivars could be expected to provide the same response. If this response is conditioned by all red cabbage, it may be possible to use red x green cabbage crosses to provide more desirable phenotypes in greater abundance than could be done breeding red and green cabbage separately.

Efficient green cabbage cultivars can be developed by crossing large headed, large leaf cultivars to small headed, small leaf cultivars. The resulting hybrid should have the large head of one parent and the smaller leaves of the other parent. Selection for efficient plants could be practiced in the F_2 generation of this cross. Large amounts of additive genetic control should increase the number of plants selected in future generations. The development of more efficient compact plants should stimulate the development of new cultural practices including closer spacing. Information from this study may be of value not only as an aid in cabbage breeding, but also as a stimulus for future research in other *Brassica* species.

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