A VISUAL MEASUREMENT OF THE RELATIONSHIP OF KERNEL SIZE AND GERM SIZE IN THE CORN GRAIN

By

BASIL TSOTSIS

Bachelor of Science

University of Thessaloniki, Thessaloniki, Greece

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Thesis Approved:

James S Brooks
Thesis Adviser

Jack R. Harlan

H. F. Murphy
Head of the Agronomy Department

Robert MacVicar
Dean of the Graduate School

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INTRODUCTION

To improve the nutritive value of corn, plant breeders have selected for high protein and oil content in the corn grain as these two constituents of the corn grain are of an importance which needs no emphasis.

It is known that the greater part of the protein and oil in the corn grain are carried in the germ. A large germ is associated with high protein and oil content and the germ thus becomes an important criterion for determining the value of the corn grain as far as its oil and protein contents are concerned.

The present investigation was undertaken with the objective to study the relationship between the size of the germ and the size of the kernel, and attempt to indicate a method for visual evaluation of the protein and oil content of the corn grain. The purposes of this investigation were to:

1. Study the relationship between the germ size and the size of the kernel and determine if the area of the germ as it appears on the kernel is a good indication of the germ size in a population.
2. Study the relationship between the depth of the kernel and the depth of the germ and to see if an increase in depth (Thickness) of the kernel is followed by a corresponding increase in depth by the germ.

REVIEW OF LITERATURE

The early paper of Hopkins (19)[1/] may be considered as the starting point for the improvement of the oil and protein content of the corn. Hopkins based on the achievements of selection on the improvement of the sugar beets, thought that selection would also be effective in corn. By chemical analyses he found out that the composition of the kernels was the same throughout the ear and that the variation from ear to ear was great. By analyzing a few rows of kernels of an ear he could thus decide on the protein and oil content of the whole ear and use the remaining seed based on that knowledge. The process was followed year after year. Through selection four lines were established and were indicated as High protein, Low protein, High oil and Low oil respectively.

Hopkins based on the anatomical structure of maize and the distribution of the protein on it, tried to determine the protein content by using pure mechanical examination in cross and longitudinal sections of the corn kernel. The results of this examination he checked by chemical analysis and he found them satisfactory. He also found that the fat content of corn varies quite uniformly with the proportion of the germ in the kernel and that this variation could be also observed with the naked eye.

The problem of breeding corn for higher protein and oil content and more generally the relationships between these two chemicals and the mode of their expression the corn grain, was approached from three

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1/ Numbers in parenthesis refer to "Literature Cited", page 37.

different points through the application of Genetical, Chemical and Physiological knowledge and methods.

The Genetic Approach

After East (8) presented evidence on the Mendelian inheritance of maize, East and Jones (9) presented a detailed genetic study on the protein content in maize. These workers considered the results of the work made by Hopkins (19) and although they recognized the effects of the selection for protein and oil content, they criticized the use of the ear as the basis of selection. They expressed the idea that the ear is a population and instead of it, the single kernel had to be considered as the basic unit of selection. The authors also indicated the complexity of the genetic problem of protein inheritance, caused by the fact that in corn there is a 2n maternal pericarp, a 2x embryo (Zygote) and a 3x Zygotic endosperm and protein is found in all three of these kernel parts. The difference in protein content between open- and self-pollinated ears was studied. A constant difference in favor of the selfed ears appeared and Hayes and Garber (17) noted that there is a high degree of inverse correlation between the number of seeds and protein content of the kernels. Self-pollinated ears contain a smaller number of seeds.

East and Jones (9) did not find any difference in protein content on different ears borne on the same plant. They considered protein content as being strongly affected by the environment and also by factors affecting the development of the plant as a whole or the seed in particular. Although they did not present any specific gene number, they stated that many hereditary factors affect protein and that the chemical composition of the seed is influenced by heterosis. The male gametes were found to be practically without immediate influence on the seed they help to form.

Similar studies conducted by Hayes (15, 16) confirmed the results of East and Jones (9) and noted that protein content was influenced by cultural practices. Low protein content was reported to be dominant over high protein and the mode of inheritance was thought to be quantitative.

Frey (12) presented the results of his work on the inheritance of protein and some of its components in maize. Frey used individual ear samples of Illinois High and Low protein corns and the F_1, F_2, B_1 and B_2 from a cross between these two types and analyzed them for protein, zein, tryptophane, valine, leucine, and isoleucine. The same analyses were made on material from the cross H_y x I_{198}. He (12) reported that low protein percentage and low zein percentage were completely dominant in both cases and suggested that low protein percentage and hybrid vigor may be confounded. Frey (12) also stated that the protein differences between high and low protein corns are determined by the same number of genes as proposed for the oil content in corn. The inheritance was reported to be quantitative, and the nature of the interaction of the genes determining protein and its above mentioned constituents was found to be arithmetic in the Ill. High x Ill. Low protein cross.

The factors influencing the oil and protein content of the corn grain were studied also by Miller and Brimhall (22). Their work showed that increased oil content in corn grain depended primarily upon an increased proportion of germ and an increased concentration of oil in the germ. Thus, as the percentage of the oil in the whole grain was increased, the major portion of that increase was of the commercially recovered germ oil. They also reported that variation in total oil percentage was not associated appreciably with variation in total protein percentage. Total oil percentage, however, was positively correlated with the percentage of germ protein in the corn kernel. It thus appeared that increased oil percentage also may result in increased percentage of relatively high quality protein in the corn grain. In the same study, (22) the genotype of the ear bearing parent was found to have the predominant influence on the oil percentage of the grain produced.

Frey (12) examined the inter-relationships of protein and amino acids in corn. Among his other findings and suggestions he stated that the weight of corn grain per plant was negatively correlated with protein percentage, and that the protein of the low protein corn samples he used was better balanced.

Chromosome interchanges in two inbred lines isolated from the High and Low Illinois oil selection were used by Miller et al (23) for investigating the inheritance of oil in the corn kernel. The results obtained from the Low oil line were not conclusive. The data from the High oil line suggested that oil percentage is conditioned by one or more genes linked with the Wx region of chromosome 9, and at least one gene associated with the 4-7a interchange. The oil content was conditioned by a large number of genes having small and approximately equal effects and distributed more or less at random over the ten pairs of maize chromosomes.

The quantitative inheritance of oil in the corn kernel was studied by Sprague and Brimhall (26). The results obtained from their study showed that genetic constitution was more important than environment in determining the percentage of the oil in the kernels, since the variation associated with years (within lines) was less than the year x line interaction. These authors proposed that the inheritance of oil content can be simplified by breaking it into two separate factors: Percentage of germ in the kernel and percentage of oil in the germ.

Sprague and Brimhall (26) also studied the mode of gene action and the means were found to be between the arithmetic and the geometric means but nearer to the geometric mean.

The authors (26) agree with "Student" (29) that 20 to 40 genes are involved in the difference between High and Low oil strains. Boyce according to Sprague and Brimhall (26) considered these gene numbers as being too high and by using the Castle-Wright formula on F_2 data estimated 20 genes.

Woodworth et al (30) reported the results of fifty generations of selection for oil and protein on material originated from the variety Burr's White which was first used by Hopkins (19) in Illinois. The mean oil content of the foundation variety was 4.7 per cent and after 50 generations of selection the High and the Low strain means were 14.36 per cent and 1.01 per cent respectively. The selection toward high oil progressed at a remarkably uniform rate. In low oil selection small progress was made during the last 15 to 20 generations.

The mean protein content of the foundation seed was 10.92 per cent. In 1949 the High protein strain had a mean of 19.45 per cent and the Low strain 4.91 per cent. The selection toward low protein was slow in the first 25 generations and more rapid in the second 25 generations. Progress toward high protein was little in the last 15 generations of the experiment. Variation in protein content from season to season had been much more pronounced than that in the oil content.

According to Floyd (11) Winter reported that selection for oil and protein was expected not only to shift the mean chemical content of the selected strains toward the desired types, but also to reduce the variability of chemical composition within each strain. From an observation of the first 28 generations of the Illinois selection, variability was found to decrease in both High strains when the coefficient of variation was used, and to increase for both Low strains. (11) When other criteria of variations were used, the results were not uniform.

In checking the validity of two different systems of selection for oil content of the corn kernel Sprague, Miller and Brimhall (27, 28) concluded that recurrent selection was more effective than selection during inbreeding. The effectiveness was reported to be 2.5 times greater.

The Chemical Approach

Ellis *et al* (10) studied comparatively the chemical composition of diploid and tetraploid corn. Doubling of chromosomes was accompanied by an increase in the amount of nitrogen present in the grain and in the stover, the average increase being 15 per cent in the grain and 20-34 per cent in the stover. The change in chemical composition was assumed to be due to the cumulative action of certain genes, notably those concerned with protein metabolism.

The inter-relations among factors influencing the oil content in corn was examined by Brunson *et al* (2) on hand pollinated ears of F_2 lines representing Illinois High and Low oil strains. Germ oil and total oil were very highly correlated ($r=0.97$). The correlation between the oil percentage in separated endosperm was also high ($r=0.73$). Germ oil in total kernel was highly correlated with proportion of germ in the kernel (r=0.86). Germ protein in total kernel was positively correlated with proportion of germ (r=0.81) and with percentage germ oil in total kernel (r=0.48).

Schneider et al (25) examined the nitrogen fractions of the component parts of the corn kernel as affected by selection and soil nitrogen. They reported that the endosperm was principally involved in increasing or decreasing the nitrogen of the corn kernel by selection or by nitrogen fertilization of the soil.

The crude protein of corn germ and stover was significantly altered by application of nitrogen according to Zuber et al (31). An increase in the plant population was found also to decrease slightly the crude protein content. Application of 50 pounds of nitrogen gave a significantly lower protein content in the grain than where no nitrogen was applied. When additional nitrogen was applied, protein in stover was increased.

The Physiological and Agronomic Approach

Lacey (21) in studying the seed values of maize kernels coming from the butts, middles and the tips of an ear found no difference.

In a general evaluation of ear characteristics Cunningham (5) found no affirmation of the opinion that great length of the kernel was associated with good yield.

Hoffman (18), Biggar (1), and Brunson (3) in similar studies attempting to correlate seed, ear, and kernel characters with yields in corn found no basis justifying this correlation. The effect of pollination on the composition of corn plants was studied by Brunson and Lathsaw (4). When seed setting was not favored, the protein tended to accumulate in proportion greater than the normal in other parts of the corn plant.

Hybrid vigor and its effect on the weight of germs in the seed of maize was examined by Kempton and McLane (20). Germs were found in most cases to respond to hybridism by an increased weight during their dormant period.

The chemical composition of commercial hybrids and open-pollinated varieties and its relation to soil, season and degrees of maturity was examined by Dody et al (7). Seasonal variations were found to affect protein content. Protein content was also influenced by soil type and location.

The protein content was also examined with respect to the factors that affect it by Norden et al (24). Tests made on sampled shelled grain of 8 hybrids harvested at three stages of maturity for three different locations in 1948 and 1949, disclosed that protein varied from 7.44 to 12.88 per cent depending on the above given factors affecting the experiment. Environment was considered more effective than genetic constitution in determining the protein content.

MATERIALS AND METHODS

The materials used came from the following three sources: (1) an open-pollinated variety, (2) single cross seed, and (3) selfed ears grown from one ear of another open-pollinated variety.

The open-pollinated variety used was Penekin Prolific obtained originally from southeastern Oklahoma and now being maintained in the collection of local varieties of the Oklahoma Agricultural Experiment Station.

The single cross seed was grown on the pure line 115 and was pollinated by pollen from the line K201. The line 115 is characterized by its ability to grow good-sized seed and originated from the variety Denco. This material was used in the present work because it provided grain sizes comparable to those of the open-pollinated variety Penekin Prolific.

The selfed ears were obtained from plants grown from a single ear selected from the open-pollinated variety Mickles and are designated as 147-M1-1-, 147-M1-2, 147-M1-3, 147-M1-4, 147-M1-5 and 147-M1-7.

In order to study the relationship between the area of the germ and the area of the kernel, as also the relationship between the depth (thickness) of the germ and that of the kernel, the seed of the open-pollinated variety and of the single cross were classified by size and thickness into 16 different classes. The classification was made by screening with the purpose to vary the thickness of the kernel within a given kernel size. The samples used in determining the different classes came from shelled grain grown on different ears and fields, for both the open-pollinated variety and the single cross seed.

The classification according to size was accomplished by the use of four screens with 24/, 22/, 20/, and 18/64 inch round openings. The screens determining thickness had openings of the slot type and these openings were 14/, 12/ and 10/64ths of an inch wide.

By the use of the four screens for size classification, four classes were determined. In every one of these four size classes, four more classes were distinguished by varying the thickness of the grain. Thus 16 classes were described as follows: For kernel size those not passing through the round screen, 24 are designated as /24R. Those passing through the screen 24, but not through the screen 22 are designated as 24R/22R. In a similar way, the kernels passing through a 22/64 of an inch screen, but not through a 20/64 of an inch one, and those passing through a 20/64 of an inch screen, but not through an 18/64 of an inch are designated as 22R/20R and 20R/18R respectively.

Within each of the 4 size classes, 4 thickness classes were distinguished in the following manner: Kernels not passing through the 14/64 of an inch screen are designated as /14S. Those passing through a 14/64 of an inch screen, but not through a 12/64 of an inch one are shown as 14S/12S. Finally, the kernels passing through a 12/64 of an inch screen, but not through a 10/64 of an inch one, and those not passing through a 10/64 of an inch screen are designated as 12S/10S and 10S respectively.

The seed obtained from the selfed ears were not classified by the above methods and the samples used were taken from seed grown on the same ear.

Size of samples. The number of kernels measured in every class was 20 except the first four classes of the open-pollinated variety in which 30 seeds in every class were used. Before determining the size of the sample, a preliminary computation of the variance of samples of different size was made. For samples of size 20, 30 and 50 kernels, the variance was almost identical and the sample of size 20 was adopted for greater convenience.

In the grain obtained from the selfed ears a sample of 50 seeds was measured for every one of the six sampled ears.

Methods and Kinds of Measurement

The measurements of the kernel and the germ were made by optical means. For the purpose of the experiment a special apparatus designed by Brooks [1] was used. The apparatus consisted of (1) A table on which the seed to be measured was laid, (2) A projecting device, (3) A source of light, and (4) A translucent glass screen on which the picture of the kernel and the germ were projected. The projected kernel and germ were measured by a planimeter in square inches. The projected picture was 10 times greater than the normal size, but no reduction of the measurements to the normal size was needed due to the nature of the measurements which were aimed at determining ratios.

In the open-pollinated variety and the single cross seed, a surface measurement of the total kernel area and of the area occupied by the germ, and a measurement of the area of the kernel and of the area of the germ on the longitudinal section of the same kernel were made. For both measurements the ratios kernel area/germ area were computed.

In order that the measurements on the open-pollinated variety and the single cross seed be comparable, the single cross seed measured was obtained from a population which could be classified with close

1/ Dr. J. S. Brooks, Agronomist, Corn Investigations, Okla. Exp. Sta.

approximation into the same size and thickness classes as the open-pollinated variety.

The idea for these comparisons is to follow the relationship between kernel and germ in material of presumably different genetic constitution.

In the open-pollinated variety which is randomly cross-pollinated, any variation in the size and thickness measured, and also the ratios obtained from these measurements, cannot be definitely attributed to parentage or environment and it is assumed to be the combined effect of both of these factors.

In the single cross seed population, the seed is grown on a pure line which through inbreeding had reached a high degree of homozygosity. Consequently, the variation in the above mentioned measurements and ratios in the single cross material can be considered as reflecting the influence of the environment on the rather uniform genetic basis determining kernel and germ size. The effect of the pollen coming from the line K201, even in the case it is a strong effect, is not considered to cause any major disturbance because the pollen is also coming from an inbred line and is uniform.

The comparison between the variation in the open-pollinated variety and the single cross seed population permits for a rough indication of the extent at which the environment is affecting the studied relationships.

On the seed obtained from the selfed ears only surface measurements were made. Here, the aim of measurement was to study the variation between ears obtained from the same open-pollinated source and examine the possibilities of selection in a population of this kind.

EXPERIMENTAL RESULTS

Open Pollinated Variety, Penekin Prolific

In the open-pollinated variety 353 grains were measured in the surface measurement and 236 grains on the longitudinal section measurement.

The mean ratios total kernel area/germ area computed from both measurements are presented in Table 1 for all the 16 classes. Each cell of the table corresponds to one of the 16 classes into which the grains were classified.

In the upper line of each of the 16 size classifications is given the mean ratio for the surface measurement which is referred to as the Surface Ratio. The second line presents the mean ratio for the measurement on the longitudinal section. This second ratio is referred to as Section Ratio.

The mean Surface Ratio tended to become smaller with increasing thickness of the grain, i. e. the germ size increased with increasing thickness of the grain within a size class.

The mean Section Ratio tended to become greater with increasing thickness of the grains within a given class.

In order to follow how the two variates, kernel size and germ size, are related within the entire sample, overall correlation coefficients were computed for both Surface and Section measurements. The correlation coefficients were highly significant in both cases and indicate a positive correlation between kernel and germ size. The coefficient for the Section ratio measurements had a greater numerical value than the coefficients for the measurements on the surface of the grain. The coefficients with the corresponding degrees of freedom are shown in Table 2. Further correlation coefficients for the two above mentioned variates were computed for each of the four size classes, and finally, correlation coefficients were computed for every one of the 16 classes. The idea for computing these particular correlation coefficients was to see whether the correlation found for the entire sample was presenting a general scheme of relationship and up to what point this correlation could be verified in smaller size classes.

The correlation coefficients computed for the four size classes were highly significant except one which was significant and they are presented together with their corresponding degrees of freedom in Table 3. The coefficients are computed for both ratios. The correlation coefficients computed for each one of the 16 classes and for both ratios appear to be in their majority significant or highly significant.

In the 4 size classes and in each of the 16 classes, the section measurements are of a higher numerical value indicating that the germ area and the area of the kernel are more closely related in the section than in the surface measurement.

Single Cross Seed 115 x K201

The same type of measurements and computations have been made on the single cross seed material of which a total of 300 seeds was measured. The mean ratios total kernel area/germ area were computed for both surface and section measurements and are presented in Table 5. The arrangement of the table is identical to that of Table 1. The mean Surface Ratio also presented a trend to become smaller with increasing thickness of the kernel. The mean Section Ratios did not appear to follow any specific pattern. Overall correlation coefficients for the

Table 1. Mean Ratios of kernel size/germ size in the open-pollinated variety Penekin Prolific. Upper line ratio on the surface measurement, lower line ratio of the measurement on the longitudinal section.

		Thickness			
		10S	12S/10S	14S/12S	/14S
Size					
20R/18R	Surface Ratio	2.786±0.092	2.234±0.067	2.234±0.067	2.056±0.052
	Section Ratio	--- ---	--- ---	--- ---	--- ---
22R/20R	Surface Ratio	2.609±0.060	2.259±0.062	2.260±0.054	2.046±0.051
	Section Ratio	2.322±0.136	2.247±0.084	2.240±0.072	2.560±0.071
24R/22R	Surface Ratio	2.876±0.091	2.786±0.232	2.465±0.083	2.102±0.065
	Section Ratio	2.171±0.095	2.197±0.110	2.289±0.113	2.467±0.085
/24R	Surface Ratio	2.911±0.075	2.811±0.070	2.814±0.100	2.529±0.087
	Section Ratio	2.144±0.136	2.234±0.111	2.363±0.125	2.226±0.055

Table 2. Correlation coefficients for kernel area and germ area in surface and longitudinal section measurements of the open-pollinated variety Penekin Prolific.

Surface Measurement	Measurement on the Longitudinal Section
r=0.4964**	r=0.7078**
d.f.=351	d.f.=234

** Indicates a value significant at the 1% level.

Table 3. Correlation coefficients for kernel area and germ area in surface and longitudinal section measurement, in the 4 size classes of the open-pollinated variety Penekin Prolific.

Size	Surface Measurement	Measurement on the Longitudinal Section
20R/18R	r=0.5416** d.f.=115	
22R/20R	r=0.4822** d.f.=78	r=0.6491** d.f.=78
24R/22R	r=0.2172* d.f.=79	r=0.6849** d.f.=78
/24R	r=0.4304** d.f.=74	r=0.7458** d.f.=74

* Indicates a value significant at the 5% level.

** Indicates a value significant at the 1% level.

Table 4. Correlation coefficients for the 16 size and thickness classes of the open pollinated variety Penekin Prolific. Upper line in each cell shows r for surface measurement, Lower line shows r for measurement on the longitudinal section.

Thickness

Size		10S/	12S/	14S/12S	/14S
20R/18R	Surface	r=0.5173**	r=0.6196**	r=0.7780**	r=0.6400**
	Section	--------	--------	--------	--------
22R/20R	Surface	r=0.4780*	r=0.6589**	r=0.6652**	r=0.6633**
	Section	r=0.1807	r=0.7640**	r=0.7019**	r=0.8579**
24R/22R	Surface	r=0.3448	r=0.4460*	r=0.7146**	r=0.5058*
	Section	r=0.7974**	r=0.6951**	r=0.7556**	r=0.6090**
/24R	Surface	r=0.4943*	r=0.6451**	r=0.5191*	r=0.3790
	Section	r=0.6140**	r=0.6493**	r=0.7445**	r=0.7908**

* Indicates a value significant at the 5% level.

** Indicates a value significant at the 1% level.

Table 5. Mean Ratio of kernel size/germ size in the single cross seed 115 x K201. Upper line Ratio of the surface measurement, Lower line Ratio of the measurement on the longitudinal section.

		Thickness			
		10S	12S/10S	14S/12S	/14S
Size					
20R/18R	Surface Ratio	2.754±0.068	2.381±0.058	2.177±0.050	2.104±0.072
	Section Ratio	2.200±0.061	2.279±0.067	2.495±0.074	2.483±0.147
22R/20R	Surface Ratio	2.564±0.065	2.413±0.059	2.306±0.062	2.107±0.083
	Section Ratio	2.209±0.085	2.183±0.062	2.265±0.102	2.476±0.097
24R/22R	Surface Ratio	2.814±0.073	2.496±0.050	2.514±0.067	1.974±0.116
	Section Ratio	2.135±0.073	2.103±0.076	2.215±0.081	2.111±0.141
/24R	Surface Ratio	-----------	2.723±0.065	2.491±0.044	2.417±0.048
	Section Ratio	-----------	1.973±0.060	2.024±0.058	2.071±0.014

variates kernel size and germ size were computed and are presented in Table 6. Both coefficients are highly significant and the coefficient for the section areas are, as in the case of the open-pollinated variety, of a higher numerical value.

The correlation coefficients computed for the 4 size classifications and the 15 classes of the sample were computed as in the case of the open-pollinated variety and are presented in Tables 7 and 8, respectively. The results were similar to those obtained from the open-pollinated material, i. e. the correlation coefficients for the 4 size classifications were all highly significant and those computed for section measurement also had a greater numerical value. The coefficients for the 15 classes were in their majority significant or highly significant.

In order to compare the variation in kernel and germ sizes and also in the kernel/germ ratio in the open pollinated variety and the single cross seed, the overall variance of both kernel and germ sizes were computed as well as for the ratios of these measurements. These variances are presented in Tables 9 and 10, respectively. The variances in all cases were greater in the open-pollinated variety than in the single cross seed.

The same appeared to be true for the coefficients of variation computed from the above variances although the differences were less pronounced, Tables 11 and 12.

<u>Selfed Ears Grown on the Open-pollinated Variety, Mickles</u>

Six ears were sampled from plants grown from the seed of a single ear selected from the open-pollinated variety, Mickles. Each one of

Table 6. Correlation coefficients for kernel area and germ area in surface and longitudinal section measurements in the single cross seed 115 x K201.

Surface Measurement	Measurement on the Longitudinal Section
r=0.5617**	r=0.7267**
d.f.=298	d.f.=298

** Indicates a value significant at the 1% level.

Table 7. Correlation coefficients for kernel area and germ area in surface and longitudinal section measurements, in the 4 size classes of the single cross seed 115 x K201.

Size	Surface Measurement	Measurement on the Longitudinal Section
20R/18R	r=0.4633** d.f.=78	r=0.7315** d.f.=78
22R/20R	r=0.4936** d.f.=78	r=0.6678** d.f.=78
24R/22R	r=0.5308** d.f.=78	r=0.812** d.f.=78
/24R	r=0.3378** d.f=58	r=0.7707** d.f.=58

** Indicates a value significant at the 1% level.

Table 8. Correlation coefficients for the 15 size and thickness classes of the single cross seed 115 x K201 grain. Upper line in each cell shows r for surface measurements, Lower line shows r for measurements on the longitudinal section of the grain.

Size		Thickness			
		10S/	12S/10S	14S/12S	/14S
20R/18R	Surface	r=0.7801**	r=0.5884**	r=0.2663	r=0.7905**
	Section	r=0.7181**	r=0.8213**	r=0.5360*	r=0.5178*
22R/20R	Surface	r=0.5111*	r=0.5320*	r=0.7556**	r=0.4895*
	Section	r=0.8455**	r=0.8330**	r=0.6020**	r=0.4038
24R/22R	Surface	r=0.2442	r=0.3504	r=0.3664	r=0.7048**
	Section	r=0.7683**	r=0.6410**	r=0.7048**	r=0.8406**
/24R	Surface	--------	r=0.0067	r=0.4716	r=0.3474
	Section	--------	r=0.6906**	r=0.7766**	r=0.6625**

* Indicates a value significant at the 5% level.

** Indicates a value significant at the 1% level.

Table 9. Variance of the kernel and germ size in the open-pollinated variety Penekin Prolific and the single cross seed 115 x K201 for surface and longitudinal section measurements.

	Surface Measurement		Section Measurement	
	Kernel size	germ size	Kernel size	germ size
Penekin Prolific	2.2317	0.3961	1.1438	0.3694
115 x K201	0.9954	0.1572	0.5970	0.1585

Table 10. Variance of the ratios kernel size/germ size measured on the surface and on the longitudinal section of grains in the open-pollinated variety Penekin Prolific and the single cross seed 115 x K201.

	Surface Ratio	Longitudinal Section Ratio
Penekin Prolific	0.2096	0.2067
115 x K201	0.1444	0.1684

Table 11. Coefficients of variation for the kernel and germ size for surface and longitudinal section measurements in the open-pollinated variety Penekin Prolific and the single cross seed 115 x K201.

	Surface Measurements		Section Measurements	
	Kernel size	Germ size	Kernel size	Germ size
Penekin Prolific	17.40	17.79	19.65	24.83
115 x K201	15.93	15.21	20.27	22.85

Table 12. Coefficients of variation for the Ratios Kernel size/germ size measured on the surface and on the longitudinal section of grains in the open-pollinated variety Penekin Prolific and the single cross seed 115 x K201.

	Surface Measurement	Measurement of the Section
Penekin Prolific	18.42	19.86
115 x K201	15.73	18.53

the 6 ears was obtained from a different plant. In each ear 50 grains were measured and only a surface measurement of the kernel and germ sizes was made. The ratios kernel area/germ area are presented in Table 13.

In order to see if the variation in the mean ratios in the 6 different ears was of any significance an analysis of variance was made. The results are presented in Table 14 and show that the ear mean square is highly significant indicating that the ears do not belong to the same population.

Table 13. Mean Ratios, Kernel size/germ size, in selfed grain obtained from 6 ears of 6 different plants grown from an ear selected from the open-pollinated variety Mickles.

Ears	Ratios
147-M1-1	2.263±0.042
147-M1-2	2.306±0.042
147-M1-3	2.325±0.036
147-M1-4	2.210±0.042
147-M1-5	2.332±0.031
147-M1-7	2.554±0.041

Table 14. Analysis of variance of the mean ratios kernel size/germ size computed for the 6 selfed ears of the open-pollinated variety, Mickles.

Source of Variation	D.F.	Sum of Squares	Mean Square
Total	299	25.840	
Ears	5	4.190	0.838**
Within Ears (error)	294	21.650	0.073

F=0.838/0.072=11.47 d.f.5 and 294

** Indicates a value significant at the 1% level.

DISCUSSION

The information furnished by the investigation raises the following points:

1. For both the open-pollinated variety and the single cross material, the size of the kernel and the size of the germ appear to be positively correlated. This correlation appears to be better established on the ratio obtained from the measurements on the longitudinal sections. This higher correlation value might be considered as indicating that in selecting by optical means for a larger germ size, the observation on the surface is liable to greater variation than the observation on the thickness of the grain. It is then considered to be a reasonable deduction that selection for better germ/kernel relationship can be based more on surface than on thickness measurement.

2. The variation within the two measured characters, kernel and germ, and also the variation of their ratios in both types of measurements appear to be greater for the open-pollinated than the single cross seed material. This may be attributed to the environmental conditions similarly affecting the common genetic background of the single cross seed, or that the role of the environment is more limited on an isogenic population than in an heterozygous one. Another alternative is that in the heterozygous open-pollinated variety, the different genetic elements may present different starting points for the action of the environment. Which one of these alternatives approximates the mechanism

determining the relationship between kernel and germ could not be shown by the information provided by this work.

Although these two types of material are not ideal for an absolutely reliable comparison, they help to indicate that the variation on a genetically more or less isogenic material is smaller than on a meterial of an unknown and presumably heterozygoud composition. In attempting to distinguish between the genetic and environmental influence on the kernel/germ relationship, the coefficient of heritability was computed from the variances of the kernel and germ sizes and their ratios in the open-pollinated and single cross seed material.

By applying the formula: Coefficient of heritability=

$$\frac{\text{variance of the O.P.V. - variance of the single cross seed}}{\text{variance of the O.P.V. (open-pollinated variety)}} \times 100$$

these coefficients were found to be:

(a) For the ratio kernel size of germ size measured on the surface of the seed = 31.10%.

(b) For the ratio kernel size/germ size measured on the longitudinal section of the seed = 18.53%.

(c) For the kernel size measured on the surface of the seed = 55.30%.

(d) For the germ size measured on the surface of the seed = 60.31%.

(e) For the kernel size measured on the longitudinal section = 47.80%.

(f) For the germ size measured on the longitudinal section = 57.00%.

These coefficients of heritability indicated that the variation due to genetic factors is great and that any method of breeding can be applied when the kernel and the germ size are selected in a breeding program by mere visual measurement on the surface or on the surface or on the longitudinal section of the grain.

The smaller heritability coefficients for the ratios kernel size/germ size can be attributed to the fact that these ratios are conditioned by a larger number of factors than the single measurements of the kernel and germ sizes used for their computation. The greater numerical values of the heritability coefficients for the measurements of the kernel and seed size on the surface of the grain indicate that selection based on them might be more effective than the selection on the measurements on the section.

3. The measurements made on the selfed ears grown on plants originating from a single ear selected on the open-pollinated variety, Mickles, show that the plants grown from this single ear are already differentiated from the original population. It thus follows that selection is effective at this stage of departure from the original population.

4. The method used for carrying out these measurements is thought to be helpful in distinguishing corn grains having a desirable relationship between kernel and germ even in cases that this relationship changes by small amounts. If the results provided by the method are, as it is believed, identical with those furnished by other methods for selecting for high oil and protein content (i. e. the chemical method), then the method in addition to its other advantages will make possible to decide on the quality and value of small precious samples of seed which cannot be sacrificed for chemical analysis and must be preserved for planting.

SUMMARY AND CONCLUSIONS

An investigation of the relationship between the kernel and the germ in corn grain was made by the use of optical means. The purpose of this investigation was to see what is the visual relationship between these two variates and attempt to decide whether by visual observation corn grain could be selected for higher oil and protein content. The observations were made on three types of material, (1) An open-pollinated variety, (2) Single cross seed and, (3) Selfed ears of a second open-pollinated variety.

All the measurements were made with a planimeter tracing a projected image of the kernel. The open-pollinated variety and the single cross seed were classified by size and thickness of the kernel into 16 different classes through screening. Two types of measurement were made in every class (a) a measurement of the size of the kernel and the size of the germ in a surface observation and (b) a measurement of the size of the kernel and the germ in a longitudinal section. For both measurements, the ratio kernel size/germ size was computed.

A total of 353 kernels were measured from the open-pollinated variety and 300 kernels from the single cross seed 115 x K201. Correlation coefficients were computed for kernel and germ sizes, for the samples as a whole, for the 4 size classes and for each of the 16 classes.

The coefficients of variation for these two types of material were computed for kernel size, for germ size and for their ratios in both types of measurement.

In the selfed ears 6 ears grown on different plants were used and 50 grains from every ear were sampled. A total of 300 grains was measured. One measurement was made on surface, and the ratio of kernel size/germ size was computed. For each ear the variance between ears was examined through analysis of variance. The results obtained from this investigation were as follows:

1. There is a significant positive correlation between kernel size and germ size. The correlation is found significant even in small classes of size 20 kernels. The correlation coefficients have a higher numerical value when computed for the measurement on the longitudinal section.

2. The variances for kernel size and germ size are higher for the open pollinated variety than the single cross seed 115 x K201, in both types of measurement. The same was found to be the case for the ratios kernel size/germ size computed from both measurements.

3. The selfed ears appeared to be differentiated and have significantly different means and therefore do not belong to the same population.

This work attempted to furnish information on the possibility of using the proposed optical method for selecting corn for higher protein and oil content through the selection of a larger germ.

The results are considered to be promising, however, they must be compared with the other methods for selecting for high oil and protein content before they are definitely affirmed. Also, continuation of the measurements on other material would be helpful. It appeared that the method would accurately determine the size relationship and the belief was expressed that it would be found helpful in corn grain evaluation.

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VITA

Basil Tsotsis
candidate for the degree of
Master of Science

Thesis: A VISUAL MEASUREMENT OF THE RELATIONSHIP OF KERNEL SIZE AND GERM SIZE IN THE CORN GRAIN

Major: Field Crops

Biographical and Other Items:

Born: July 20, 1928 at Thessaloniki, Greece

Undergraduate Study: University of Thessaloniki, Thessaloniki, Greece. 1946-1951

Graduate Study: O. A. M. C., 1954-55

Experiences: Superintendent of the Field Crop Section of the University of Thessaloniki Experiment Farm, 1951. Greek Army, 2nd. Lieutenant of the Corps of Engineers 1952-1954. From July 1954 visiting the United States as a participant of the Exchange Program sponsored by the U. S. government.

Date of Final Examination: May, 1955.

THESIS TITLE: A VISUAL MEASUREMENT OF THE RELATIONSHIP OF KERNEL SIZE AND GERM SIZE IN THE CORN GRAIN.

AUTHOR: Basil Tsotsis

THESIS ADVISER: Dr. J. S. Brooks

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TYPIST: Mrs. Louise Kee