Inheritance of awnedness, kernel smoothness, kernel length, and reaction to two physiologic races of Tilletia in a spring wheat cross
by Orlie W Smith

A THESIS Submitted to the Graduate Committee in partial fulfillment of the requirements for the Degree of Master of Science in Agronomy at Montana State College
Montana State University

Abstract:
TMs investigation is an inheriatance study of awnedness, kernel smoothness, kernel length, and mode of reaction to two physiologic races of Tilletia in the progeny of a cross between Ceres-(Hope-Florence) and Renown. Ceres-Hope-Florence) is fully awned (awn type 5)? moderately resistant to two physiologic hunt races (T-11 of Tilletia tritioi and L-3 of T. levis_), and has kernels with the following characteristics: cheeks, mostly angular and knife-edged; crease, mid-wide to wide, mid-deep to deep, and mostly pitted; and an average length of about 6.8 millimeters* Renown is weakly anwletted (awn type 3-), more resistant to the two bunt races, T-11 and L-3, than Ceres-(Hope*Florence), and-has kernels with the following characteristics: cheeks, mostly rounded to semi-angular; crease, narrow to mid-wide, shallow to mid-deep, and usually closed but some may be slightly pitted; and an average length of about 6.4 mm.

One major factor was found to govern the awn development between the parents of this cross with the awnletted condition being incompletely dominant to the awned.

The F2 and F3 were classified into eight classes depending upon the degree of roundness or angularity of cheeks, depth and width of crease, and pittedness of the kernels. A uniform breeding difference was demonstrated for the parents and the prog ny segregated for a complete range of an between the parents but no definite factorial analysis was established.

A total length of fifteen selected kernels from each plant were measured in millimeters to determine kernel length differences. In the F2 a very regular segregation seemed to be indicated with a weak dominance ox the smoother types suggested. The parents and F3, were so variable it was impossible to check the F2 classification by the F3 breeding behavior.

Bunt infections in the parents, progeny, and susceptible check, Ulka, were so slight it was decided from observational data that a differential reaction of the progeny could not be demonstrated.

INHERITANCE OF AWNEDNESS, KERNEL SMOOTHNESS, KERNEL LENGTH, AND REACTION TO TWO PHYSIOLOGIC RACES OF <u>TILLETIA</u> IN A SPRING WHEAT CROSS

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

INHERITANCE OF AWNEDNESS, KERNEL SMOOTHNESS, KERNEL LENGTH, AND REACTION TO TWO PHYSIOLOGICE RACES OF TILLETIA IN A SPRING WHEAT CROSS

ABSTRACT

This investigation is an inheriatance study of awnedness, kernel smoothness, kernel length, and mode of reaction to two physiologic races of Tilletia in the progeny of a cross between Ceres-(Hope-Florence) and Renown. Ceres-Hope-Florence) is fully awned (awn type 5), moderately resistant to two physiologic bunt races (T-11 of Tilletia tritici and L-3 of T. levis), and has kernels with the following characteristics: cheeks, mostly angular and knife-edged; crease, mid-wide to wide, mid-deep to deep, and mostly pitted; and an average length of about 6.8 millimeters. Renown is weakly anwletted (awn type 3-), more resistant to the two bunt races, T-11 and L-3, than Ceres-(Hope*Florence), and has kernels with the following characteristics: cheeks, mostly rounded to semi-angular; crease, narrow to mid-wide, shallow to mid-deep, and usually closed but some may be slightly pitted; and an average length of about 6.4 mm.

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Bunt infections in the parents, progeny, and susceptible check, Ulka, were so slight it was decided from observational data that a differential reaction of the progeny could not be demonstrated.

INHERITANCE OF AWNEDNESS, KERNEL SMOOTHNESS[1], KERNEL LENGTH, AND REACTION TO TWO PHYSIOLOGIC RACES OF *TILLETIA* IN A SPRING WHEAT CROSS

Orlie W. Smith

INTRODUCTION

From the earliest times men have recognized the fact that "like begets like" and that the offspring differ somewhat among themselves and from their parents. They have long used this knowledge, more or less unconsciously, perhaps, in choosing for breeding purposes those individuals among their domesticated animals and plants which best suited their requirements. Only rarely were deliberate breeding methods used which depended upon an empirical knowledge of the methods of reproduction, such as the artificial pollination of the female date palm, which was practiced in Egypt and Mesopotamia many centuries before the Christian era. The early husbandmen bred their animals and plants without any general knowledge of the reproductive processes, and the legacy of valuable cultivated plants, which is the earmark of permanent civilizations, resulted from taming the wild species and selecting fortuitous variations among them. A scientific understanding of the problems of heredity and variation, however, has befun to be reached only recently.

In a little over on-third of a century, genetics has developed into an exact science comparable to such older sciences as physics and

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[1] Kernel smoothness as used throughout this paper pertains only to the condition of the cheeks, crease, and pittedness of the kernels.

chemistry. The mode of inheritance of many plant characters has been studied and in many cases a factorial analysis has been established but this research is surely yet in its infancy. Many problems remain to be solved before the geneticist will be able to combine all desired qualities into a preconceived perfect variety. Exact information regarding the underlying principles of inheritance of various characters has aided in establishing more efficient breeding operations.

The mechanism of heredity was first conceived and worked out by Gregor Mendel whose experiments in plant hybridization laid the foundation for most of the modern work in genetics. Mendel's four laws dealt with unit characters, dominance, segregation and recombination. Although published in 1866, his findings lay in obscurity until 1900 when they were independently and simultaneously rediscovered by Devries, Correns, and Von Tschermak. Unit characters have not proved to be as simple in wheat as was first thought and dominance is incomplete in most cases, but in spite of this the single character is still the foundation in studying wheat inheritance and dominance the primary basis for genetic interpretations.

During the past 15 or 20 years considerable information has been accumulated on the mode of inheritance of many characters of wheat. The inheritance of some of these characters has been found to be relatively simple, whereas in other cases complex reactions are found which indicate that a large number of genetic factors are involved. The so-called "qualitative characters", such as awnedness, kernel color, color of straw, pubescence and color of glumes, and dwarf and normal plants, are usually more simple to study than "quantitative characters" which include such characters as time of maturity, yield, winterhardiness, height of plant, and strength of straw. This is because the qulaitative characters can readily be placed into distinct classes and groups, whereas quantitative characters are classified in numerical or percentage frequencies.

Kernel smoothness and kernel length are two characters of wheat on which there has been very little systematic study to determine their mode of inheritance. These qualities are very important since the length of kernel is the main differentiating character between spring and winter wheat and smoothness of kernel seems to be closely associated with test weight and consequently yield of flour. A smooth, plump, and short kernel is the desired type in hard red spring wheat and with these characters in mind the wheat breeder is able to eliminate in early generations those selections not having the desired kernel characteristics. It seems evident that kernel smoothness and kernel length have a definite mode of inheritance because it has been possible to select varieties true breeding for smooth, plump, and short kernels from the progeny of parents contrasted in these respects. Obviously, then, to proceed more efficiently in a wheat breeding program, it is desirable to know the exact mode of inheritance of these two characters.

The investigations reported in this paper consist of inheritance studies in a spring wheat cross, Ceres-(Hope-Florence) x Renown, on awnedness, kernel smoothness, kernel length, and reaction to two physiologic races of bunt.

LITERATURE REVIEW

Awnedness

In the early reports on studies of inheritance of awnedness in wheat, only two classes, awned and awnless, were differentiated. More recent studies have established the fact that there are true breeding awn types intermediate between completely awnless and fully awned wheats. Until these intermediate types were fully recognized, much confusion resulted among early workers who studied the inheritance of this character.

According to Hayes and Garber (1927), Biffen in 1905 reported the first systematic genetic study of awnedness. He concluded from the study of several crosses of bearded with so-called "beardless" wheats that the "awnless" condition was dominant and the awned condition recessive. Plants having awns up to one-half inch in length were regarded as "awnless", thus the F_1 was always "beardless" and the F_2 segregated into 3:1 "awnless" to awned. The awned types always bred true, while about one-third of the "beardless" types bred true and two-thirds segregated into awned and "awnless" types.

Several other workers obtained similar ratios in the F_1 and a 3:1 beardless to bearded segregation in the F_2. Saunders (1907) seems to be the first worker to question the idea that the F_1 of a cross between a beardless and a bearded wheat is always beardless. He maintained that the type of awns obtained in the F_1 depends upon the difference between the parent forms used. Percival (1921) later reported that in numerous crosses the F_1 plants have awns which are easily distinguished from the beardless parent and that the F_2 segregated into a 1:2:1 ratio of beadless, semi-bearded, and bearded. Many workers have verified these results. Hayes and Asmodt (1923) found that the F_1 of a cross between and awned and a semi-awned variety was strongly awnletted and the F_2 segregated as a simple monohybrid. Clark and Quisenberry (1929) verified these results by a reciprocal cross of the same varieties. Several other investigations have revealed that a one-factor difference would account for the awn types found in the progeny of crosses between semi-awned and awned varieties. Workers who have reported such results are: Gaines and Singleton (1926), Stewart and Woodward (1931), Stewart and Dalley (1932), Quisenberry and Clark (1933), Ausemus (1934), and Tingey and Tolman(1934).

Stewart and Tingey (1928) found that when a true beardless wheat was crossed with semi-bearded wheat that a monohybrid ratio was obtained. Also Quisenberry and Clark (1933) and Ausemus (1934) obtained similar results from similar crosses.

The first work with true awnless and fully awned wheats was reported by Howard and Howard (1912, 1915) and they concluded that two factors were necessary to explain the difference in inheritance between these two types. They grouped all awned and tip-awned classes together as awned, which in comparison with the awnless gave a 15:1 ratio. They thus concluded that the awned condition was dominant, which was an opposite conclusion to that of other workers.

A number of other investigators have obtained a two-major-factor difference for awnedness when awnless and awned types were crossed. In most cases it was assumed that the awnless and semi-awned condition was dominant to the awned condition. Also in a number of cases the workers have found it necessary to assume that one or more minor modifying factors were present to fully explain their results. In a Kota (fully-awned) x Hard Federation (true awnless) cross, Clark (1924) concluded that the awnless condition was dominant, as the F_1 (apically awnletted) approached more nearly the awnless than the awned variety, and also that two genetic factors could not entirely account for the breeding behavior in the F_2 and F_3 generations. Clark, Florell, and Hooker (1928) studied two crosses of beardless and bearded wheats and found a two-major factor difference in one cross and a three-factor, two major and one minor, difference in the other. Apparently the only effect of the minor factor, in the presence of one major factor, is to uniformly reduce the extent of awnedness. From this study they concluded that as many as four factors may be involved in the inheritance of awnedness in wheat. Other investigators who have found two-factor differences in wheat are: Stewart and Heyward (1929), Stewart and Judd (1931), Clark, Quisenberry, and Powers (1933) , and Ausemus (1934). Litzenberger (1939) reported a two-major factor difference in two crosses of beardless and bearded wheats. A phenotypic ratio of 1:4:5:3:2:1 for awnless, apically awnletted, weakly awnletted, strongly awnletted, half awned, and awned respectively was found in one cross and a 1:8:1:3:2:1 phenotypic ratio for the six classes in the other cross. He also made several test hybridizations involving the parents and progeny ofone of the original crosses and from this he concluded that the awn-group classification as originally made was correct.

A number of investigators have reported that there are genetically different types of semi-awned wheats. Love and Craig (1926) state that when Sonora is crossed with awnless types of common wheat (Triticum vulgare), the F_1 is awnless, while in the F_2 and later generation awned and partly awned types appear. The results approached a 15:1 ratio which indicated this variety although sem-awnless carried a factor for the bearded condition. Stewart (1932) crossed two true breeding awnletted types which he obtained as segregates from a cross of Sevier x Federation and obtained all types again. Four true breeding types were recovered--one fully awned, one completely awnless and two awnletted types. Clark and Quisenberry-(1933) crossed two awnletted wheats, Sonora and Quality, and obtained similar results. There was a complete range from awnless to awned in the F_2 and in the F_3 there were obtained true breeding awnless and awned strains as well as strains awnletted like both parents. It was assumed that Sonora contains the genetic factors aaBB and Quality AAbb, whereas awnless segregates are AABB and awned ones aabb.

The literature reviewed indicates that the mode of inheritance of awns in wheat is relatively simple in some crosses and rather complex in others. Usually a single-factor difference will explain the segregation of semi-awned x awned or semi-awned x true awnless crosses and two factors, the true awnlessx fully awned crosses. However, as many as two major and two minor factors were necessary to fully explainthe segregation obtained in one cross. The four true breeding types most often found are awnless, awned, weakly awnletted, and strongly awnletted. True breeding apically awned and half awned types have been obtained from a few crosses. Dominance of awnlessness is incomplete--the F_1 more nearly approaches the awnless parent than the awned type.

Kernel Smoothness

The writer was unable to find any literature dealing with a systematic study of the inheritance of kernel cheek, crease, and pitted characteristics.

Kernel Length

The length of kernel is used as a major character in distinguishing varieties of wheat. The shorter types are usually characteristic of the hard red spring wheats and the longer ones, the red winter wheats. This generalization, however, is becoming more confusing every year because of the distribution of more varieties of hard red spring wheat with long kernels and some hard red winter wheats with short kernels.

Engledow (1920) seems to be the first person to report any inheritance studies of grain length of wheat. He crossed *Triticum polonicum* which had a mean grain length of about 10.2 mm. and *T. durum* with a mean length of about 7.7 mm. and found that the F_1 was intermediate. In the F_2 three types were found with the following mean grain lengths: 8.84, 8.67, and 8.33 mm. representing the extracted polonicums, heterozygous intermediates, and extracted *durums* respectively. He concluded the segregation was such as to suggest a one-factor difference---approximately a 1:2:1 ratio. No grains were found as long as the grand parental *polonicum* and none as short as the *furum* ancestor, an inward "shift" toward the mean of the two grandparents having occurred.

In a recent study of kernel length, Webster (1937) used 10 primary kernels selected at random from one spike of each F_2 and F_3 plant and recorded the total length in millimeters. The parents used in the cross studied were Baart (*Triticum Vulgare*) which had a mean lenth of 75.60±.55 mm. and Shot wheat (*T. sphaeroccoccum*) with a mean length of 48.27±.35 mm., a difference of 27.33mm. He found that in the F_2 there was a cedided dominance of the longer type kernels and in the F_3, 24 homozygous long types appeared but only one homozygous short type was recovered. He concluded that segregation for kernel length could not be satisfactorily explained on a simple factor basis.

Bunt Reaction

The mode of inheritance of resistance to physiologic races of *Tilletia tritici* (Bjerk.) Wint. and *T. Levis* (Kühn) has been studied by a large number of workers and explained on one-, two-, three-, and multiple-factor differences. Schlehuber (1938) has reviewed the literature on the nature of segregation rather exhaustively and has trouped the authors according to the number of factors involved in the cross with which they worked. Since the writer was unable to find any bunt inheritance work more recent than that summarized by Schlehuber, no additional literature review has been attempted.

MATERIALS AND METHODS

The purpose of the study was to determine the mode of inheritance of awnedness, kernel smoothness, kernel length, and reaction to two physiologic races of Tilletia in a cross between Ceres-(Hope-Florence) (C. I. 11872)[1] and Renown (C. I. 11709). The Ceres-(Hope-Florence,) parent is a selection out of a cross of Ceres with Hope x Florence, is full awned (awn type 5) and has kernels of the following characteristics: cheeks, mostly angular and knife-edged; crease, mid-wide to wide, mid-deep to deep, and mostly pitted; average length about 6.8 millimeters; and moderately resistant to bunt races T-11[2] and 1-3[2]. The other parent, Renown, is weakly awnletted (awn type 3-) and possesses kernels of these characteristics: cheeks, mostly rounded to semi-angular; crease, narrow to mid-wide, shallow to mid-deep, usually closed but some may be slightly pitted; average length about 6.4 millimeters; and more resistant to the two bunt races T-11 and L-3 than Ceres-(Hope_Florence). Ceres-(Hope-Florence) was produced at a North Dakota Agricultural Experiment Station and is resistant to most of the known physiologic races of bunt and Renown was produced at the Dominion Rust Research Laboratory at Winnipeg, Canada, and is also resistant to most of the known physiologic races of bunt.

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[1] C.I. refers to accession number of the Division of Cereal Crops and Diseases.

[2] T-11 and L-3 refer to known specific physiologic races of Tilletia tritici and T. levis respectively.

The parent varieties, Ceres-(Hope-Florence) and Renown, were grown in a bunt physiologic race nursery at Bozeman, Montana, and Pullman, Washington, in 1937. Because these were two varieities giving low percentages of infection to all known races of <u>Tilletia tritici</u> and <u>T. levis</u>, a cross was made in an effort to combine the smut resistance of the two parents with the high yield of Ceres-(Hope-Florence) and the short smooth kernel type and weakly awnletted condition of Renown. The cross was made at Bozeman, Montana, under the supervision of Dr. R. H. Bamberg and advanced through the F_2 in 1939 as a part of the wheat improvement program.

The F_2 progeny consisting of six families of approximately 100 plants each and the parents were studied in the laboratory for awnedness, kernel smoothness, and kernel length.

For awnedness inheritance studies, the F_2 hybrid plants were classified according to the following classes:

Awn class	Description of awn type
L	Awnless, no development of awnlets over 2 mm. in length.
2	Apically awnletted, has awns from 2 to 15 mm. long at the apex of the spike.
3	Weakly awnletted, has awnlets from 3 to 20 mm. long, the shorter occurring at the base of the spike and the length increasing toward the apex.
3+	Strongly awnletted, has awnlets from 3 to 40 mm. long, the shorter occurring at the base of the spike and the length increasing toward the apex. The lower awnlets in this class are usually incurved.
4	Half awned, has short awns varying throughout the spike from 18 to 50 mm. long--approximately one-half the length of a fully awned type.
5	Awned, the awns vary from 30 to 100 mm. in length.

For kernel smoothness inheritance studies, the seeds of the F_2 plants were classified according to the following classes:

Kernel smoothness classes	Description of kernel smoothness classes
2	Cheeks, round; crease, narrow, shallow and closed
3	Cheeks, semi-angular; crease, narrow, shallow and closed.
4	Cheeks, mostly rounded; crease, shallow to semi-deed and closed except a few kernels may be slightly pitted near center of crease.
5	Cheeks, mostly semi-angular to angular; crease mostly narrow to mid-wide and mid-deep. May be moderately pitted.
6	Cheeks, mostly angular; crease, mostly mid-wide to wide, mid-deep to deep and pitted.
7	Cheeks, mostly angular, knife-edged, and rough or scaly; crease, mostly wide to semi-wide, deep to mid-deep, and pitted. Ventral surface usually sloping from cheek margins to bottom of pit and wrinkled around margins of pit.
8	Cheeks, angular, knife-edged, rough and scaly; crease, mostly wide, deep and extensively pitted. Ventral surface usually rough and sloping from margins of cheek into the deep pit. Depth of pit about one-half of dorsoventral thickness of kernel.

For kernel length inheritance studies, heads were selected from the three main tillers of each F_2 plant. Fifteen kernels were then taken from the two lower florets of spikelets selected at random from the center of these spikes, laid end to end, and measured in millimeters.

For F_3 inheritance studies of awnedness, kernel smoothness, kernel length, and reaction to two physiologic races of <u>Tilletia</u>, two separate nurseries of the same F_3 lines were grown. One nursery was seeded for awnedness, kernel smoothness, and kernel length studies and the other was treated with two races of bunt and seeded for bunt inheritance studies.

In the F_3 awnedness, kernel smoothness, and kernel length nursery, 60 lines of 30 seeds each were selected at random from each of four F_2 families. These lines were seeded in single rows 12 inches apart with the seed spaced about three inches apart within the rows. Two families were grown at Bozeman and two at Moccasin, Montana. One row of each parent was included after every 20 rows of progeny. Also, thirty seeds each of all questionable awn types found in the F_2 were grown at Bozeman and Moccasin.

The awnedness classification was made in the field by determining whether the plants in each row were segregating or breeding true for awn types as determined in the F_2.

At Bozeman 20 plants were pulled from each of the 120 F_3 lines and from 18 parent rows. The seeds were then threshed and classified for kernel smoothness and measured for kernel length in the same manner as was done for the F_2. Twenty plants were pulled from each line at Moccasin for similar studies.

For the F_3 bunt studies, 140 seeds of the same lines as were studied for awnedness, kernel smoothness, and kernel length were planted in duplicate rows of 70 seeds each. Seed for one of the duplicate rows of each line was inoculated with race T-11 of _T. tritici_ and the other with race L-3 of _T. levis_ by shaking an excess of the spores and the seed together in a small paper envelope. One row of each parent and a susceptibel check, Ulka, were inoculated in the same manner and included after every 15 rows of progeny. Also, F_2 populations of each family were inoculated with each of the physiologic races of bunt used and grown adjacent to the F_3 lines in order to compare the bunt reaction of both the F_2 and F_3 generations in the same year. One hundred forty seeds of each family were inoculated with each bunt race.

EXPERIMENTAL RESULTS

Awnedness

The F_2 generation consisting of six families of from 94 to 108 plants each were studied in the laboratory and classified for awnedness. The breeding behavior of each family and 68 plants of Ceres-(Hope-Florence) and 98 plants of Renown are given in Table I. The progeny were classified into three breeding groups, namely: (1) true breeding weakly awnletted types, (2) true breeding fully awned types, and (3) apically awnletted types which segregated for all three classes. The parents were homozygous and clear cut for their respective awn types and no questionable types were found. In the progeny, 24 questionable types were found which could not be definitely placed in either the 3- or 3+ class. They appeared as intergrades between these two classes. These were grown in the F_3 and found to be all breeding true and weakly awnletted except three which were segregating and classified as strongly awnletted. Of the 240 F_3 rows grown at Bozeman and Moccasin, only two lines bred different than was expected from the F_2 classification.

Out of 621 plants classified in the F_2 and corrected according to their F_3 breeding behavior, as given in Table I, 156 were found to be weakly awnletted (3-), 136 fully awned (5), and 329 apically awnletted (3+). These data indicate a close fit to a 1:2:1 ratio which may be explained by a single major-factor difference with the awnletted condition being incompletely dominant to the fully awned condition.

Table I The classification of parents and F_2 plants for awnedness corrected on the basis of F_3 breeding behavior of questionable types in a cross of Ceres-(Hope-Florence) with Renown grown at Bozeman in 1939 and at Bozeman and Moccasin, Montana in 1940

Ceres-(Hope-Florence) x Renown Family and plant number	Total number of plants in each family	Number of quentionable 3- or 3+ awn types	F_3 classification of F2 questionable types		Number of plants after F_3 correction having awn type		
			3-	3+	3-	3+	3%
Row-26 Plant-4	98	8	7	1	25	52	21
Row-26 Plant-8	108	4	4	0	18	58	28
Row-2 Plant-11	94	4	3	1	22	49	23
Row-26 Plant-9	104	6	5	1	27	51	26
Row-23 Plant-7	111	0	0	0	31	61	19
Row-2 Plant-2	106	2	2	0	27	58	19
Total	621	24	21	3	156	329	136
Renown C.I. 11709	98				98		
Ceres-(Hope-Florence) C.I. 11872	68						68

The calculation of chi-square for goodness of fit to a 1:2:1 ratio of the 621 F_2 plants, as given in Table II, shows the observed number to be very close to the expected. The P value for goodness of fit between the observed and calculated data is between 0.90 and 0.80.

Table II Calculation of Goodness of Fit to a 1:2:1 monohybrid ratio for awnedness from a Ceres-(Hope-Florence) x Renown cross grown at Bozeman in 1939 and at Bozeman and Moccasin, Montana in 1940

F_2 classes based on breeding behavior of F_3	Observed	Calculated on one factor difference	o-c	$(o-c)^2$	$\frac{(o-c)^2}{c}$
Weakly awnletted (3-)	156	155	1	1	0.008
Strongly awnletter ( )	329	311	18	324	1.042
Fully awned (5)	136	155	-19	361	2.329
Total	621	621		X^2 =	3.477

Degrees of freedom = 2

P = between 0.90 and 0.80

Kernel Smoothmess

Since the parental varieties of the Ceres-(Hope-Florence) x Renown cross differed in degree of roughness and pittedness of seed, an attempt has been made to discover the mode of inheritance of this character.

Six F_2 families consisting of 635 plants were classified into eight groups according to these characteristics: degree of roundness or angularity of cheeks, depth and width of crease, and degree of pittedness.

The classification of the F_2 and parent material is given in Table III. Assuming from an analysis of the F_2 and parent data that class 5 in the breaking point or intermediate class between the rougher and smoother types, approximately one-half of the progeny approaches a likeness of the smoother Renown parent and one-half like the rougher Ceres-(Hope-Florence) parent. This is also true of five of the F_2 families when considered individually. However, one of the F_2 families (R2P2) had a greater percentage of plants resembling the rougher parent type and more nearly approzches a 3:1 than a 1:1 ratio.

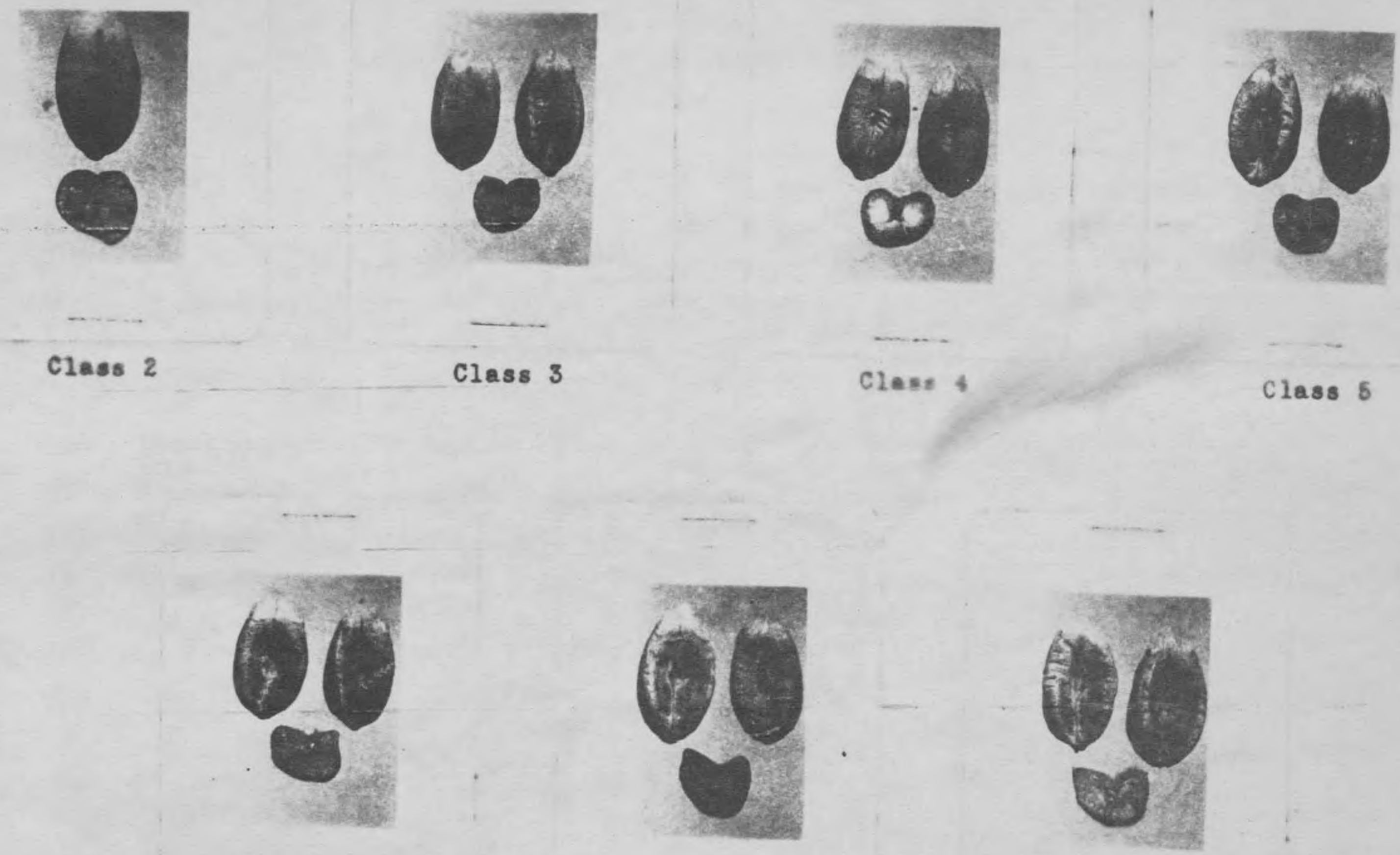
Table III Classification into kernel smoothness classes of parents and F_2 progeny from a cross of Ceres-(Hope-Florence) with Renown grown at Bozeman, Montana in 1939

Kernel smoothness classes	Parents		F_2 progeny						F_2 Total
	Renown	C.H.F.	R26P8	R26P9	R23P7	R23P14	R2P2	R2P11	
2	6		3		4	3	7		17
3	41		10	15	30	15	24	4	98
4	29	3	27	28	33	28	23	7	146
5	14	6	24	15	17	23	19	13	111
6	6	23	20	31	15	21	24	33	144
7		24	16	13	9	9	4	28	79
8		13	6	5	4	4		9	28
9		1	2	3	2	1	2	2	12
Total	96	70	108	110	114	104	103	96	635

Photographs of the class ranges of kernel smoothness found in the F_2 are included in Figure 1. The Renown parent resembles those types in classes, 2, 3, and 4 with the greater frequency of class 3 and the Ceres-(Hope-Florence) parent more nearly resembles those in classes 6, 7, and 8 with a greater frequency of class 7.

In the F_3, three of the F_2 families were studied--R26P9 grown at bozeman and R2P2 and R2P11 grown At Moccasin, Montana. A complete classification of each F_2 line and F_3 plants of these lines, and of each parent is given in Table IV. A comparison of the standard deviation of the parents grown with the F_2 at Bozeman in 1939 and with the F_3 at Bozeman and Moccasin in 1940 are as follows: Bozeman 1939, Renown 3.7±1.0; Ceres-(Hope-Florence) 6.7±1.1; Bozeman 1940, Renown 3.8±1.2; Ceres-(Hope-Florence) 5.6±1.5; Moccasin 1940, Renown 3.2±1.0; Ceres-(Hope-Florence) 6.8±0.97. The deviations of the 1939 Bozeman parents and the 1940 Moccasin parents are very similar, whereas the 1940 Bozeman parents have a much larger standard deviation and, thus, much more variable in their range of classification. Unforseen complications in the environmehtal conditions are probably the main causes of this greater variability.

Grouped class summaries of the breeding behavior of the three F_2 families studied in the F_3 are given in Table V. Grouped classes were also determined by the probable error of the parents but the group method as used in Table V seemed more satisfactory since fractional numbers as classes were avoided and the line segregations in the F_3 fell more easily and definitely into the 2, 3, and 4; 4, 5, and 6; and 6, 7, and 8 groups. Both grouping methods illustrated approximately the same segregational



Class 2

Class 3

Class 4

Class 5

Class 6

Class 7

Class 8

Figure 1 Range of kernel smoothness found in the F_2 of a cross between Ceres-(Hope-Florence) and Renown

Table Iv The classification of parents and progeny from a cross of Ceres-(Hope-Florence) with Renown for awnedness and kernel smoothness in F2 lines grown at Bozeman in 1939 and F3 lines grown at Bozeman and Moccasin, Montana in 1940

Parent or progeny	1940 row No.	F3 line No.	Awnedness: Parent or F2 phenotype	Awnedness: Parent or F3 genotype	Parent and F2 classification	Kernel smoothness classes, Parents and F3, No. of plants: 2	3	4	5	6	7	8	9	Mean
			Bozeman											
Ceres-(Hope-Florence)C. I.11872	3003	3-5-24	5	5	7		6	7	4	3				4.2
do	3029	3-5-21	5	5	7			4	2	5		1	1	5.6
do	3065	3-5-22	5	5	8				1	3	7	5	4	7.4
do	3083	3-5-23	5	5	8			1	4	7	5	3		6.3
do	3101	3-5-22	5	5	8				3	9	7	1		6.3
do	3119	3-5-21	5	5	7		2	6	8	4				4.7
do	3137	3-5-24	5	5	7		1	3	5	6	5			5.6
do	3155	9-8-28	5	5	7			6	7	4	3			5.2
do	3158	988-7	5	5	6			2	4	10	4			5.8
Renown C.I. 11709	3027	7-10-3	3-	3-	3	8	6	5	2					3.2
do	3045	7-10-2	3-	3-	3	8	9	1	2					2.9
do	3063	1-6-24	3-	3-	4			9	4	5				4.8
do	3081	1-6-24	3-	3-	4	3	8	5	4					3.5
do	3099	7-10-1	3-	3-	2	5	7	6	2					3.3
do	3117	7-10-1	3-	3-	2	16	4							2.3
do	3135	7-10-2	3-	3-	3		7	5	5	3				4.2
do	3153	7-10-5	3-	3-	4			9	10	1				4.6
do	3156	7-10-7	3-	3-	3			7	9	4				4.9
Cross	3031	26-9-17	3-	3-	3		4	8	5	2	1			4.4
do	3048	26-9-31	5	5	3	4	5	7	3	1				3.6
do	3087	26-9-64	3-	3-	3		1	3	6	3	6	1		5.1
do	3106	26-9-80	5	5	3	1	4	7	7	1				4.2
do	3115	26-9-89	3+	3+	3		6	7	3	4				4.3
do	3132	26-9-103	3+	3+	3			4	6	8	2			5.4
do	3143	26-9-143	3+	3+	3		1	1	1	4	1	5	7	7.3
do	3092	26-9-69	3-	3-	4	1		1	1	4	6	7		6.7

Table IV (continued)

Parent or progeny	1940 row No.	F3 line No.	Awnedness Parent or F2 pheno- type	Awnedness Parent or F3 geno- type	Parent and F2 classi- fication	Kernel smoothness classes Parents and F3 No. of plants 2	3	4	5	6	7	8	9	Mean
Cross [illegible]	3095	26-9-72	5	5	4		5	3	6	6				4.7
do	3096	26-9-73	5	5	4		2	5	6	6	1			4.9
do	3102	26-9-76	5	5	4			1	5	10	3	1		5.9
do	3098	26-9-75	5	5	4			4	7	6	3			5.4
do	3113	26-9-87	5	5	4	4	6	4	5	1				3.7
do	31122	26-9-93	3+	3+	3		1	6	9	2	1	1		5.0
do	3130	26-9-101	3+	3+	4		1	3	6	7	3			5.4
do	3131	26-9-102	3+	3+	4		5	2	7	6				4.7
do	3142	26-9-110	3+	3+	4	2	4	6	6	2				3.9
do	3144	26-9-112	3+	3+	4				2	8	7	2	1	6.6
do	3145	26-9-113	3+	3+	4				6	9	5			6.0
do	3146	26-9-114	3+	3+	4			2	2	9	6	1		6.1
do	3147	26-9-115	3+	3+	4			1	1	4	6	6	2	7.1
do	3086	26-9-63	3+	3-	5				3	6	8	2	1	6.6
do	3090	26-967	3-	3-	5		2	9	5		2	1	1	4.9
do	3106	26-9-80	5	5	5			2	7	5	5	1		5.8
do	3107	26-9-81	5	5	5	3	7	7	3					3.6
do	3127	26-9-98	3+	3+	5		5	8	3	4				4.3
do	3150	26-9-118	3+	3+	5			2	4	6	7	1		6.0
do	3139	26-9-107	3+	3+	5		1	1	2	6	4	6		6.5
do	3084	26-9-61	3-	3-	6				5	2	5	5	2	6.6
do	3085	26-9-62	3-	3-	6			1	1	10	4	4		6.5
do	3088	26-9-65	3-	3-	6				1	3	6	4	6	7.5
do	3091	26-9-68	3-	3-	6		3	5	5	4	1	1	1	5.1
do	3097	26-9-74	5	5	6			5	4	6	4	1		5.6
do	3104	26-9-78	5	5	6	1	2	9	7	1				4.3
do	3105	26-9-79	5	5	6	1	10	6	3					3.6
do	3109	26-9-83	5	5	6	2	8	7	3					3.6
do	3110	26-9-84	5	5	6	4	2	7	4	3				4.0

Table IV (continued)

Parent or progeny	1940 row No.	F3 line No.	Awnedness Parent or F2 phenotype	Awnedness Parent or F3 genotype	Parent and F2 classification	Kernel smoothness classes Parents and F3 No. of plants 2	3	4	5	6	7	8	9	Mean
			Bozeman											
Cross	3111	26-9-85	5	5	6	5	8	3	3	1				3.3
do	3116	26-9-90	3+	3+	6		1	4	7	6	1	1		5.3
do	3121	26-9-92	3+	3+	6	1	1	5	6	5	2			4.9
do	3123	26-9-94	3+	3+	6			9	5	4	1			4.7
do	3124	26-9-95	3+	3-	6	2	4	9	3	2				4.0
do	3126	26-9-97	3+	3+	6		1		7	7	3	2		5.9
do	3133	26-9-104	3+	3+	6			3	5	6	4	2		5.9
do	3138	26-9-106	3+	3+	6				2	5	3	7	3	7.2
do	3141	26-9-109	3+	3+	6				2	2	4	5	7	7.7
do	3149	26-9-117	3+	3+	6			2	2	6	7	3		6.4
do	3151	26-9-119	3+	3+	6		1		2	3	7	4	3	7.0
do	3089	26-9-66	3-	3-	7					4	6	7	3	7.5
do	3094	26-9-71	3-	3-	7			1	2	5	7	3	2	6.8
do	3103	26-9-77	5	5	7	1	8	7	4					3.7
do	3104	26-9-78	5	5	7				1	5	2	7	5	7.5
do	3112	26-9-86	5	5	7			1	5	8	6			6.0
do	3114	26-9-88	5	5	7		1	6	11	2				6.7
do	3148	26-9-116	3+	3+	7				5	7	6	1	1	6.3
do	3152	36-9-120	3+	3+	7				4	3	7	3	2	6.7
do	3093	26-9-70	3-	3-	8		3	4	3	5	4	1		5.3
do	3108	26-9-82	5	5	8		1	3	7	8	1			5.3
do	3125	26-9-96	3+	3+	8		1	7	7	4	1			4.9
			Moccasin											
Ceres-(Hope-Florence)C.I.11872	4003	9-8-28	5	5	7					2	7	1		6.9
do	4029	9-8-27	5	5	8			2	3	3	2			5.5
do	4047	9-8-29	5	5	7				1	1	3	5		7.2
do	4065	9-8-27	5	5	8					1	6	3		7.2

Table IV (contineued)

Parent or progeny	1940 ROW No.	F3 line No.	Awnedness: Parent or F2 phenotype	Awnedness: Parent or F3 genotype	Parent and F2 classification	Kernel smoothness classes, Parents and F3, No. of plants: 2	3	4	5	6	7	8	9	Mean
Ceres x(Hope-Florence)C.I.11872	4083	3-5-26	5	5	7					6	3	1		6.5
do	4101	3-5-26	5	5	7					1	5	3		7.2
do	4119	3-5-25	5	5	6					2	5	3		7.1
do	4137	3-5-25	5	5	6					3	3	4		7.1
do	4155	9-8-29	5	5	7				2	4	3	1		6.3
Renown C.I.11709	4001	1-6-25	3-	3-	3	1	2	2	3	2				4.3
do	4027	1-6-26	3-	3-	3	3	5	1	1					3.0
do	4045	1-6-25	3-	3-	2	9	1							2.1
do	4063	1-6-26	3-	3-	4		5	1	3	1				4.0
do	4081	1-6-27	3-	3-	4	3	4	1	21	1				3.5
do	4099	1-6-27	3-	3-	3	1	5	3	1					3.4
do	4117	1-6-28	3-	3-	3	2	1	3	4					4.9
do	4135	1-6-28	3-	3-	4	5	3	2						2.7
do	4153	7-10-4	3-	3-	2	6	4							2.4
Cross	4022	2-2-11	3-	3-	2			1	3	4	1			5.2
do	4057	2-2-42	3+	3+	2	1	3	2		4				4.1
do	4059	2-2-44	3+	3+	2			9	1					4.1
do	4060	2-2-45	3+	3+	2					3	5	2		6.9
do	4067	2-2-49	3+	3+	2			4	3	2	1			5.0
do	4012	2-2-1	3-	3-	3			1	4	4		1		5.6
do	4014	2-2-3	3-	3-	3			1	3	4	2			5.7
do	4015	2-2-4	3-	3-	3			3	4	2	1			5.1
do	4018	2-2-7	3-	3-	3				2	2	3	3		6.7
do	4020	2-2-9	3-	3-	3		1	1	3	5				2.5
do	4032	2-2-20	3-	3-	3	1	3	3		2	1			4.2
do	4035	2-2-23	3+	3+	3	3	6		1					2.9
do	4044	2-2-32	3+	3+	3	1	5	1	2	1				3.8
do	4049	2-2-34	3+	3+	3		1	2	2	4	1			5.3
do	4050	2-2-35	3+	3+	3			1	5	1	3			5.8

Table IV (continued)

parent or progeny	1940 row No.	F3 line No.	Awnedness Parent or F2 pheno-type	Awnedness Parent or F3 geno-type	Parent and F2 classi-fication	Kernel smoothness classes, Parents and F3, No. of plants: 2	3	4	5	6	7	8	9	Mean
Cross	4056	2-2-41	3+	3+	3				4	5				5.5
do	4061	2-2-46	3+	3+	3		1	1	4	4				5.1
do	4062	2-2-47	3+	3+	3			1	3	5	1			5.6
do	4066	2-2-48	3+	3+	3		1	1	1	4	2	1		5.8
do	4075	2-2-57	5	5	3	1		4	5					4.3
do	4077	2-2-59	5	5	3			3	4	2	1			5.2
do	4030	2-2-18	3-	3-	4	1	5	2	3					3.7
do	4031	2-2-19	3-	3-	4	3	6		1					2.9
do	4033	2-2-21	3+	3+	4	1	3	2	3	1				4.0
do	4034	2-2-22	3+	3+	4		4	1	4	1				4.2
do	4036	2-2-24	3+	3+	4	3	4	3						3.0
do	4039	2-2-27	3+	3+	4	2		1	2	2		1	2	6.5
do	4040	2-2-28	3+	3+	4		3	2	2	1	1	1		4.8
do	4041	2-2-29	3+	3+	4	2	5	1	2					3.3
do	4052	2-2-37	3+	3+	4			1	3	2	2	2		6.1
do	4058	2-2-43	3+	3+	4				1	3	2	3	1	7.0
do	4069	2-2-51	3+	3+	4			2	4	4				6.0
do	4073	2-2-55	5	5	4				1	4	3	2		6.6
do	4074	2-2-56	5	5	4	2	4	3	1					3.3
do	4076	2-2-58	5	5	4				1	5	3	1		6.4
do	4080	2-2-13	3-	3-	4			1	3	3	2	1		5.9
do	4102	2-11-16	5	5	4				2	5	3			6.1
do	4114	2-11-28	3-	3-	4					2	4	4		7.2
do	4120	2-11-31	3-	3-	4				1	2	5	2		6.8
do	4025	2-2-16	3-	3-	5	2	3		2	3				4.1
do	4038	2-2-26	3+	3+	5		1	5			3	1		5.2
do	4043	2-2-31	3+	3+	5		3	2	4	1				4.3
do	4054	2-2-39	3+	3+	5				2	5	3			6.1
do	4055	2-2-40	3+	3+	5		1			7	2			5.9

Table IV (contineud)

Parent or progeny	1940 row No.	F3 line No.	Awnedness Parent or F2 pheno-type	Awnedness Parent or F3 geno-type	Parent and F2 classi-fication	Kernal smoothness classes Parents and F3 No. of plants 2	3	4	5	6	7	8	9	Mean
Cross	4068	2-2-50	3+	3+	5					9	1			6.1
do	4071	2-2-53	5	5	5	1		2	6	1				4.3
do	4072	2-2-54	5	5	5			1	5	4				5.3
do	4086	2-11-3	5	5	5				1	6	3			6.2
do	4087	2-11-4	5	5	5		1	1	3	5				5.2
do	4090	2-11-7	5	5	5			3	4	1	2			5.2
do	4093	2-11-10	5	5	5				3	4	1	2		6.2
do	4106	2-11-20	3-	3-	5					2	4	3	1	7.3
do	4116	2-11-30	3-	3-	5				2	1	3	4		6.9
do	4121	2-11-32	3-	3-	5			2		3	3	2		6.3
do	4131	2-11-42	3+	3+	5				1	5	3	1		6.5
do	4132	2-11-43	3+	3+	5				3	1	2	3	1	6.8
do	4141	2-11-49	3+	3+	5				4	6				5.6
do	4148	2-11-56	3+	3+	5				2	4	2	1		6.2
do	4152	2-11-60	3+	3+	5			3	4	3				5.0
do	4016	2-2-5	3-	3-	6					3	6	1		6.8
do	4017	2-2-6	3-	3-	6					2	4	4		7.2
do	4019	2-2-8	3-	3-	6				3	5	1	1		6.0
do	4021	2-2-10	3-	3-	6				1	4	3	2		6.6
do	4023	2-2-14	3-	3-	6			2	1	1	3	3		6.4
do	4024	2-2-15	3-	3-	6		2	1	1	2	4			5.6
do	4026	2-2-17	3-	3-	6	1	1	3	2	2				4.3
do	4037	2-2-25	3+	3+	6	1	1	1	2	3		2		5.3
do	4042	2-2-30	3+	3+	6	1	3	3	3					3.8
do	4048	2-2-33	3+	3+	6	1	5	1	1	1	1			3.9
do	4053	2-2-38	3+	3+	6					1	3	6		7.5
do	4070	2-2-52	5	5	6				3	3	4			7.3
do	4978	2-2-60	5	5	6				1	2	4	3		6.9
do	4079	2-2-12	3-	3-	6					2	5	3		7.1

Table IV (continued)

Parnet or progeny	1940 row No.	F3 line No.	Awnedness Parnet or F2 pheno type	Awnedness Parnet or F3 geno type	Parent and F2 classification	Kernel smoothness classes, Parents and F3, No. of plants: 2	3	4	5	6	7	8	9	Mean
Cross	4084	2-11-1	5	5	6		1	1	5	3				5.0
do	4085	2-11-2	5	5	6			1	4	4	1			5.5
do	4091	2-11-8	5	5	6			1	4	3	2			5.6
do	4092	2-11-9	5	5	6			3	3	2	3			5.3
do	4097	2-11-14	5	5	6				1	3	2	4		6.9
do	4105	2-11-19	3-	3-	6				2	5	3			6.1
do	4107	2-11-21	3-	3-	6				6	3	1			5.0
do	4111	2-11-25	3-	3-	6			1	2	4	2	1		6.0
do	4124	2-11-35	3+	3+	6					2	5	3		7.1
do	4126	2-11-37	3+	3+	6						6	4		7.4
do	4127	2-11-38	3+	3+	6				3	5	2			5.9
do	4133	2-11-38	3+	3+	6					1	5	3	1	7.4
do	4142	2-11-50	3+	3+	6				5	4	1			5.6
do	4146	2-11-54	3+	3+	6					1	7	1	1	7.2
do	4147	2-11-55	3+	3+	6				2	2	6			6.4
do	4149	2-11-57	3+	3+	6			2	2	3	2	1		5.8
do	4151	2-11-59	3+	3+	6			1	2	5	2			5.8
do	4013	2-2-2	3-	3-	7			1	2	4	2	1		6.0
do	4051	2-2-36	3+	3+	7		2	2	1	2	1	2		5.2
do	4094	2-11-11	5	5	7				3	3	4			6.1
do	4096	2-11-13	5	5	7				4	4	2			5.8
do	4098	2-11-15	5	5	7				1	6	2	1		6.3
do	4103	2-11-17	5	5	7					5	5			6.5
do	4108	2-11-22	3-	3-	7			1		6	1	1		6.1
do	4109	2-11-23	3-	3-	7			1		3	1	5		6.9
do	4113	2-11-27	3-	3-	7			1	1	6	2			5.9
do	4115	2-11-29	3-	3-	7						3	6	1	7.8
do	4122	2-11-33	3+	3+	7				2	3	3	2		6.5
do	4123	2-11-34	3+	3+	7			2	2	3	2	1		5.8

Table IV (contineued)

			Awnedness Parent or			Kernel smoothness classes Parents and F3 No. of plants								
Parent or progeny	1940 row No.	F3 line No.	F2 pheno-type	F3 geno-type	Parent and F2 classi-fication	2	3	4	5	6	7	8	9	Mean
Cross	4125	2-11-36	3+	3+	7				3	5	2			5.9
do	2128	2-11-39	3+	3+	7				3	1	2	4		6.7
do	4129	2-11-40	3+	3+	7					2	3	5		7.3
do	4134	2-11-45	3+	3+	7				2	8				5.8
do	4140	2-11-48	3+	3+	7					4	5	1		6.7
do	4143	2-11-51	3+	3+	7			2		3	5	1		6.5
do	4145	2-11-53	3+	3+	7				1	3	5	1		6.6
do	4150	2-11-58	3+	3+	7			1	2	1	4	2		6.4
do	4088	2-11-5	5	5	8			1	4	5				5.3
do	4095	2-11-12	5	5	8			2	1	5	1		1	5.9
do	4104	2-11-18	5	5	8						5	5		7.5
do	4110	2-11-24	3-	3-	8				4	2	3			5.7
do	4112	2-11-26	3-	3-	8					2	5	3		7.1
do	4139	2-11-47	3+	3+	8				2	6	2			6.0
do	4130	2-11-41	3+	3+	9			1	2	2	2	1	2	6.6

Table V Classification of parents, F2, and F3 for kernel smoothness. (F3 progeny placed into the group of greatest frequency)

Family R26P9 - Bozeman

F3	F2 classes for kernel smoothness								
groups	2	3	4	5	6	7	8	9	Total
2-3-4			1	1	5	1			8
4-5-6		4	9	3	8	2	3		29
6-7-8		1	3	4	7	5			20
Grand total									57

Family R2P2 - Moccasin

F3	F2 classes for kernel smoothness								
groups	2	3	4	5	6	7	8	9	Total
2-3-4	1	2	6		2				11
4-5-6	3	13	5	5	3	2			31
6-7-8	1	1	4	3	9				18
Grand total									60

Family R2P11 - Moccasin

F3	F2 classes for kernel smoothness								
groups	2	3	4	5	6	7	8	9	Total
2-3-4									
4-5-6				4	10	4	4		22
6-7-8			3	8	7	13	4		35
Grand total									57

Parents- Bozeman

F3	Kernel smoothness classes									
groups	2	3	4	5	Total	6	7	8	9	Total
		Renown						C. H. F.		
2-3-4	2	3			4					
4-5-6		2	3		5		6			6
6-7-8								3		3
Grand total					9					9

Parents - Moccasin

F3	Kernel smoothness classes									
groups	2	3	4	5	Total	6	7	8	9	Total
		Renown						C.H.F.		
2-3-4	2	2	3		7					
4-5-6		2			2			1		1
6-7-8						2	5	1		8
Grand total					9					9

trends of the progeny. The F_3 lines were placed in the groups according to their greatest respective frequencies.

Since there was more variation in the parental material at Bozeman than at Moccasin, it was expected that there should be a greater variation in the progeny. This analogy seems to be true, because the F_3 lines at Bozeman apparently segregated less definite in regards to the expected from the F_2 classification than the Moccasin F_3 material. Family R26P9 which was grown at Bozeman does not seem to approach any definite heritable ratio. Some segregation for every F_3 group occurred in all F_2 classes with a dominance of the rougher types seemingly apparent. In family R2P2 which was grown at Moccasin, the F_2 was classified mostly into classes 2, 3, 4, 5, and 6. The greater percentage of the F_2 smoother types segregated into the smoother classes in the F_3 and the F_2 rougher types had the greatest percentage segregating into the rougher classes. Again, a dominance of the rougher types seems to be evident, since 48 F_3 lines segregated into groups 4, 5, and 6, and 6, 7, and 8, and only 11 were placed in group 2, 3, and 4. The second F_2 family, R2P11, which was grown at Moccasin in the F_3 had a mojority of its plants fall into the roughter class in the F_2. In the F_3 no segregates were found in the 2, 3, and 4 smooth group. Of the 57 lines classified, 22 fell into the 4, 5, and 6 group and 35 into the 6, 7, and 8 group. This again illustrates a dominance of the rougher types.

Several methods of grouping were tried but no plausible fit to a one- or two-factor ratio was obtained. It seems evident that if one or two factors would explain the difference between smoothness and roughness,