THE RELATIONSHIP OF SPIKE DRYING RATE AND GRAIN COLOR IN BARLEY

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THESIS

ABSTRACT

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By

John Barnard

Sampling of twelve barley lines indicated varietal differences in grain color at harvest. The two-row lines gave the better colored grain. Within the six-row lines the lax spikes, i.e., the spikes with the longer internodes, tended to produce less discolored grain.

Six types of barley spike, selected for visual differences in shape and form, were collected and dried in the laboratory at room temperature. Computed 'drying indices' were tested for association with grain color as determined from field collections of the same lines taken at harvest. A significant correlation was observed between final grain color and drying index. Spikes from the two-row barleys were observed to possess the lower drying indices, indicating that they dried faster than the six-row. In one of the six-row lines, drying rate and internode length were correlated.

It was concluded that spike drying rate was associated with structure and that the faster drying spike tended to produce the less discolored grain.

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INTRODUCTION

Grain color is an important quality in malting barley since it is an indicator of microfloral contamination. Microbial contamination has been shown to be responsible for a number of undesirable qualities in malt and malt products.

The relationship of poor barley color, variously termed as 'staining,' 'weathering' and 'scabbing,' to high humidity environments is apparent from the literature. It has been suggested that spike morphology might be one of the factors determining the moisture environment of unthreshed grain. In particular, the more streamlined two-row spike might dry faster than the aerodynamically more complex six-row. If differences in spike drying do occur, then it is possible that such differences will explain, to some degree, intervarietal differences in grain color at harvest.

In the present thesis, spike morphology and its effect on drying is studied. The postulated effect of spike drying rate on grain color is examined.

LITERATURE REVIEW

The literature pertaining to the etiology of grain color was reviewed and the industrial significance of discolored barley was briefly examined. The importance of high humidity as an environmental prerequisite of grain discoloration led to a consideration of factors affecting moisture loss in the small grain spike.

1. Grain color formation

Grain color is a function of genotype, climate under which the grain is grown and stored, and the activity of microflora in association with the grain.

Varietal differences in kernel pigmentation were described by Harlan (1914). Differences were attributed to the varying presence, absence or combination of blue anthocyanin in the aleurone layer, red anthocyanin in the glumes and pericarp, and the degree of melanization. Hence, the 'blue grains' of the brewer can be accounted for by a blue aleurone pigmentation together with a clearing of overlying tissue during steeping.

Mullick *et al*. (1958) discuss the genetic aspects of anthocyanin pigmentation.

Of more immediate interest as a factor in the formation of color, is the 'weathering' discoloration of barley due to staining and surface molding during the latter part of the growing season. This discoloration is especially noticeable in wet seasons. Weathering discoloration appears to be a complex phenomenon that usually involves microfloral activity.

Pepper (1960) has undertaken an extensive review of the literature concerning grain discoloration in wheat and barley and the reader is directed to this work for complete literature references. Two of Pepper's own experiments will be mentioned here.

In one experiment Pepper plated grains onto agar plates inoculated with bacteria and produced severely discolored grain. Varietal differences in the location and intensity of staining were observed.

In an experiment with grain samples from diverse locations within the United States, Pepper cultured microflora present on and in the grain and recorded the relationship of a visual color score with numbers of specific organisms. Correlations calculated from Pepper's data are given in table 1. The color association with Alternaria is striking although the presence of most other microbe groups was also correlated with discoloration.

There is evidence that not all staining involves microflora. Broadfoot and Robertson (1933) isolated

Alternaria, *Cladosporium* and *Macrosporium* from glumes of Reward wheat but concluded that staining was mainly due to the interaction of light with color factors present in certain strains of the wheat.

Table 1.--Simple correlations between a visual color score and numbers of various microbes found on and in barley grains from 84 different sources.

Organism	r
Alternaria	.83 **
Helminthosporium	.49 **
Fusarium	.47 **
Cladosporium	.36 **
Bacteria	.19
Yeasts	.28 **
Storage fungi	.13
Others	.10

** sig. at P=.01

Hagborg (1936) discussed the influence of environmental factors in the browning process generally associated with certain pathogens.

Johnson and Hagborg (1944) in a greenhouse experiment with wheat, concluded that melanism could be induced by environmental conditions alone, especially high temperatures with high humidities. In their experiment, Johnson and Hagborg proceeded to demonstrate the absence of pathogens that could have been implicated as causing the browning.

Pepper (1960) discusses a possible biochemical model for the discoloration process. It is suggested that a material in the husks may be oxidized or polymerized by the environment or by interaction with certain microflora. The phenolic nature of the staining and its possible connection with disease resistance mechanisms is discussed.

From the literature, Alternaria emerges as an organism commonly associated with grain discoloration. The reduced infection by Alternaria in drier climates has been reported by Whitehead (1949). Pepper's data (1960) bears out the association of drier climates with reduced Alternaria infection and reduced grain discoloration. Johnson and Hagborg (1944), mentioned above, indicate the importance of humidity in the non-microbial discoloration process.

In conversations with S. T. Dexter it was deduced that spike morphology might affect staining by influencing the humidity of the microclimate. Differences in spike morphology might explain, to some extent, the differential staining observed between lines of barley. Grafius (1969) suggested that the success of the morphologically distinct two-row barley in Europe may, in part, be due to its more rapid drying.

2. The relevance of color to quality

The importance of grain color as a quality feature of malting barley is due to its close association with the microfloral burden on the grain.

The following listing of some of the principle effects of high levels of microflora on the brewing process is taken from a review by Anderson, Gjertsen and Trolle (1967). Some of the important effects are:

(1) More rapid uptake of water on steeping

(2) High protein modification resulting in high nitrogen wort and beer

(3) Increase in beer color

(4) Abnormal beer taste and aroma

(5) Beer from weathered barley was susceptible to gushing

Kneen (1963) in an interesting demonstration, compared a bright barley sample with two weathered ones. One of the weathered samples came from a field source; the other had weathering stimulated by treating the steeped barley with a large dose of microbial spores. Both natural and synthetic weathering gave similar results, viz., lower agtron values, increases in nitrogen modification and beer color, decrease in haze stability, and poor flavor.

3. Moisture loss in small grain spikes

Tull (1733) was probably the first to mention differences in spike drying characteristics when he remarked that awnless wheat "does not hold the drops of rain so long as the bearded (or cone) wheat."

Harlan (1923) in his examination of the water relations of barley kernels, suggested that loss of water would be impeded in those kernels which were covered by awns or overlain by other kernels.

Miller, Gauch and Gries (1944) refer to work by a number of European researchers pertaining to the role of awns in transpiration. Zoebl and Mikosch (1892) found that removal of awns from barley reduced spike transpiration by 75%. Vasilyev (1897), working with wheat, barley, rye and Stipa capillata, confirmed the conclusions of Zoebl and Mikosch. Schmid (1898) found that removal of wheat awns lowered transpiration rate by 10 to 30%.

Pool and Patterson (1958) discussed moisture relations in certain wheats. Varietal differences in rate of drying were observed after rains or dews. In a laboratory study, awns were shown to increase the magnitude of moisture losses and gains in ripe wheat stands. It was suggested that selection for awns in a breeding program would be an efficient method of obtaining faster drying varieties for humid climates. The presence of waxy glumes was shown to slow moisture changes in the grain.

EXPERIMENTAL SECTION

1. Field survey

The field survey was conducted in order to determine the degree of change of grain color, as determined by the agtron reflectance meter, with time, and to assess interline differences in color.

Materials and methods

Samples were collected from the 1969 winter barley variety trials at Hillsdale County, Michigan, and at East Lansing, Michigan. Two replicates were sampled at each location. The lines sampled were selected to obtain a range of spike conformations. Samples were taken at four weekly intervals with the fourth coinciding with harvest. The samples were dried and then submitted to the U.S.D.A. Barley and Malt Laboratory, Madison, Wisconsin, for color measurement using the agtron reflectance meter.

Eight six-row lines were taken from the plots at Hillsdale County. The same six-row lines were collected at East Lansing and in addition two two-row types were taken. The first collection of samples from Hillsdale was of insufficient size for agtron determination.

Results

Figures 1 to 4 show the time trends of color observed in the experiment. In all cases, agtron value declined with time indicating reduction in color quality. In the variety Wong and in the two-row lines some recovery was observed at the last collection. Such recovery could be real, perhaps due to environmental bleaching, but the possibility of sampling error remains.

Tables 2 and 3 show the analyses of variance for the experiment. As expected, line and collection effects were very highly significant. The significance of the interaction at East Lansing reflects the relative recovery of agtron value in Wong and the two-row barleys at the last sampling.

Within each location, lines were ranked according to final agtron value and examined for visual correlation with spike character. The results are shown in table 4.

The samples from East Lansing demonstrate a relationship between spike density, as indexed by internode length, and color. The samples from the last collection at Hillsdale were at a physiologically later stage, were all badly discolored, and no pattern was readily discernible.

At East Lansing the two-row lines produced the better colored grain. Cass, a variety currently being examined for possible malting barley production in south-western Michigan, was the superior barley with respect to

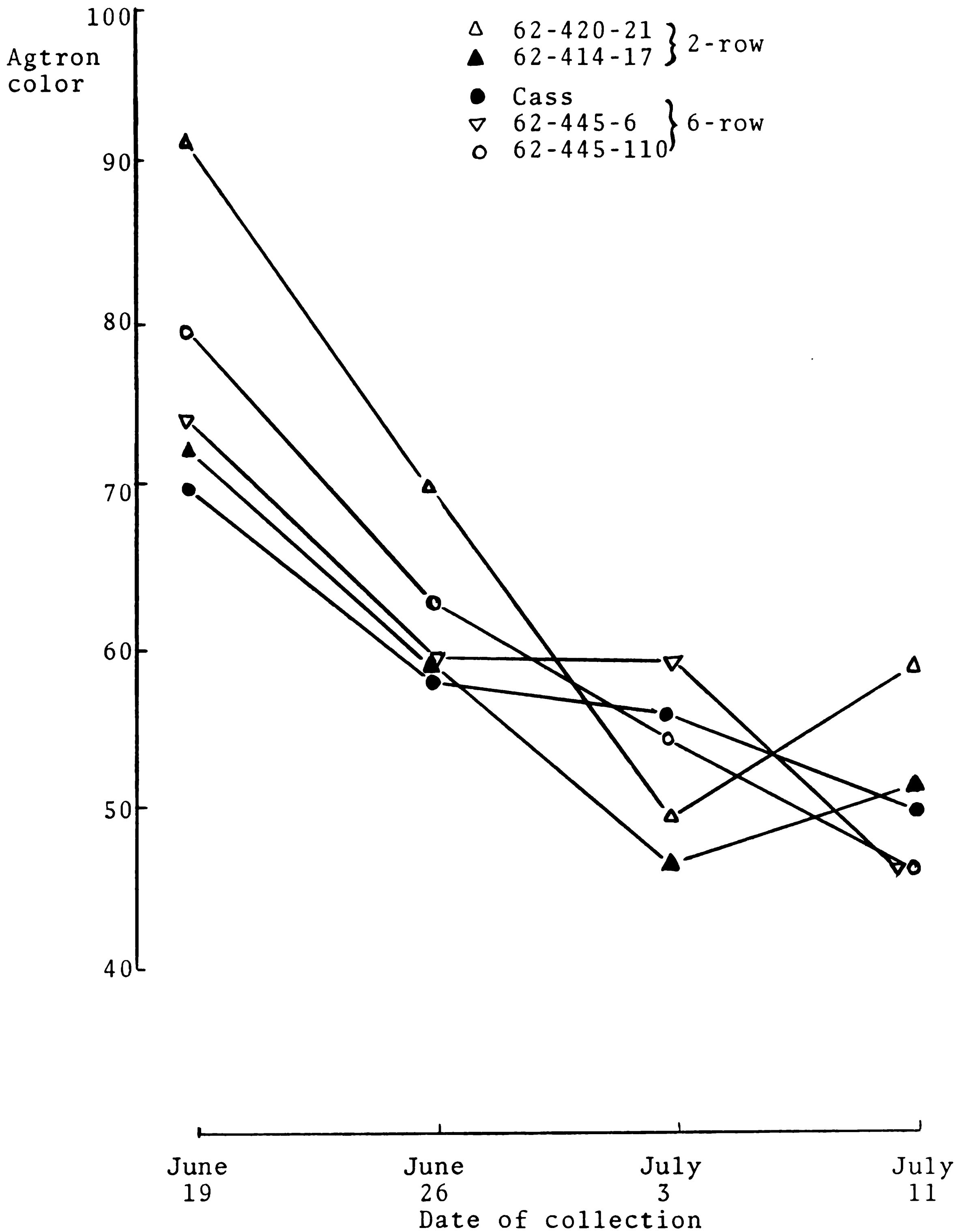


Figure 1.--The change in agtron value with time at East Lansing for the five lines giving the highest agtron values at harvest.

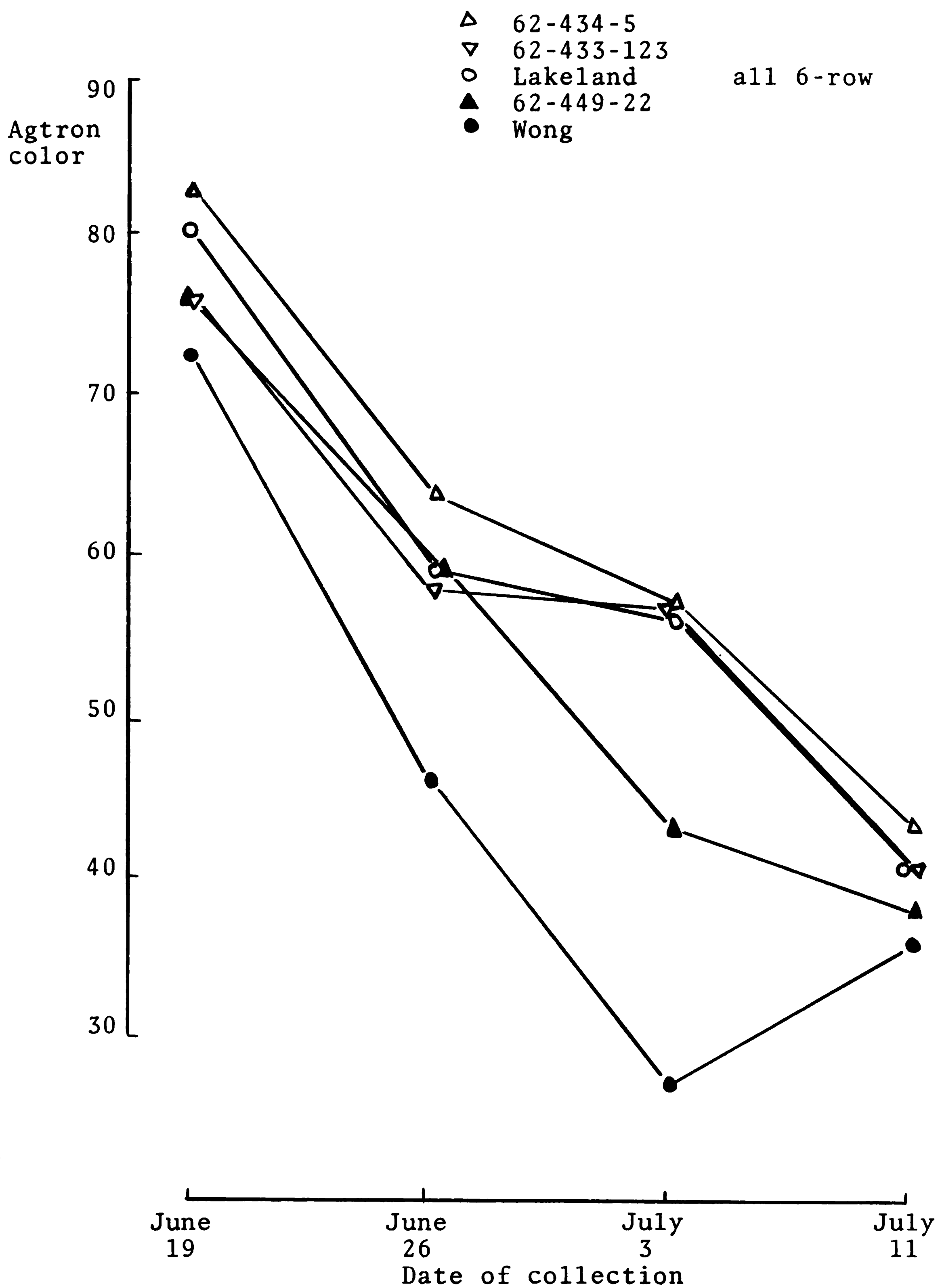


Figure 2.--The change in agtron value with time at East Lansing for the five lines giving the lowest agtron values at harvest.

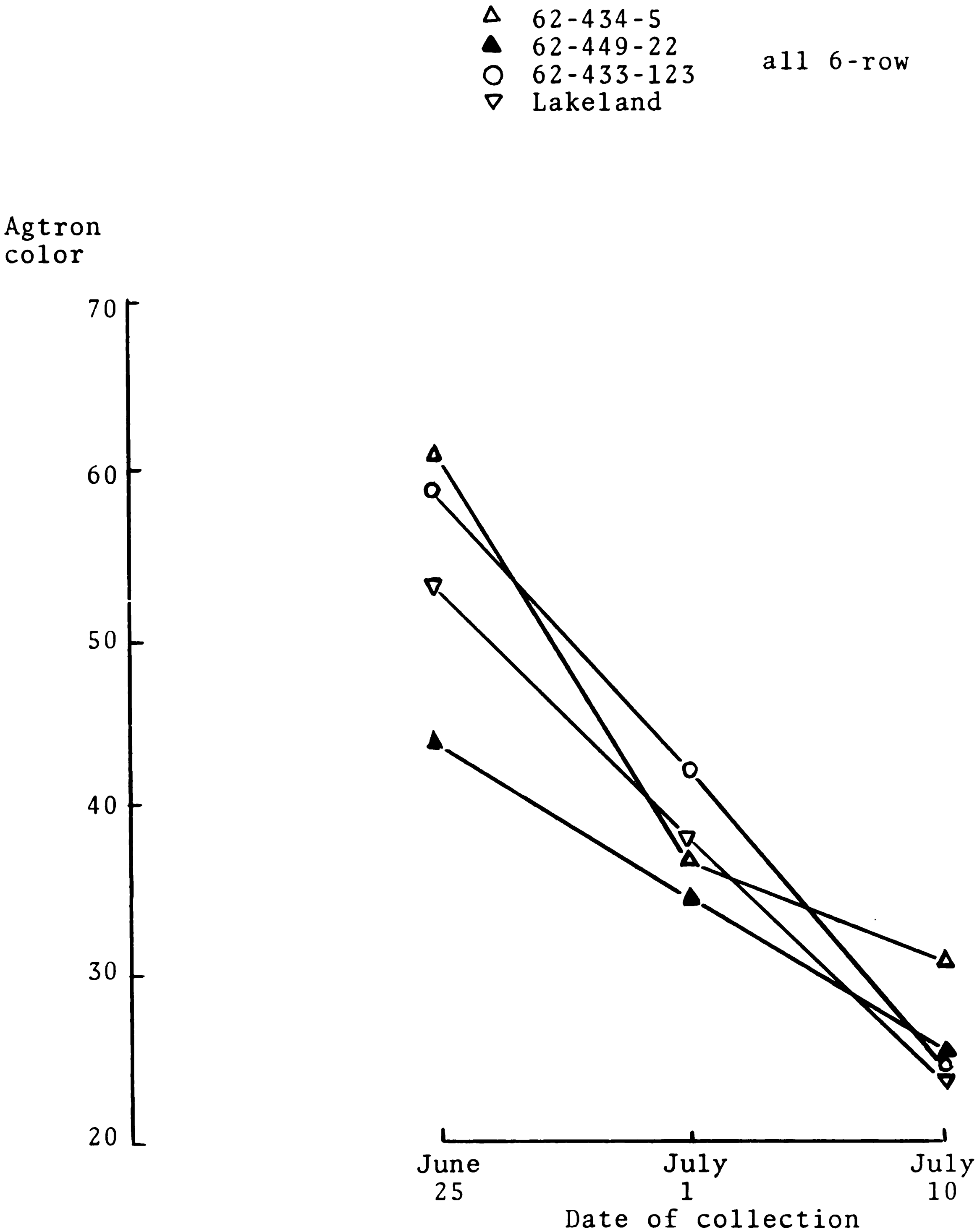


Figure 3.--The change in agtron value with time at Hillsdale County for the four lines giving the highest agtron values at harvest.

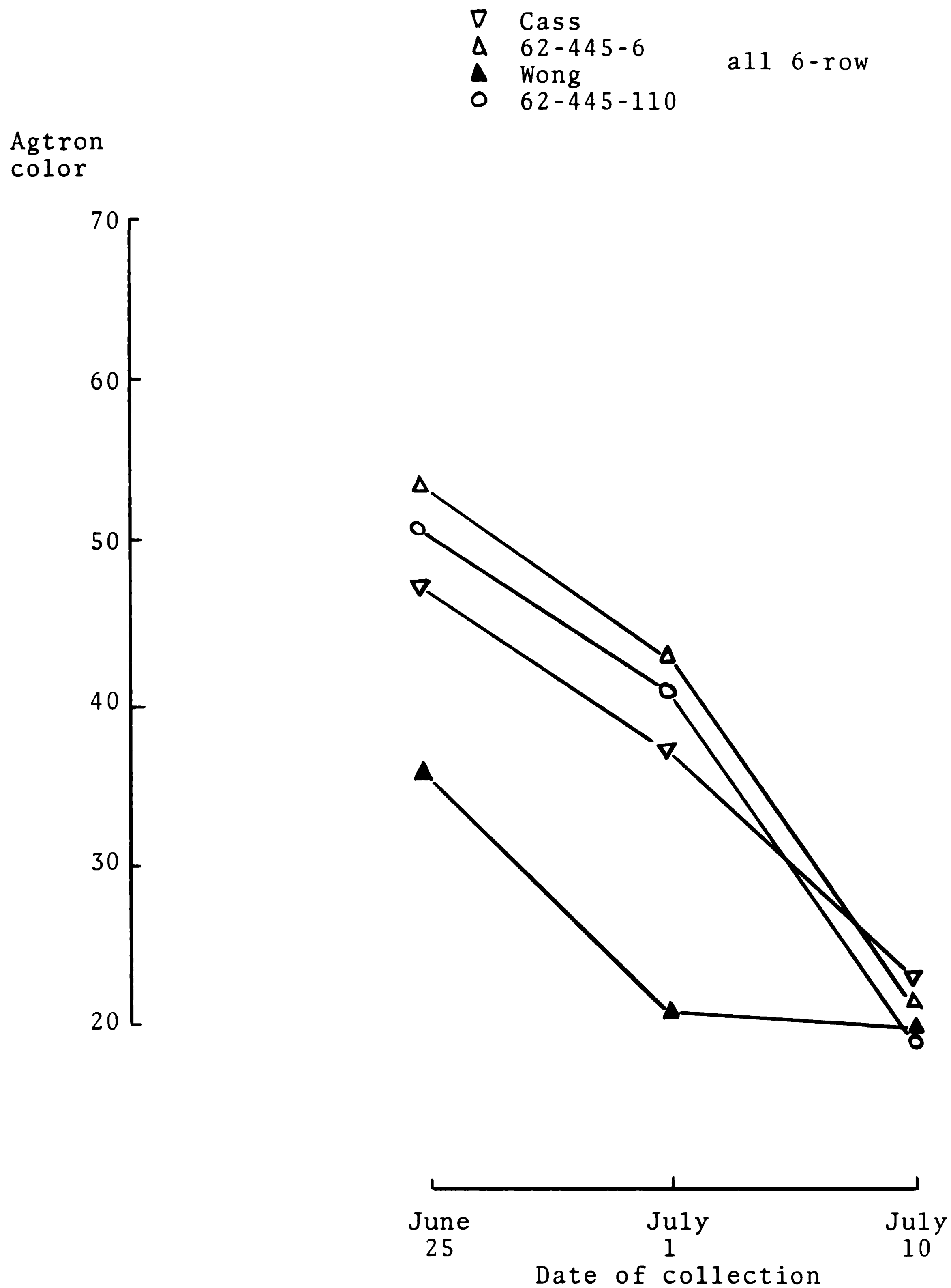


Figure 4.--The change in agtron value with time at Hillsdale County for the four lines giving the lowest agtron values at harvest.

Table 2.--Analysis of variance for the East Lansing field survey. Agtron value is the dependent variable.

Source	df	SS	MS	F
Reps	1	25.3500	25.3500	1.05
Lines	9	1558.1062	173.1229	7.19 ***
Collections	3	8496.0128	2832.3042	117.65 ***
L x C	27	1725.7548	63.9168	2.66 **
Residual	29	698.1499	24.0741	
Total	69	12503.3737		

Table 3.--Analysis of variance for the Hillsdale County field survey. Agtron value is the dependent variable.

Source	df	SS	MS	F
Reps	1	50.3809	50.3809	2.75
Lines	7	767.3809	109.6259	5.98 ***
Collections	2	5256.3809	2628.3519	143.38 ***
L x C	14	518.0889	37.0063	2.02
Residual	20	366.6190	18.3309	
Total	44	6959.1734		

*** sig at P=.001
** sig at P=.01

color. The lines with the more compact spikes, i.e., those with shorter internodes, were observed to collect at the bottom of table 4. Wong, a compact-spiked, six-row, and the only awnless barley included in the experiment, produced the poorest colored grain.

Table 4.--The relationship of agtron color at harvest to internode length and spike length.

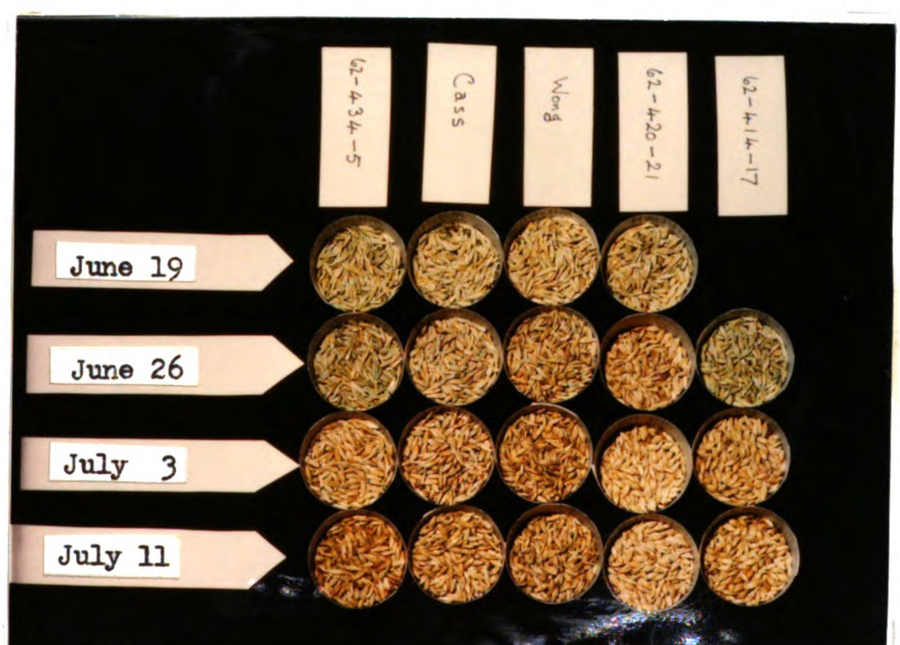
Line	Av. internode length (cm)	Av. spike length (cm)	Agtron East Lansing	Agtron Hillsdale
62-420-21]2-row			59.0	-
62-414-17]2-row			51.5	-
Cass	.81	6.5	50.0	23.0
62-445-6	.85	6.3	46.5	21.5
62-445-110	.76	6.3	46.5	19.0
62-434-5	.76	5.6	43.5	31.0
62-433-123	.76	4.7	40.5	24.5
Lakeland	.56	4.4	40.5	23.5
62-449-22	.68	4.3	38.0	25.0
Wong	.54	4.3	35.0	20.0

2. Drying experiment

The objectives of the drying experiment were to establish whether or not differences in spike drying existed between the lines examined, and to determine whether any such differences could be attributed to structural variation.

Plates 1 and 2.--The change in agtron value with time illustrated by sequential samples from one replicate at East Lansing.


62-449-22
62-445-110
Lakeland
62-445-6
62-433-123
June 19
June 26
July 3
July 11


62-434-5
Cass
Wong
62-420-21
62-414-17
June 19
June 26
July 3
July 11

The drying experiment and the field survey (experiment 1) were tied together with a correlation analysis to ascertain whether any association existed between spike drying and grain color.

Materials and methods

Twelve spikes from each of six varieties were collected from the 1969 winter barley trials at East Lansing, Michigan. The six varieties used were among those represented in the field survey (experiment 1). The spikes were detached with 8 centimeters of culm retained with the spike. The specimens were immediately transferred to the laboratory and supported on modified paper clips, affixed to a table top, to ensure free drying. The spikes were arranged in a twelve-replicate randomized block design. Additional border blocks, around the margins of the table, eliminated any edge effect. The assembly is shown in plates 3 and 4.

At intervals, individual spikes were 'unplugged' from the paper clips and weighed. A systematic order of weighing was followed to ensure that the same time interval elapsed between successive weighings of the individual spikes. Weights were taken over a period of 84 hours.

The following measurements were taken on individual spikes: spike length, number of nodes on the spike, diameter across the spike (lateral floret to lateral floret), diameter through the spike (central floret to central floret), and average awn length.

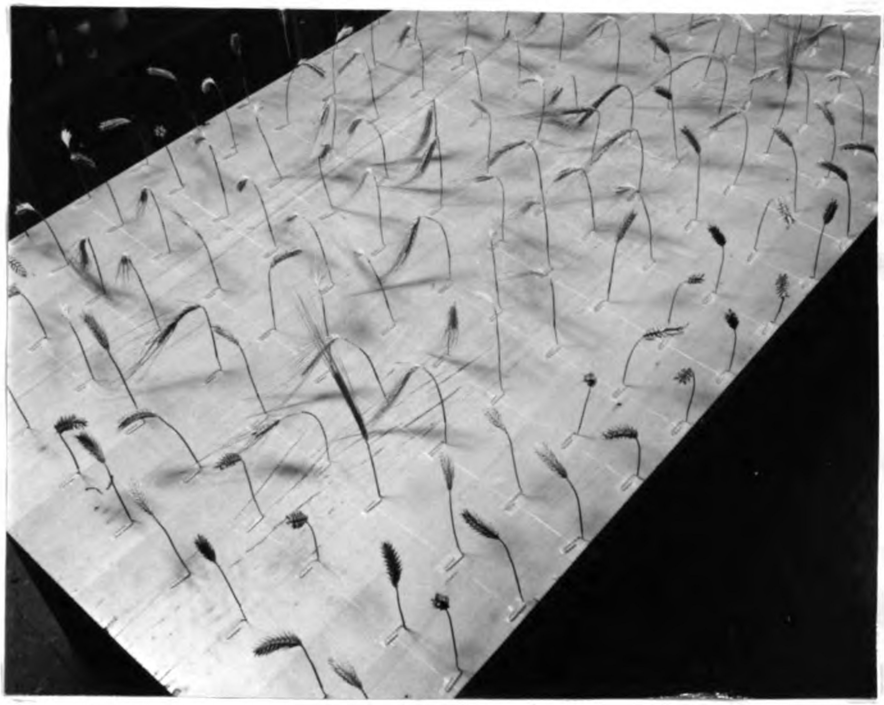


Plate 3.--The drying experiment.

Plate 4.--Detail of assembly in the drying experiment.

Results

Exponential drying functions of the following form were assumed and applied to the data.

$$M_t = M_0 \exp(-bt)$$

where M_t = moisture % of spike at time t

M_0 = moisture % at collection (time zero)

t = time elapsed since collection

b = drying index

b being the parameter of particular interest in this study.

The above exponential function reflects the progressive reduction in rate of moisture loss as the spike dries out. The equation can be derived as follows. It is assumed that rate of moisture loss at any given time is directly proportional to the moisture content at that time. Symbolically it follows,

$$\frac{dM}{dt} = -b\ M$$

where M = moisture content, %

$\frac{dM}{dt}$ = rate of change of moisture content with time

b = proportionality constant (minus because moisture % is decreasing)

rearranging and integrating over time elapsed since collection, i.e., since t

$$\int_{M_0}^{M_t} \frac{dM}{M} = \int_{0}^{t} -b \, dt$$

$$\ln M_t - \ln M_0 = -bt$$

discarding logarithms and rearranging,

$$M_t = M_0 \exp(-bt) \qquad \text{(Q.E.D.)}$$

By taking natural logarithms of both sides of the above equation, the statistical mechanics of curve fitting become simply that of linearly regressing the logarithm of moisture percentage on time,
i.e.,

$$\ln M_t = \ln M_0 - bt$$

$\ln M_0$ appears as the overall constant, a, of the familiar

$$Y = a - bx$$

Curves were fitted to individual spikes and to spikes pooled together into varieties. The regression statistics are given in tables 5 and 6.

When the spikes were collected, differences in maturity were observed between varieties. In particular, the variety Wong was found to be in the dough stage while the other five lines were in various stages of milkiness.

Table 5.--Regression statistics for the drying experiment. Regressions of ln M_t on time within lines and with single spikes of each line.

Line	Regression within lines			Regressions within single spikes of a line			
	b	s_b	sig $P \leq$	b	R^2	b	R^2
62-420-21	-.01835	.00058	.0005	-.01798	.9850	-.01525	.9811
				-.01841	.9833	-.01981	.9937
				-.01944	.9571	-.01659	.9838
				-.01976	.7951	-.01897	.9980
				-.02152	.9896	-.01407	.8872
				-.01686	.9312	-.01944	.9791
62-414-17	-.01497	.00034	.0005	-.01501	.9509	-.01690	.9900
				-.01380	.9193	-.01430	.9533
				-.01486	.9512	-.01533	.9582
				-.01415	.9543	-.01461	.9489
				-.01457	.9500	-.01755	.9681
				-.01526	.9500	-.01480	.9671
Wong	-.01488	.00036	.0005	-.01436	.9923	-.01465	.9952
				-.01678	.9946	-.01279	.9930
				-.01806	.9956	-.01278	.9869
				-.01295	.9914	-.01347	.9982
				-.01733	.9958	-.01323	.9966
				-.01623	.9976	-.01591	.9975

Lakeland	-.01389	.00078	.0005	-.01232	.9636	-.02513	.9925
				-.01337	.9651	-.01352	.9780
				-.01299	.9643	-.01222	.9732
				-.01367	.9772	-.01292	.9717
				-.01234	.9460	-.01297	.9765
62-434-5	-.01361	.00162	.0005	-.01113	.9802	-.01034	.9579
				-.01271	.9739	-.01121	.9799
				-.01062	.9592	-.04239	.9250
				-.01045	.9665	-.01026	.9502
				-.01131	.9733	-.01028	.9598
				-.01039	.9531	-.01055	.9601
62-449-22	-.01347	.00072	.0005	-.01488	.9905	-.00982	.9750
				-.01436	.9984	-.01377	.9930
				-.01268	.9652	-.01071	.9918
				-.01428	.9907	-.01252	.9925
				-.01405	.9930	-.01507	.9951
				-.01519	.9891	-.01511	.9956

b is the regression coefficient of $\ln M_t$ on time

s_b is the standard error of the regression coefficient

R^2 is the proportion of sums of squares of the dependent variable accounted for by regression

Table 6.--Test for heterogeneity of within line regression coefficients (drying indices) in the drying experiment.

Line	df	Residual SS
62-420-21	176	7.9605
62-414-17	175	2.6958
Wong	177	3.0420
Lakeland	178	14.6874
62-434-5	175	60.1515
62-449-22	177	12.4347
	1058	100.9719
Single Regression	1063	114.5665
Heterogeneity of slopes	5	13.5946

$$F = \left(\frac{13.5946}{5}\right) \left(\frac{1058}{100.9719}\right)$$

= 2.851, differences existing between line drying indices are significant at P=.025

In order to obtain a fairer comparison of drying between lines, a set of transformed drying indices was calculated from those determined directly from the experiment, by removing the effects of maturity. Differences between the ratios of seed number/3gm sample from field plot samples taken at the time of the experiment and at harvest, were used as measures of maturity,

i.e.,

$$m = \frac{S_1 - S_4}{S_4}$$

where m = maturity score

S_1 = seed #/3gm at time spikes were collected for the experiment

S_4 = seed #/3gm at harvest

Correlations between the maturity scores and the drying indices were removed by the method discussed by Rao (1952) using the maturity scores as the base vector. Thus we have,

$$\underline{b}' = \underline{b} - \left[\frac{\mathrm{cov}(b,m)}{\sigma_m^2}\right] \underline{m}$$

where $\underline{m}$ = vector of maturity scores

$\underline{b}$ = vector of drying indices

$\underline{b}'$ = vector of transformed drying indices

$$cov(b,m) = \text{covariance of maturity scores and drying indices}$$

$$\sigma_m^2 = \text{variance of drying indices}$$

e.g., for line 62-420-21,

$$-.02083 = -.0184 - \left[\frac{.00006}{.02099}\right] .84$$

$$\text{where } b = -.0184$$

$$m = .84$$

$$cov(b,m) = .00006$$

$$\sigma_m^2 = .02099$$

The coefficient of m in the equation is chosen such that the covariance (b',m) is set to zero, i.e.,

$$cov(b',m) = cov(b,m) - \left[\frac{cov(b,m)}{\sigma_m^2}\right] \sigma_m^2 = 0$$

The progression of seed number/3gm with time is shown in figure 5. Flattening of the curves indicate the points in time when grain dry matter accumulation has apparently ceased. Since only the initial and terminal points on figure 5 were used in calculating the vector m, non-linearity of the ratio over time was ignored for the present purpose.

The transformed drying indices, together with maturity scores for the six lines are given in table 7. The two-row lines possessed the higher drying indices.

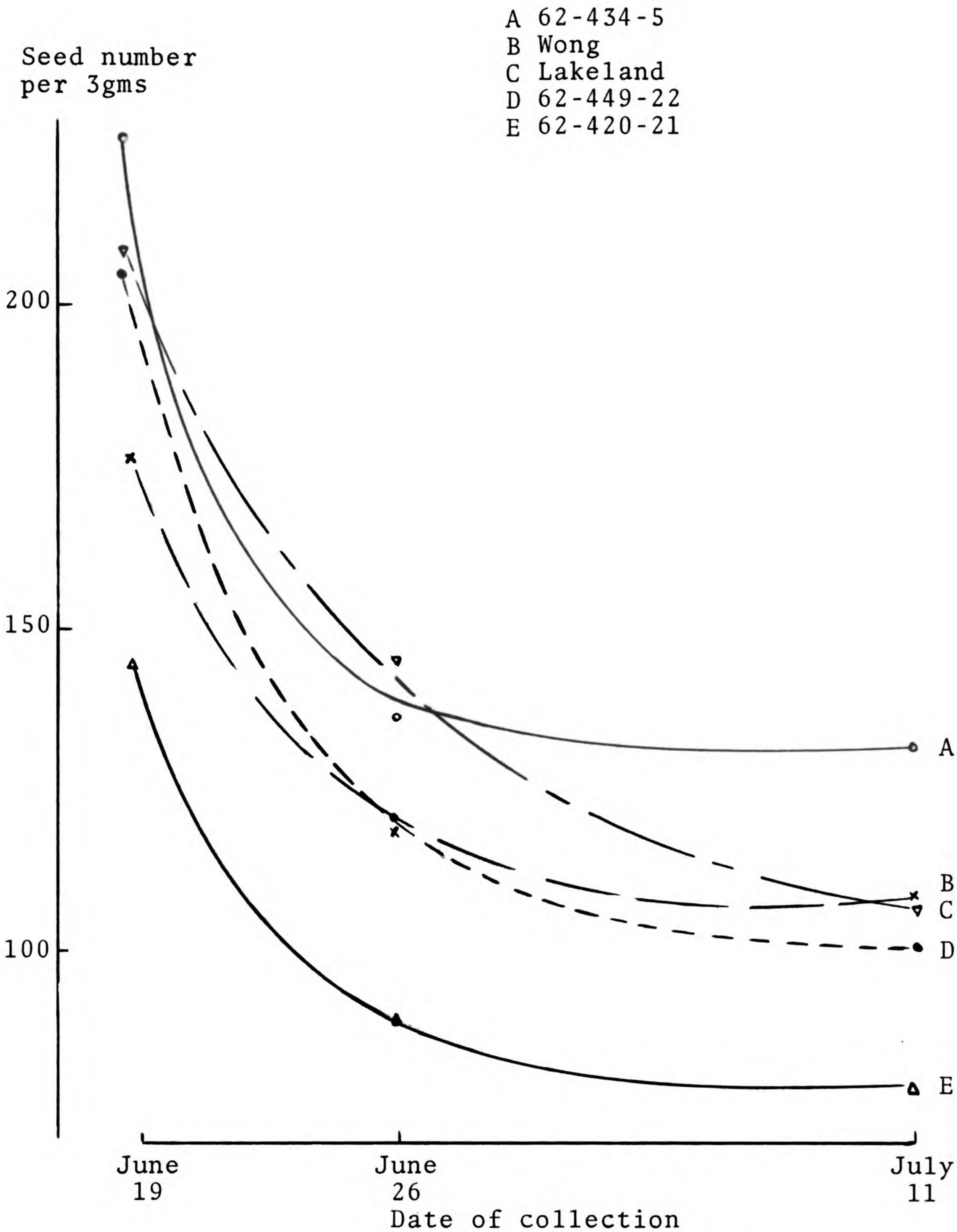


Figure 5.--The change in the ratio $\frac{\text{seed number}}{\text{3 gms}}$ with time. Flattening of the curves demonstrates reduction in dry matter accretion.

Transformation effected a greater degree of separation of the two-row types and the six-row types.

Table 7.--Maturity scores, untransformed and transformed drying indices for individual lines.

Line	m	b	b'
62-420-21	.84	-.0184	-.02083
62-414-17	1.00	-.0149	-.01779
Wong	.68	-.0149	-.01687
Lakeland	.99	-.0139	-.01676
62-434-5	.76	-.0136	-.01580
62-449-22	1.03	-.0135	-.01648

The relationship of the drying indices to grain color at harvest is shown in figures 6 and 7. Comment on these figures will be reserved for the discussion.

Regressions of individual spike drying indices on a number of morphological measurements were made. The measurements used were:

i. Average awn length

ii. Spike length

iii. Internode length

$$= \frac{\text{spike length}}{\text{number of nodes}}$$

iv. Average diameter

$$= \frac{\text{diameter across spike} + \text{diameter through spike}}{2}$$

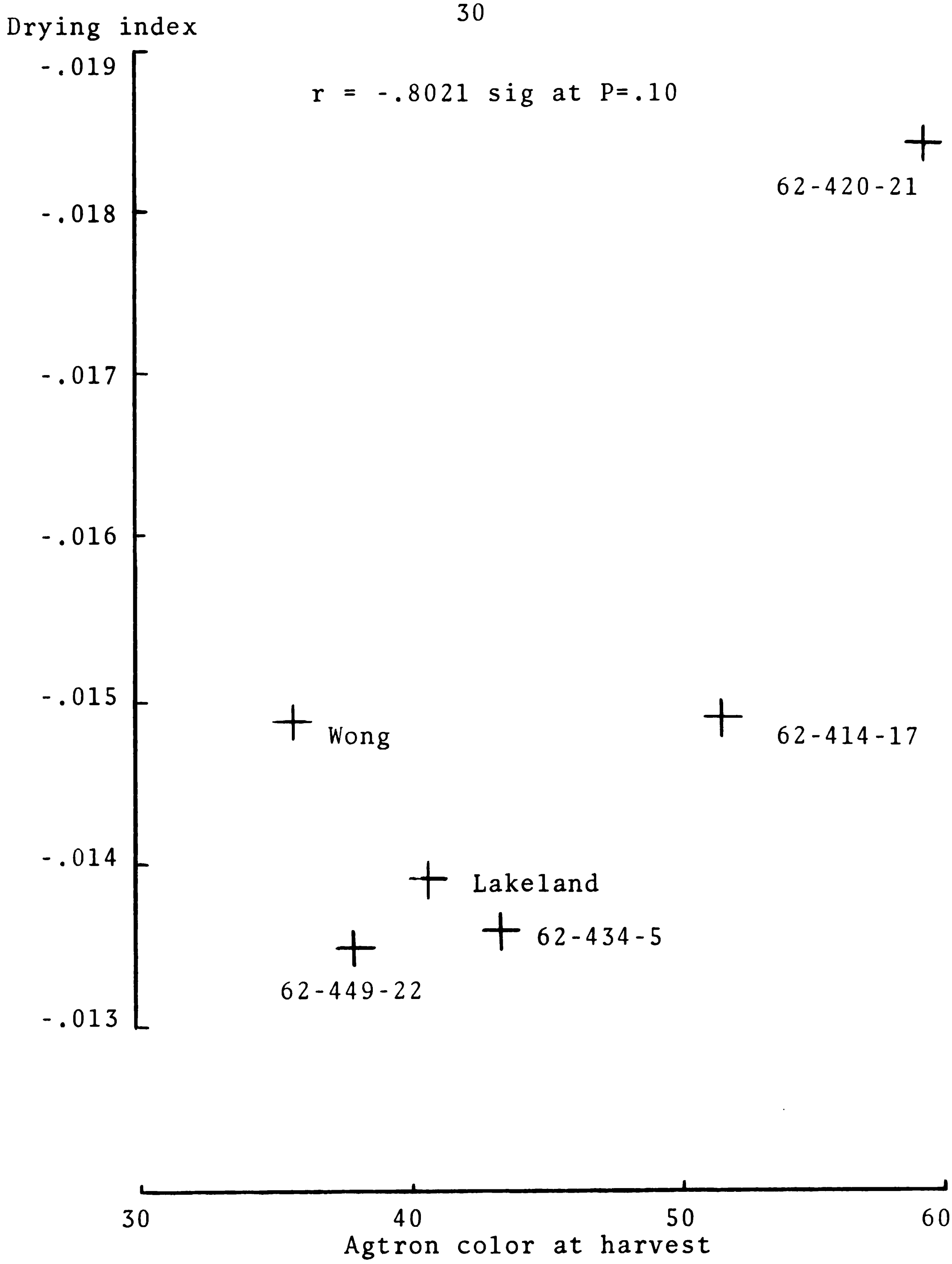


Figure 6.--The relationship of drying index, b, and agtron value at harvest.

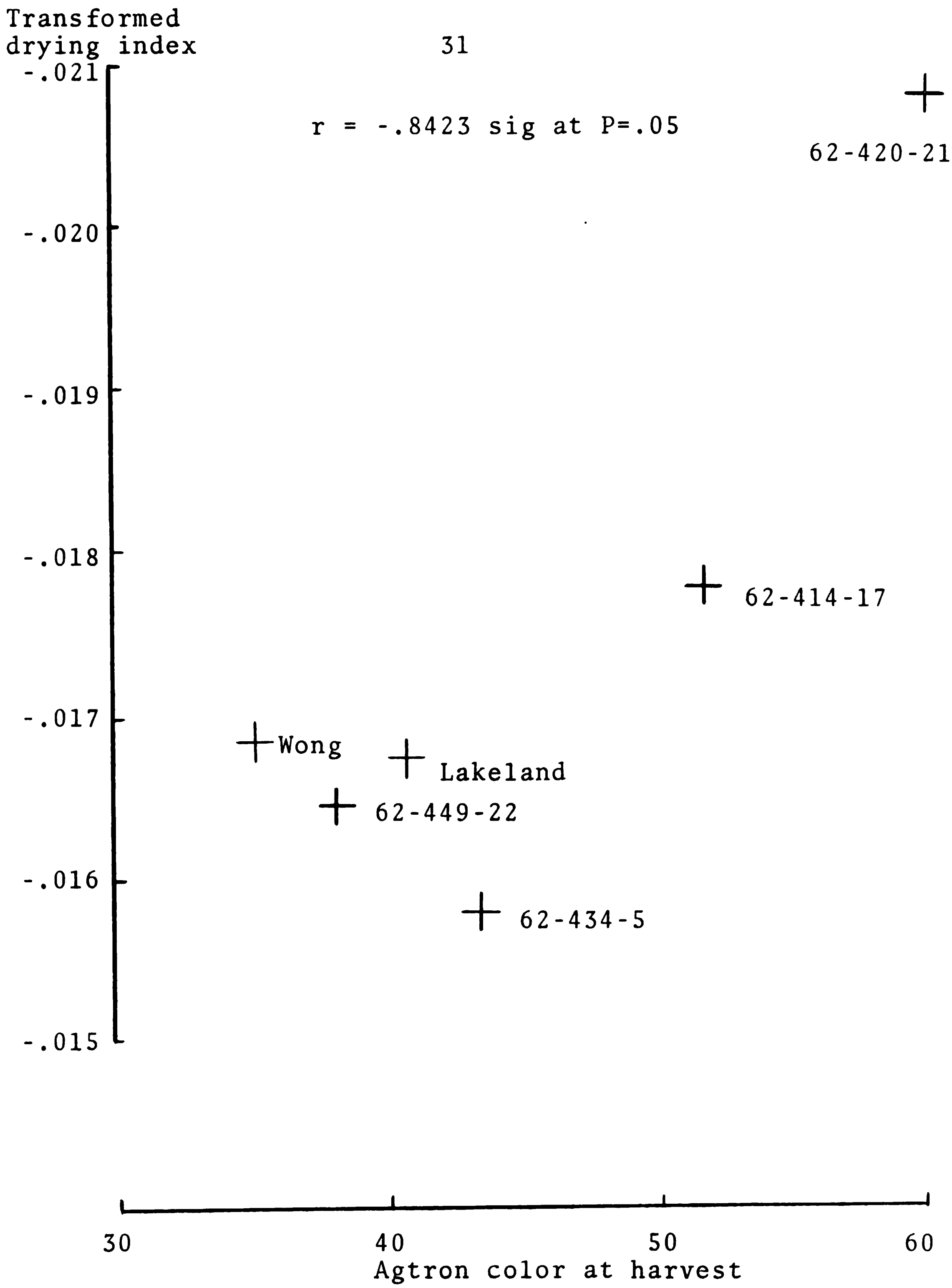


Figure 7.--The relationship of transformed drying index, b', and agtron value at harvest.

v. 'Volume'

$= \pi r^2 h$ where h = spike length

r = half the average diameter

vi. 'Density'

$= \frac{\text{weight of spike}}{\text{'Volume'}}$

Average diameter may also be interpreted as volume-surface ratio, differing from it by a scaling factor. i.e.,

$$\frac{\text{Volume}}{\text{Surface}} = \frac{\pi r^2 h}{2\pi r h} = \frac{\text{diameter}}{4}$$

Regression over all lines together failed to produce any significant results but a number of within line correlations were significant. These are given in table 8.

Table 8.--Correlations of drying index with structural features of the spike

Line	Variables correlated with drying index, r significant at P=.05 or less	
62-420-21	Awn length	-.85
62-414-17	Diameter x internode	-.85
Wong	Internode length	-.81
62-449-22	[Diameter	-.97
	[Volume	-.84

DISCUSSION

A suggested model combining the various environmental and genotypic factors influencing grain color in barley is given in figure 8.

Grain discoloration is most commonly the result of microbe-genotype interaction. Field climatic conditions during the period following spike emergence will influence the build-up of microflora on barley spikes. Humidity, in particular, would appear to be an important factor.

It has been suggested that morphological features of the barley spike play an important role in determining the rate of moisture loss during the in-field curing process. The slower drying spike might be suspected of retaining a higher moisture regime, advantageous for the establishment and maintenance of a microfloral population, and being prone to grain discoloration. Influence of spike form on any purely environmental discoloration process is also a possibility.

The present work attempts to link grain color, as determined by the agtron reflectance meter, with spike drying.

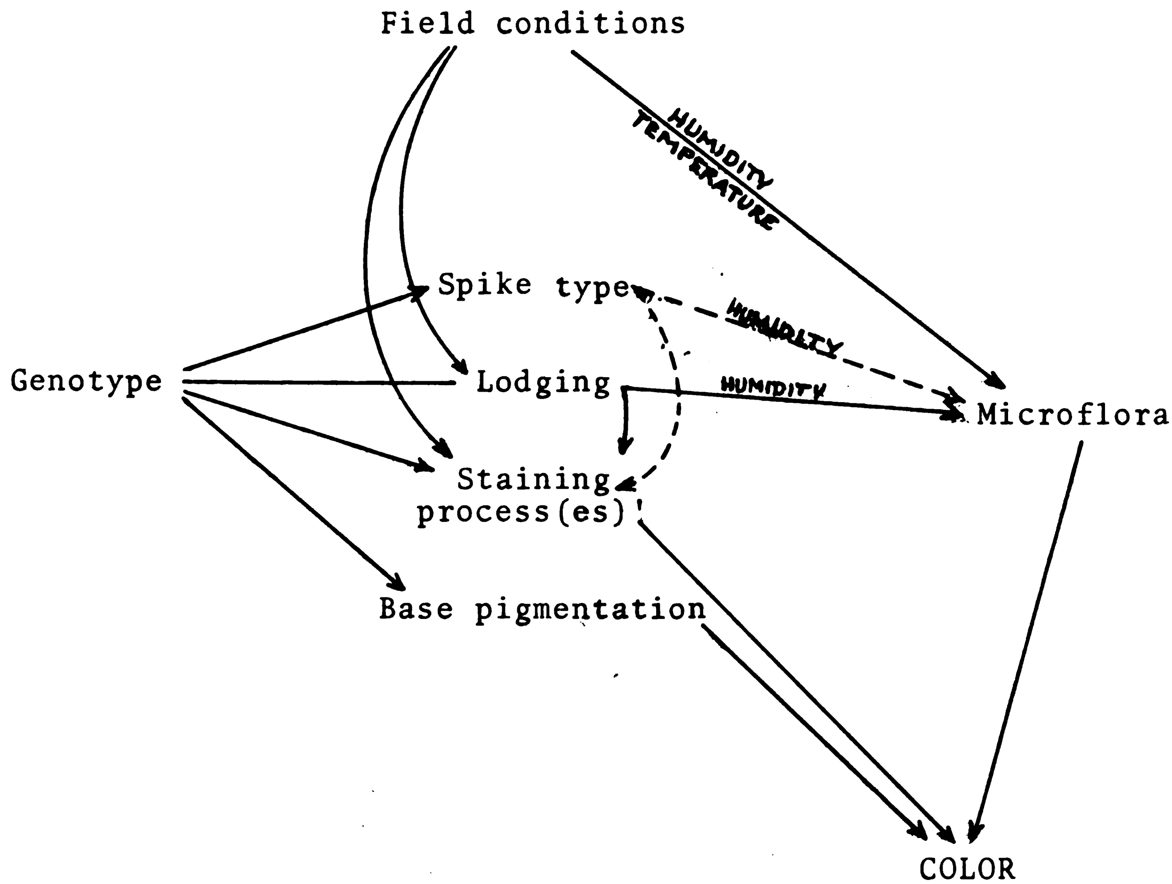


Figure 8.--Factors influencing barley grain color.

The figure relates the genotypic, environmental and microfloral factors contributing to the formation of grain color. Arrows indicate paths of influence. The broken arrow indicates the postulated effect of spike conformation on microfloral population.

Drying indices, b and b', were computed from a laboratory experiment. It was hypothesized that the indices might be an indication of drying during the period from grain set to harvest.

Correlation analysis suggested a number of relationships between spike structure and drying index. Although no significant overall relationship was found, within line correlation produced some interesting results (table 8).

In the two-row line 62-420-21, drying index was found to be negatively* correlated with average awn length. This result is compatible with the conclusions of Pool and Patterson (1958) who observed that awns increased moisture losses in wheat.

In the variety Wong, internode length was negatively correlated with drying index. This relationship is particularly interesting in view of the data in table 4, which demonstrates an association between higher agtron values and longer internodes.

Figures 6 and 7 show the association between final agtron readings, i.e., readings from samples taken at harvest, and drying indices. Figure 6 demonstrates the results for the drying indices calculated directly from the

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*Confusion of signs should be avoided. It should be remembered that a 'fast' drying index is a larger negative magnitude hence the correlations actually come out negative.

experiment. Figure 7 shows the results for the transformed indices described earlier in this thesis. Transformation brought about a greater degree of differentiation of two-row and six-row lines with respect to drying index, and improved the correlation of drying index with final agtron.

One deficiency in the concept of drying index is that it does not take into account any drastic morphological changes that may occur as the season progresses. For example, in some lines fracture or loss of awns occurred during the season. Following such reduction, the drying characteristics of the spike might be considerably altered. If the latter is the case then final grain color could not be expected to be too closely related to an index determined with the awns intact. An experiment which included removal of awns from test lines would help to clarify the position.

Two other phenomena that are modifying influences on spike drying are necking and lodging. Necking, i.e., the bending over of the spike that occurs shortly before maturity, would be expected to induce shedding of more of the incident rainfall. Lodging, on the other hand, will cause many spikes to be covered with straw and while rain may penetrate the resulting mat, evaporation from underlying grain will be reduced. In the consequent humid conditions the formation of discolored grain would tend to be severe.

Grafius (1969) has proposed that better grain color might be one of the benefits to be gained by introducing the two-row character into Michigan winter malting barley. The research herein confirms the relatively rapid drying properties of two randomly chosen two-row lines and their superiority over six-row types with respect to color at harvest. A comparison among the six-row lines further suggests that the lax spike will tend to produce better colored grain than the compact. From the foregoing it is inferred that drying is most rapid in those spikes which are physically disposed such as to permit a greater degree of air flow through the spike.

In figure 8 a direct path has been inserted between genotype and the staining processes. It is suggested that variation in these processes occurs *per se* and may be the ultimate factor determining differences in discoloration between lines of similar spike type, lodging resistance and initial pigmentation. The physiological inclination to stain may, in some cases, over-ride the morphological and 'ontological' features discussed in this thesis. It is strongly suspected that in case of the variety Wong, such an over-riding factor was in operation for although a relatively 'fast' drying index was determined for this variety, poor colored grain was consistently produced both in 1969 and in previous years.

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