A STUDY ON THE IMPROVEMENT OF THE ESSENTIAL AMINO ACID BALANCE OF CORN PROTEIN

I. Correlation between Racial and Varietal Characteristics and Lysine Levels of Corn[1]

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ABSTRACT

Racial and varietal trends affecting the nutritive value of corn were investigated. Kernel lysine levels, protein contents, germ solids contents, and total lysine-nitrogen ratios of numerous varieties from many areas are reported. Varieties were first grouped in terms of selected composition parameters. These were set forth after frequency ditribution patterns were determined and mean values of the composition characteristics analyzed. Resulting groups were further reveiwed, on the basis of their ancestral origin, to establish racial and varietal influences. A selection was made, as well, of some of the most promising varieties within races, from the standpoint of their use as starting materials for breeding work, leading toward the development of more nutritious corn hybrids. Among the races or racial complexes influencing the high-lysine-content varieties, the most outstanding appear to be the Tepecintle, White Nal-Tel, Salvadoreño Complex (TWNTS), and the races Chepo, Flint Cubano, Shandelle, and Pira. All but two of the 20 varieties, randomly selected as representatives of the TWNTS complex from Central America, were high in lysine. The two exceptions were, however, rather intermediate in lysine content. High-lysine Mexican races are Pepitilla, Chalqueño, Cónico Norteño, and Celaya. In contrast to the high-lysine varieties, all seven varieties within the Tuxpeño race from Mexico proved to be lysine-low, regardless of location of cultivation or other environmental influences.

In Mexico, Central America, and many other areas, corn serves as the basis of human and animal diets. This grain, however, contains a relatively low protein level, which also has an unbalanced pattern of essential amino acids. Improvement of its basic protein composition would have far-reaching consequences in terms of the ever-increasing world problems in nutrition.

The previous genetic work on corn has dealt with greater yield and too little on quality improvement. In the last two decades the major concern has been to increase the protein-quality content of corn. Frey (1) has shown a straight-line relationship between total protein

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content and zein content. The latter becomes an increasing proportion of the total protein as the protein percentage is increased. This increase makes the corn protein more unbalanced as far as the distribution of amino acids is concerned (2). Miller *et al.* (3) have shown that with single crosses the amino acids varied directly with the crude protein content. Doty *et al.* (4) showed that in single crosses of inbred lines the amounts of tryptophan and other amino acids are related to the genetic constitution of the plant. Wolfe and Fowden (5) showed significant differences in the ratio of amino acids in seven varieties of corn from Africa. Lysine varied from 4.2 to 7.5 g. per 100 g. of total protein. Bressani *et al.* (6) stated that tryptophan and lysine, the two most limiting amino acids in corn, showed varietal differences at each of four localities where corn was grown. Frey *et al.* (7) believed that it should be possible to obtain corn hybrids with low zein-protein ratio; this in turn would improve the pattern of essential amino acids in the endosperm protein.

The relative amounts of zein, glutelin, and acid-soluble protein fractions in the endosperm of many varieties of corn follow a pattern of 37, 29, and 34%, respectively. Mertz *et al.* (8) have found a mutant gene, opaque-2, that changes the protein composition and increases the lysine content of maize endosperm. The opaque kernels have a protein-pattern composition which departs from the normal. This pattern has been shown by these Purdue University authors to be 26, 39, and 35% respectively for zein, glutelins, and the acid-soluble proteins. This outstanding work indicates that in the opaque kernels the composition shift takes place at the expense of zein to render a higher proportion of the glutelins, the acid-soluble values remaining about the same.

Germ protein contains a better ratio of essential amino acids than that of endosperm protein. Germ protein usually represents 15–25% of total protein and contains about 5.4–5.8% lysine. Since the germ may contribute 25–40% of the over-all kernel lysine (9,10,11), a large germ improves the nutritive value of the total protein in a kernel of corn. Thus, corn with a large germ must have a quite high total lysine content to be classified in a high-endosperm-lysine group.

Lysine levels were chosen as the key to protein quality evaluation. Varieties exhibiting high lysine levels coupled with comparatively low protein and germ solids content may be regarded as endosperm-lysine-rich. Also, the amount found of this essential amino acid in such instances is a good indication of the type of protein make-up to be expected in the endosperm protein.

Tryptophan could have been used as an alternative indicator of protein quality, since both amino acids are absent in zein, the most abundant protein fraction of the endosperm, and are present in appreciable quantities in the glutelins (12,13). However, the tryptophan content of glutelins is comparatively smaller than the lysine content and presents a number of disadvantages from the standpoint of its analysis (7,14).

Lysine content was determined on 182 varieties of corn, and attempts were made to find evidence of differences in the amino acid pattern when compared with varietal and racial backgrounds of the corn. Varieties were selected out of about 5,000 collections from Mexico, Central America, and the Caribbean, ranging from very primitive corns to modern types.

Materials and Methods

Detailed evaluation of analytical procedures included comparison of chromatographic techniques, chemical methods, and microbiological assays (15–21). The microbiological method gave an accuracy of ± 5%. To accomplish the hydrolysis of ground samples, a modified method (18,22), using a 2.8*N* hydrochloric acid solution at 121°C. during 5 hr., was found adequate. Two series of eight culture test tubes each were employed per analysis. In all instances *Leuconostoc mesenteroides* P-60 strain, ATCC No. 8042, was used. This simplified method gave accuracy similar to that of the original microbiological method.

To establish the probable endosperm lysine levels within which varieties tend to fall, composite samples made up of several collections of each variety were analyzed. In several instances a group of varieties were evaluated after they were properly blended into composite samples representing a given race. The moisture, protein, fat, and ash contents were determined, according to AOAC Methods of Analysis (23). The amounts of seed coat, germ, and endosperm were measured (24). In each case 30 to 50 kernels per sample were used.

For reference purposes, main morphological characteristics were recorded. The number of grains per 100 g., the spoiled grains per 100 g., as well as the approximate average length and width of grains, were also determined.

Protein level will be found most significant, especially in cases of germ solids content below mean value of 7.2%. In such instances, lysine levels under the mean lysine value of 325 mg. per 100 g. of kernel, coupled with a comparatively high protein, above 11%, are expected to imply comparatively low endosperm lysine contents.

Since none of the samples of corn analyzed was exceptionally high in oil content, it was assumed that the contribution of germ lysine to total lysine would be reasonably constant; therefore, total kernel lysine was determined, so as to first segregate those collections which fall beyond mean lysine values of all collections under study. Then, identified members of this group were traced among all collections which fall below mean values for total protein and for germ solids, so as to select the collections with the most favorable conditions that would place them within the range of highest endosperm lysine level. Similar comparisons were also made in order to detect the members with medium and low lysine trend, by modifying classification parameters, as will be shown.

Results

Curves 1, 2, 3, and 4, Fig. 1, show respectively the frequency distribution patterns of varieties in terms of total lysine, total protein, total germ solids, and ratio of mg. lysine per 1 g. nitrogen. The corresponding mean values arising from all the varieties are indicated.

Seventy-five collections of the total of 182 fell above the mean lysine value of 325 mg. per 100 g. of kernel, and 18 of the 75 collections were simultaneously in the area of curves 2 and 3 of Fig. 1 which comprise all figures below mean values of 11 and 7.2%, respectively, for total protein and for germ solids.[4] These 18 members may be safely regarded as belonging to the most outstanding collections, from the standpoint of their expected high endosperm lysine contents.

In Fig. 2 the plus signs represent the protein content of the grain and the dots represent the corresponding lysine content in g. per 16 g. N. In general, as the protein content increased, the lysine content decreased. However, some samples with similar germ solids content were high in both protein and lysine.[5]

Table I groups the varieties exhibiting high lysine, low protein, and low germ solids. The members are arranged in descending order in accordance with their ratio of mg. lysine per g. nitrogen. All are above the mean value of 188 mg. lysine per g. nitrogen. Nine of these 18 members belong to a single racial complex, the TWNTS (Tepecintle, White Nal-Tel, Salvadoreño complex). An additional composite belongs to the Dzit-Bacal race which is also closely related to the TWNTS complex (25). Four members in this classification belong to another single race, the Flint Cubano. The remaining four belong

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[5]A mathematical analysis of 182 varieties indicates that there are more than one natural trend as far as protein-lysine relationships are concerned. At least 30 varieties depart from the main trend, either in the extreme low protein-high lysine or high lysine-high protein groups.

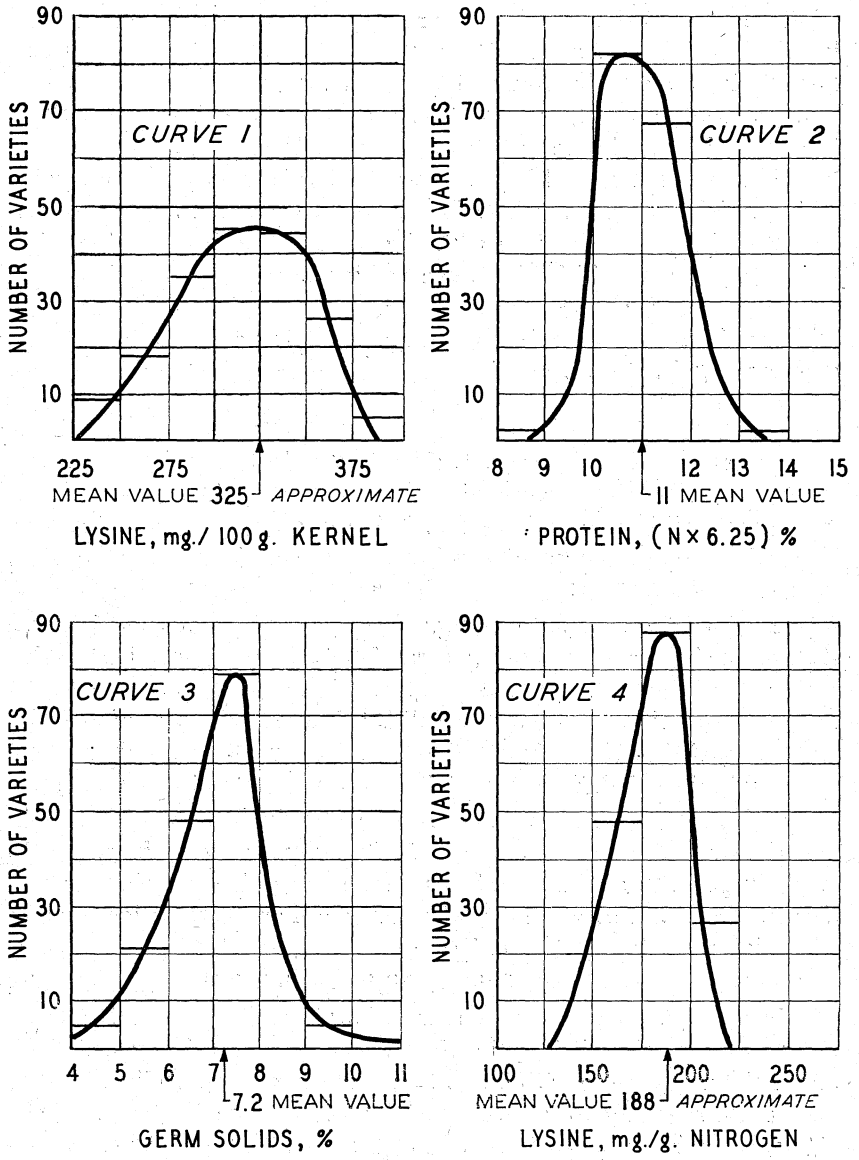

Fig. 1. Frequency distribution patterns of varieties by their total kernel lysine levels, protein content, germ solids content, and lysine-to-nitrogen ratios.

to different races: Pira, Chalqueño, Tuzon, and Celaya.

Some members, not included in the first group, have similar or even higher total kernel lysine values, but these values are bound to

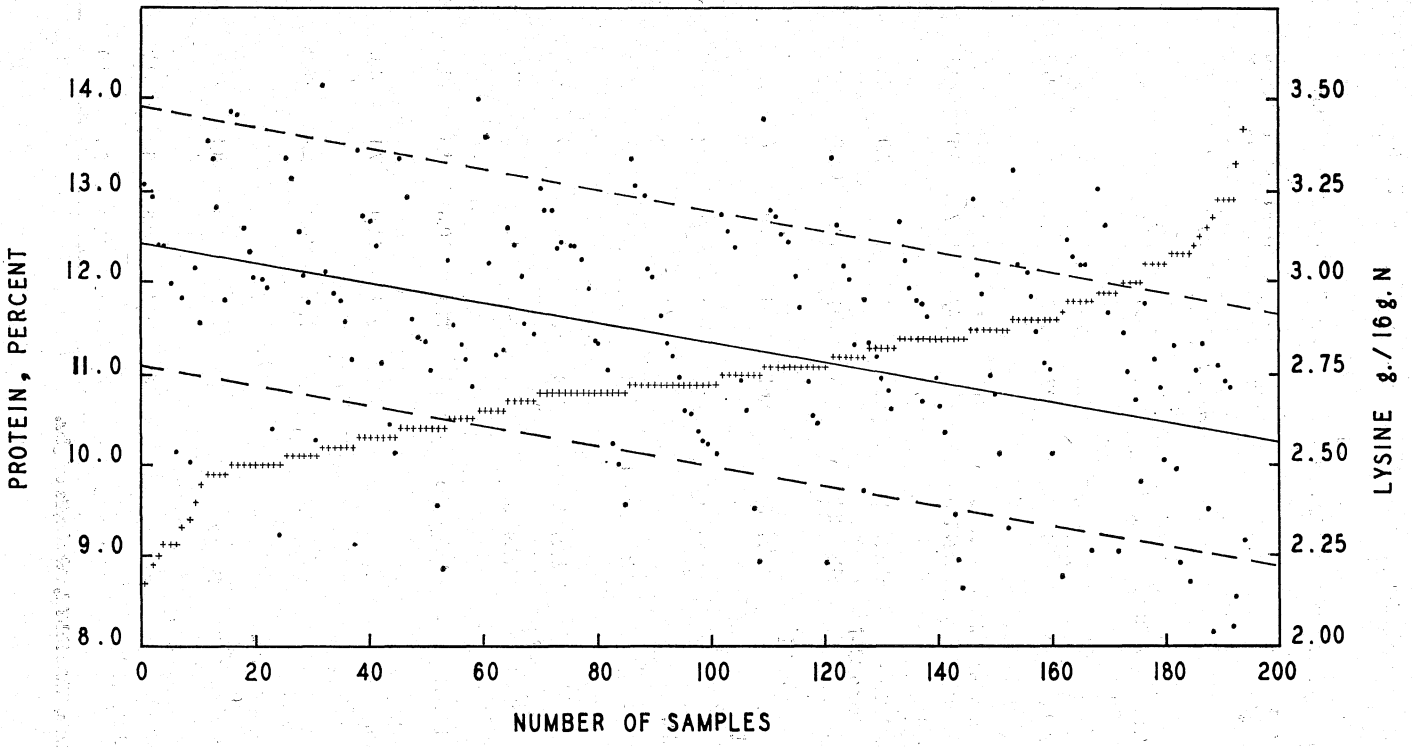

Fig. 2. Lysine-protein relationship in 182 corn varieties. Plus signs = protein content; dots = lysine content. Dotted lines represent mathematically determined regression lines, which correspond to main lysine content trend followed by most varieties.

TABLE I

GROUP WITH HIGH LYSINE, LOW PROTEIN, AND LOW GERM SOLIDS

SAMPLE IDENTIFICATION	RACE OF MAIZE	LYSINE	LYSINE	PROTEIN (N × 6.25)	GERM SOLIDS	ENDOSPERM	FAT
		mg./g.N	*mg./100 g. of kernel*	%	%	%	%
Olotillo Guat. Gpo. 6-IA No. 2221 × 2222	Dzit-Bacal	222	363	10.2	4.4	82.7	6.7
Salvadoreño Guat. 260 Gpo. 2-3 No. 2159	TWNTS[a]	219	372	10.1	7.1	83.0	4.4
Guat. 333 No. 2284	TWNTS	217	346	10.0	5.8	83.6	4.9
Amiláceo Morado Gro. Gpo. 36 Tep. 61-62 No. 2142	TWNTS	215	380	11.0	6.2	81.5	5.2
Guat. 316 No. 2201	TWNTS	211	347	10.7	6.6	83.1	4.6
Shandelle Rep. Dom. 22-D Gpo. 8 No. 2467	TWNTS	208	364	10.9	7.0	82.0	4.4
Guat. 459 Gpo. 23-1 No. 2357	Flint Cubano	208	347	10.4	5.8	83.4	5.0
Salvadoreño Guat. 105 Gpo. 4-1 No. 2168	TWNTS	204	356	10.9	6.8	82.4	4.8
Nal-Tel Guat. 279 Gpo. 22-2 No. 2351	Flint Cubano	203	336	10.4	7.2	82.8	4.9
Panamá 2 Pan. 18-B Gpo. 79 No. 1172	Flint Cubano	202	352	10.9	6.1	84.8	4.6
Salvadoreño Honduras 60j No. 1045	TWNTS	198	326	10.3	5.4	83.1	6.0
Guatemala Gpo. 18-IA No. 2302 × 2303	TWNTS	196	345	11.0	6.9	81.9	4.7
Chalqueño Méx. 172 Chap. 61 No. 2021	Chalqueño	194	333	10.8	4.3	81.0	5.6
Tuzon Trinidad 14-D Gpo. No. 2614	Tuzon	193	336	11.0	7.1	81.0	4.8
Salvadoreño Salvador 72j No. 1086	TWNTS	193	330	10.7	5.8	83.2	5.4
Celaya Medio Gto. Gpo. 2 × Gto. Gpo. 4 Tep. 61-62 No. 2044 × 2045	Celaya	192	332	10.8	3.1	85.1	4.1
Pira Pira Colombia Sintético B No. 2706	Pira	190	327	10.6	6.3	82.7	4.6
C. R. 26 Gpo. 29 No. 1165	Flint Cubano	189	330	10.9	6.7	83.9	4.7

[a] Tepecintle, White Nal-Tel, Salvadoreño complex.

TABLE II

HIGH LYSINE, LOW PROTEIN, AND ABOVE-MEAN-VALUE GERM SOLIDS CONTENT

SAMPLE IDENTIFICATION	RACE OF MAIZE	LYSINE	LYSINE	PROTEIN (N × 6.25)	GERM SOLIDS	ENDOSPERM	FAT
		mg./g.N	*mg./100 g. of kernel*	%	%	%	%
Guat. 280 Gpo. 4-5 No. 2200	TWNTS[a]	217	347	10.0	7.6	81.6	4.6
Semi-Dent Honduras 5j No. 1065	Flint Cubano	213	363	10.6	7.4	82.0	4.6
Celaya Tardío Gto. Gpo 14 × Jal. 187 Tep. 61-62 No. 2047 × 2048	Celaya	211	335	9.9	7.4	77.8	4.9
Azufrado C. R. 108 Gpo. 6 No. 1135	TWNTS	208	336	10.1	7.4	81.3	5.0
Dent-Ancho P. Rico 7-D Gpo. 3 No. 2510	Saint Croix	208	330	9.9	7.7	80.8	4.8
Costarrisal C. R. 138 Gpo. 7 No. 1136	TWNTS	204	328	10.1	7.5	81.2	4.4
Shandelle-Dent Rep. Dom. 66-D Gpo. 3 No. 2452	Shandelle	203	352	10.8	7.3	80.5	4.7
Guat. 77 Gpo. 21-1 No. 2308	Flint Cubano	200	347	10.8	7.7	81.2	5.0
Guat. 66 Gpo. 15-2A No. 2280	TWNTS	200	345	10.8	7.6	82.5	4.8
Panamá 21 Pan. 16-M Gpo. 99 No. 1198	Chepo	199	351	11.0	7.6	82.4	5.2
Maicena A C. R. 166 Gpo. 13 No. 1146	Pira	199	329	10.3	7.7	80.4	4.6
Olancho Nicaragua Gpo. 74 No. 1125	TWNTS	197	337	10.7	8.6	81.9	4.6
Flint Dent. Haití 24-J Gpo. 6 No. 2424	Flint Cubano	196	339	10.8	7.8	79.2	4.6
Flint Dent. Sta. Lucía 4-D Gpo. 1 No. 2548	FCT[b]	193	335	10.8	7.9	78.8	4.7
Dentillo Nicaragua Gpo. 68 No. 1116	Pira	191	330	10.8	8.0	80.5	5.1

[a] Tepecintle, White Nal-Tel, Salvadoreño complex.
[b] Flint Costeño Tropical.

a higher protein content or to a higher germ solids level. Under these circumstances they may be classified in the upper lysine level

range, even though some members may tend to depart from the line of high lysine levels in endosperm protein. These members are, however, worth classifying in a separate category, because of the relationships between total kernel lysine and either protein content or germ solids content.

Table II includes a group of 15 varieties which show total lysine levels above 325 mg. per 100 g. of kernel and a protein content below 11%; they exhibit, however, a comparatively higher germ solids content, above 7.2%, and a ratio of mg. lysine per g. nitrogen above the mean value of 188 mg. found for all collections. The list has been arranged in terms of mg. lysine per g. nitrogen. Five of these 15 members

TABLE III

GROUP WITH COMPARATIVELY HIGHER LYSINE, LOW GERM SOLIDS, AND ABOVE-MEAN-VALUE PROTEIN

SAMPLE IDENTIFICATION	RACE OF MAIZE	LYSINE	LYSINE	PROTEIN (N × 6.25)	GERM SOLIDS	ENDOSPERM	FAT
		mg./g.N	*mg./100 g. of kernel*	%	%	%	%
Cónico Norteño Gto. 49 Chap. 61 No. 2179	Cónico Norteño	207	383	11.6	6.6	81.2	5.0
Cónico Norteño Qro. 25 Chap. 61 No. 2198	Cónico Norteño	204	387	11.9	7.0	80.7	5.2
Panamá 21 Pan. 11-M Gpo. 99 No. 1196	Chepo	201	375	11.5	6.5	84.8	5.0
Flint Cubano C. R. 71 Gpo. 3 No. 1133	Flint Cubano	198	352	11.1	6.2	82.1	5.0
Panamá 22 Pan. 12-M Gpo. 100 No. 1199	Chepo	197	377	11.9	6.7	82.8	4.9
Panamá 23 Compuesto Gpo. 101 No. 1252	Chepo	194	355	11.1	6.3	80.6	4.5
Vandeño Precoz Chis. 209 × Chis. 226 Tep. 61-62 No. 2100 × 2098	TWNTS[a]	191	361	11.8	6.9	81.9	4.5
Guat. 155 Gpo. 13-1 No. 2260	TWNTS	190	361	11.8	6.6	83.1	4.6
Panamá 1 Pan. 2-B Gpo. 78 No. 1171	Flint Cubano	191	346	11.4	7.1	83.2	4.3
Pujagua Nicaragua Gpo. 76 No. 1127	TWNTS	190	340	11.2	7.0	82.9	5.1
Guat. 769 Gpo. 22-1 No. 2349	Flint Cubano	189	348	11.5	6.9	81.3	4.5

[a] Tepecintle, White Nal-Tel, Salvadoreño complex.

belong to the TWNTS complex, three to the Flint Cubano race, two to the Pira race, and the rest to races Chepo, Celaya, Shandelle, Flint Costeño Tropical, and Saint Croix.

Table III includes a group of 11 members which show an outstandingly high total lysine level, above 325 mg. per 100 g. of kernel, and a low germ solids content, below mean value of 7.2%, coupled with a protein content above the mean protein value of 11%. They have been arranged in descending order in accordance with the ratio, mg. lysine per g. nitrogen. Races included are TWNTS complex with three members, Chepo with three members, Flint Cubano with three members, and Cónico Norteño with two composites.

TABLE IV

GROUP WITH SIMULTANEOUSLY HIGH LYSINE, HIGH PROTEIN, AND HIGH GERM SOLIDS

SAMPLE IDENTIFICATION	RACE OF MAIZE	LYSINE	LYSINE	PROTEIN (N × 6.25)	GERM SOLIDS	ENDOSPERM	FAT
		mg./g.N	*mg./100 g. of kernel*	%	%	%	%
Salvadoreño Guat. 588 Gpo. 17-IA No. 2289	TWNTS[a]	208	374	11.2	8.2	82.4	4.7
Pepitilla Gro. Gpo. 27 × Gro. Gpo. 20 Tep. 61-62 No. 2145 × 2147	Pepitilla	200	360	11.1	9.0	77.1	4.6
Guat. 100 Gpo. 8-1 No. 2235	TWNTS	198	361	11.4	10.0	78.5	4.6
Salvadoreño Guat. 231 Gpo. 7-1 No. 2232	TWNTS	197	353	11.2	7.5	82.7	4.8
Shandelle Rep. Dom. 39-D Gpo. 15 No. 2495	Shandelle	195	368	11.8	8.0	80.0	4.4
Guatamala Compuesto Gpo. 30-IA No. 2369 × 2370	TWNTS	195	348	11.1	7.6	81.9	4.7
Bl. Haitiano Haití 31-J Gpo. 8 No. 2427	Flint Cubano	191	362	11.8	7.6	80.9	4.5
San José Amarillo C. R. 5 Gpo. 28 No. 1163	Flint Cubano	189	353	11.6	8.3	81.1	4.2
Panamá 12 Compuesto Gpo. 89 No. 1247	Flint Cubano	188	335	11.1	8.1	82.2	5.3
Panamá 24 Compuesto Gpo. 102 No. 1253	Chepo	188	334	11.2	7.3	83.5	4.7

[a] Tepecintle, White Nal-Tel, Salvadoreño complex.

Table IV includes 10 members with total kernel lysine levels above 325 mg. per 100 g. of kernel, coupled with a protein content above 11% and a germ solids level above 7.2%. These are of interest because all main composition features considered, that is, their lysine content, protein content, and germ solids content, are simultaneously high. They are listed in terms of the ratio of mg. lysine per g. nitrogen, all above the mean value ratio of 188 mg. per g. nitrogen. Of these 10 members, four belong to the TWNTS complex, three to the Flint Cubano group, one to the Pepitilla race, one to the Chepo race, and the remaining one to the Shandelle race.

To determine possible trends of varieties in the low endosperm lysine range, it was deemed interesting to include Table V, which shows the seven members expected to be the low endosperm lysine level specimens of the 182 varieties studied. These have been selected in terms of the lowest ratio of mg. lysine per g. nitrogen in the range of 127 to 140 mg. per g. nitrogen. These members have a comparatively

TABLE V

VARIETIES WITH LOW KERNEL LYSINE, HIGH PROTEIN, AND LOW GERM SOLIDS CONTENT

SAMPLE IDENTIFICATION	RACE OF MAIZE	LYSINE	LYSINE	PROTEIN (N × 6.25)	GERM SOLIDS	ENDOSPERM	FAT
		mg./g.N	*mg./100 g. of kernel*	%	%	%	%
Reventador Nay. 49 × Son. 37 Tep. 61-62 No. 2064 × 2065	WMC[a]	127	258	12.7	6.1	82.9	5.1
Olotillo Blanco Gro. Gpo. 22 × Oax. Gpo. 1 Tep. 61-62 No. 2081 × 2082	ODBC[b]	135	246	11.4	5.4	83.1	4.5
Cónico Norteño Gto. 33 Chap. 61 No. 2176	Cónico Norteño	136	267	12.3	5.4	80.2	6.4
Comiteco Amarillo Chis. Gpo. 32 × Chis. 206 Tep. 61-62 No. 2110 × 2111	ODBC	138	227	12.3	7.0	83.0	3.7
Nal-Tel Guat. 313 Gpo. 4-4 No. 2192	Nal-Tel	138	244	11.0	6.8	81.7	4.9
Tuxpeño Mix. 1 Guat. Tep. 61-62 No. 1970	Tuxpeño	138	258	11.7	6.0	83.1	3.6
Am. Haitiano Haití 8-J Gpo. 2 No. 2411	Amarillo Haitiano	140	257	11.4	7.2	81.4	4.7

[a] Western Mexico complex.
[b] Olotillo Dzit-Bacal complex.

low kernel lysine content, mostly under 270 mg. per 100 g. of kernel, coupled with high protein content, over 11%, and a low germ solids content.

Table VI shows an additional group of four members in which the lowest kernel lysine levels among the 182 specimens studied are

TABLE VI

VARIETIES WITH LOWEST KERNEL LYSINE, LOW PROTEIN, AND LOW GERM SOLIDS CONTENT

SAMPLE IDENTIFICATION	RACE OF MAIZE	LYSINE	LYSINE	PROTEIN (N × 6.25)	GERM SOLIDS	ENDOSPERM	FAT
		mg./g.N	*mg./100 g. of kernel*	%	%	%	%
Tabloncillo Jal. Gpo. 22 × Jal. Gpo. 23 Tep. 61-62 No. 2054 × 2055	WMC[a]	146	233	10.0	7.0	82.0	4.8
Blanco de Junio N. L. 8× N. L. Gpo. 7 Tep. 61-62 No. 2137 × 2138	WMC	155	249	10.4	6.4	83.2	4.4
Celaya Gto. 61 Chap. 81 No. 2183	Celaya	157	226	9.4	6.2	81.2	4.3
Arrocillo Amarillo Pue. 122 Chap. 61 No. 2092	CPTC[b]	158	230	9.1	5.9	81.7	4.5

[a] Western Mexico complex.
[b] Cónico Palomero Toluqueño-Cacahuacintle.

coupled with low protein content, under 11%, and low germ solids content. Members in both Tables V and VI exhibit lysine-nitrogen ratios below 160 mg. per g. No members in this group fall within the TWNTS complex, Chepo, Flint Cubano, Pira, or Shandelle races.

A search for the low lysine level members throughout the entire scope of 182 varieties will show, for instance, that all Tuxpeño race members, many of which are by themselves composites of several collections, fall below 166 mg. lysine per g. nitrogen, and that all but two members exhibit lysine values under 270 mg. per 100 g. of kernel.

Discussion

Analysis of 182 different corn varieties which fall under practically all known corn races has made it possible to correlate racial characteristics and lysine levels of specimens in terms of selected analytical parameters.

Seventy-five members exhibited lysine levels above mean value. These, however, include 21 varieties with a ratio in mg. lysine per g.

nitrogen below the mean value, but with a protein level above mean value of 11%. Thus, endosperm protein quality is expected to range low in these members, in spite of their comparatively high lysine levels. Two exceptions in this group of 21 should not follow the expected trend of low endosperm lysine, in view of their lysine content, above 350 mg. per 100 g. of kernel, 25 units above the mean lysine value, coupled with a germ solids content below the mean value of 7.2%. Fifty-four varieties remain as worth considering, both from the standpoint of their expected endosperm lysine levels, as well as from the races influencing their genetic formation (Tables I to IV inclusive). Strikingly, 21 varieties in the segregated group of 54 happen to belong to the TWNTS complex. They represent a good random sample of this race complex. Only two exceptions were found of varieties within this race complex which do not fall into the 54-member group. Total lysine levels were in these cases below, but not too far apart from, mean values. Other races representing the 54 high lysine group are: Chepo, Pira, Dzit-Bacal, Shandelle, Flint Cubano, Saint Croix, Tuzon, Pepitilla, Chalqueño, Cónico Norteño, and Celaya. The latter four represent the comparatively high lysine varieties from Mexico.

According to E. J. Wellhausen (unpublished work), the race Tepecintle is thought to be the progeny of Teosinte introgression into a large-eared Guatemala flour corn. It is one of the most tripsacoid of all the Mexican and Central American races, because of its external characteristics and its chromosome knob numbers. The latter is regarded as possibly a result of either Tripsacum or Teosinte introgression.

Chepo race members, all collected around Chepo, northeast of Panama City, were found to be in all instances high-lysine members. The same may be said of a composite of the Pira race collected in Colombia (26) and analyzed along with similar varieties of this race from Costa Rica and Nicaragua. Their lysine levels were consistently high. Varieties of the Shandelle race are prevalent in the Dominican Republic and occasionally found in the Caribbean. Closely related to the Pira complex, these varieties were found to be high in lysine, although some medium and low members indicate a greater racial variation.

Thirteen varieties of the Flint Cubano race analyzed and collected in different areas of Central America fall in the high-lysine group; two others exhibit intermediate lysine levels. Ten varieties of Coastal Tropical Flint (27) present lysine values somewhat under those found for Flint Cubano.

Two composites involving 13 different varieties of the Pepitilla race were analyzed. This race prevails in the States of Morelos and Guerrero in Mexico and is characterized by ears of a high row number and long, slender-beaked kernels. These were found definitely high in lysine.

Wellhausen *et al.* (28) have pointed out that the Chalqueño race was derived from intercrossing of the Tuxpeño and Cónico Norteño races, both of which, according to these analyses, are low in lysine. The Tuxpeño race follows a definitely low-lysine trend. Nevertheless, the particular varieties analyzed all have a high ear-row number and long slender kernels, characteristics which were most likely acquired through an introgression of Pepitilla from the neighboring State of Morelos. Their relatively high lysine content would then be explained through such a mechanism.

The Cónico Norteño race has also been influenced in its evolution by the Pepitilla race, in Mexico areas with an elevation of 1,800 to 2,000 meters. Many of the varieties of this race are called Pepitilla because of their high ear-row number and long seedlike ("pepita") kernels. They originated from the Cónico race of the Central Plateau through the introgression of Pepitilla and Celaya or their precursors. The seven varieties analyzed of this race are quite variable, as might be expected on the basis of their origin. The earlier-maturing forms adapted to the higher altitudes probably have a greater proportion of Cónico in their genetic constitution and reflect the generally low lysine content of these high-altitude races.

Wellhausen *et al.* (28) described Celaya as the product of interhybridization of Tuxpeño and Tabloncillo. On this basis it is harder to account for the high lysine content of the typical varieties of this race, since its two putative parents are low in lysine. However, three different flour corns, among them Tepecintle, have entered into its ancestry and it has received teosinte genes from three different sources, which may in part have contributed to their comparatively high lysine content.

Two of the four varieties analyzed of Celaya are high in lysine and two are relatively low. One of the high-lysine varieties is a composite of 10 typical collections of the race. The other represents a mixture of four collections somewhat atypical in this respect, and the others are composite samples of Celaya varieties from the Cienega de Chapala and Jalisco, Mexico, with a definitely greater proportion of Tuxpeño in their genetic make-up.

Tuxpeño was among the lowest of the races analyzed in regard to lysine content. All seven varieties analyzed of this race exhibited low

TABLE VII

COMPARISON BETWEEN RACES AND LYSINE LEVELS IN TERMS OF VARIETIES WITHIN ± 5% VARIATION RANGES

RACE OF MAIZE	TOTAL NUMBER OF VARIETIES STUDIED	NUMBER WITHIN RANGE OF ± 5% OF MEAN LYSINE VALUE	MEAN LYSINE VALUE FOR RANGE	LYSINE RANGE	PROTEIN RANGE (N × 6.25)	GERM SOLIDS RANGE	ENDOSPERM RANGE	FAT RANGE
			mg./100 g. of kernel	*mg./g.N*	%	%	%	%
Chepo	5	4	364	194–201	11.0–11.9	6.3– 7.6	80.6–84.8	4.5–5.2
Shandelle	6	4	358	170–208	10.8–12.9	7.0– 8.2	80.0–82.0	4.4–4.7
Flint Cubano	15	13	347	188–215	10.4–11.8	5.8– 8.3	79.2–84.8	4.2–5.3
Tepecintle, White Nal-Tel, Salvadoreño complex	25	18	345	190–217	10.0–11.8	5.4–10.4	78.5–83.6	4.4–6.0
Tepecintle, Salvadoreño complex[a]	5	4	336	181–185	11.4–12.1	7.3– 7.9	81.2–81.4	4.6–4.8
Pira	4	4	335	184–199	10.3–12.2	6.3– 8.0	80.4–82.7	4.5–5.1
Celaya	4	2	334	192–211	9.9–10.8	3.1– 7.4	77.8–85.1	4.1–4.9
Cónico Norteño	7	3	332	168–182	11.4–12.4	5.7– 7.3	79.1–82.0	5.1–5.6
Nal-Tel	3	2	298	134–143	13.3–13.7	6.2– 6.8	83.4–83.6	3.7–3.9
Amarillo Haitiano	4	2	297	161–178	10.4–11.4	6.9– 7.0	80.3–81.3	4.6–4.8
Chalqueño	5	3	292	171–202	8.9–10.9	4.7– 5.8	79.0–82.2	4.0–5.4
Flint Costeño Tropical	10	6	291	161–193	9.1–10.9	6.8– 8.9	77.5–81.1	4.4–5.6
Olotillo Dzit-Bacal	11	5	289	158–165	10.9–11.5	5.8–12.4	72.9–84.1	4.3–5.7
Cónico Palomero Toluqueño-Cacahuacintle	4	3	279	185–190	9.3–10.0	5.6– 7.4	79.5–83.3	4.2–5.8
Tabloncillo, Jala, Reventador, Harinoso de Ocho[b]	5	2	270	127–204	8.7–12.7	4.1– 6.1	82.9–83.3	5.1–5.8
Tuxpeño	7	4	264	138–158	10.3–11.9	6.0– 8.3	81.2–83.1	3.3–4.3
Tuxpeño, Vandeño-Blanco de Junio	3	3	260	149–186	9.1–11.0	6.4– 8.3	85.5–83.2	4.4–4.8

[a] Mixed with some other races.
[b] Western Mexico complex.

lysine levels, in striking contrast to the high-lysine races described above. This is especially significant since the varieties analyzed represent different areas, namely, Guatemala and the States of Colima, Oaxaca, Veracruz, and Tamaulipas in Mexico.

In the light of the above, it becomes very apparent (Table VII) that lysine content is a racial characteristic. It is expected that further work on this subject will throw additional light on the manner in which endosperm lysine content is controlled. Work on single ear kernel isolates is now under way, to further clarify the correlations between racial characteristics and lysine levels and to further select specimens for breeding work leading to more nutritious corn hybrids. It is hoped that as geneticists and hybrid corn breeders put more emphasis on improvement in content of essential amino acids, better corn will be developed for both humans and animals.

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