Quality Protein Maize Improvement at the National Maize and Sorghum Research Center CNPMS/EMBRAPA/BRAZIL

Paulo E. O. Guimarães, Maurício A. Lopes, Elto E.G. Gama, Manoel X. Santos, Sidney N. Parentoni, Maria C.D. Paes, Pedro A. Vieira Júnior, Álvaro E. Silva, Edilson Paiva, Luis A. Corrêa, and Cleso A. P. Pacheco

National Maize and Sorghum Research Center
CNPMS/EMBRAPA
C.P. 151, CEP 35701-970, Sete Lagoas, MG, Brazil

INTRODUCTION

Brazil has 8.5 million km^2 of land, a population of 147 million (IBGE, 1993) and a GNB of US$436.8 billion (Conjuntura Econômica, 1995). Despite its immense area with great agricultural potential, malnutrition remains one of our key problems. Solutions to this problem are complex and involvement of all segments of our society is necessary to revert this situation. One of the major contributions that agricultural research can provide is the development of more nutritive, low cost foods that can be easily produced, processed, and made available to consumers.

Maize is a traditional crop that is produced and utilized in all regions of Brazil. It occupies 61% of the cereal growing area in the country (CIMMYT, 1992), yielding 30 million tons of grain annually which is used for human and animal nutrition. This amount of grain corresponds to about 2.6 million tons of protein, which has a reduced biological value. Modified *o2* materials, known as Quality Protein Maize or simply QPM, with high lysine and tryptophan contents and a kernel phenotype similar to normal maize have been developed at CIMMYT (Vasal et al., 1980; Bjarnason and Vasal, 1992) and South Africa (Gevers and Lake, 1992). QPM development has represented an important advance that can greatly help developing countries move towards agricultural sustainability and food security. In Brazil, gradual substitution of normal maize cultivars by QPM could generate great benefits especially to low income families that would consume it directly, or indirectly as a

consequence of greater availability of swine, poultry and fish products resulting from its use as a component of feed.

Investigation of the potential for using QPM as a component of feed in Brazil indicated that it would be possible to reduce the production costs of swine feed by 4-5% and poultry feed by 3-4% (Lopez-Pereira, 1992). This could have a significant economic impact if we consider that in 1991 the Brazilian production of poultry and swine was around 1.8 million tons and 0.8 million tons, respectively (IBGE, 1993).

Our rationale to increase adoption of QPM by the farmers and the food and feed industries is to develop cultivars, either hybrids or varieties, that are equal or superior in agronomic performance to normal maize cultivars. In addition, we are implementing systematic research and extension programs to demonstrate to the public the biological advantages of QPM.

POPULATION DEVELOPMENT AND IMPROVEMENT

A breeding program to develop QPM varieties has been carried out at CNPMS/EMBRAPA since 1983. The main objectives of the program are centered on the continuation of the improvement of QPM varieties already released; on development of yellow open-pollinated varieties for low income farmers; on maintenance of genetic variability capable of sustaining development of new varieties, inbred lines and hybrids of agronomic performance similar to that of normal maize cultivated in Brazil.

Commercial Varieties

BR 451

The CNPMS's QPM program was initiated with the introduction of twenty-three QPM populations developed at CIMMYT (Vasal et al., 1980; Bjanarson & Vasal, 1992). These materials were extensively evaluated in field trials conducted in several regions of Brazil for assessment of agronomic performance. Also, flour obtained from these materials was evaluated in mixtures with wheat flour for breadmaking (Magnavaca, 1988; Peixoto et al., 1990). Based on the results of these evaluations the population 64 QPM was released in 1988 as BR 451. BR 451 matures early and is well adapted to a wide range of environments in the country. It is agronomically competitive with some of the most popular early maturity normal varieties cultivated in Brazil and its average yield (ear weight) was 4.3 tons/ha in trials conducted in 41 environments. In the same environments, the variety BR 5028, an early normal yellow variety obtained from the population Tuxpeño 1, yielded 4.0 tons/ha.

BR 451 has white dent kernels with a good level of endosperm modification and tryptophan and lysine contents about 50% superior to that of normal maize. Its flour has excellent properties for mixture with wheat flour in breadmaking and for pasta production (Magnavaca, 1992). BR 451 has been continuously improved and at present it has undergone four cycles of mass selection and three cycles of half-sib selection (Guimarães et al., 1994a). After its release, 117 tons of foundation seed were multiplied by farmers and small seed companies.

BR 473

After the release of BR 451 efforts were directed towards development of a yellow QPM variety, since farmers in Brazil traditionally grow yellow maize. The result of this effort was the development of BR 473, a synthetic variety released in 1994. BR 473 is an early maturity synthetic originating from six elite inbred lines, four of them of flint and two of dent endosperm type. These inbreds were used for production of three experimental QPM hybrids that showed agronomic performance similar to that of BR 201, a double-cross hybrid widely grown in Central and Southern Brazil. BR 473 has yellow, semi-flint, kernels (Guimarães et al., 1994b). Chemical analysis of whole kernels has shown levels of 0.09% tryptophan and 0.4% lysine, nearly 50% more than the levels of normal maize cultivars. It is expected that its semi-flint kernels will be advantageous to the industry, which requires maize cultivars with improved endosperm physical properties. During the release of BR 473, TV, radio, newspapers, and magazines were used to inform the public about the benefits of this variety.

QPM Population Improvement

CMS 453

This experimental population was derived from Population 65 QPM of CIMMYT. It is a productive early maturing genotype with several desirable agronomic traits. CMS 453 has kernels with semi-flint texture and orange/yellow color. This material is adapted to a wide range of environments in Brazil and has proved to be a good source of inbred lines. A cycle of selection against inbreeding depression was recently obtained from S_2 progenies of this population (Guimarães et al., 1994c).

CMS 474

CMS 474 is an early maturing experimental population derived from introgression of the normal, well adapted Tuxpeño variety BR 106 (25%) into Population 66 QPM (75%) of CIMMYT. It has yellow semi-

dent kernels with high nutritional quality. Initial evaluations revealed grain density of 1.24 g/cm^3.

CMS 455c

CMS 455c is an early maturing experimental population originating from the introgression of the normal aluminum tolerant population CMS 14c (25%) into Pool 25 QPM (75%). This population was synthesized to incorporate elite germplasm with good tolerance to toxic aluminum levels, a serious problem commonly found in tropical soils. CMS 455c has yellow semi-flint kernels with high nutritional quality. Initial evaluations revealed grain density of 1.22 g/cm^3 (Guimarães et al., 1994d). Introgression of CMS 14c into QPM germplasm is desirable since it shows high levels of heterosis with BR 106, a good source of inbred lines for the hybrid program.

CMS 52

The experimental population CMS 52 is a very early maturing, semi-dent, yellow synthetic variety that originated from the intercross of 12 elite QPM inbred lines. This population has shown good agronomic performance when compared to materials of similar cycle and its release in the Northern, Northeastern, and Southern regions of Brazil is being evaluated. Very early cycle QPM materials are advantageous, especially for the semi-arid regions of Northeastern Brazil, where recurrent drought has prevented more successful maize cultivation. Since the number of very early maturity varieties available in Brazil is very small, there is a good possibility to fulfill the demand with good QPM germplasm that requires short growing cycles (Guimarães et al., 1994e).

CMS 475

CMS 475 is another very early maturing experimental population originating from introgression of the population Illinois High Protein (25%) into the population CMS 52 QPM (75%). This population was synthesized with the objective of developing a high quality genotype that accumulate high levels of protein in the endosperm. Also, this population can be useful in studies of the mechanisms controlling high protein accumulation in the kernel. At this point this population has predominantly yellow kernels of semi-dent type. Preliminary evaluations revealed that grains derived from this population have 11.8% total protein and 0.11% tryptophan. (Guimarães et al., 1994d).

CMS 476

CMS 476 is an early maturing experimental synthetic variety generated by the intercross of six QPM inbred lines. This population has semi-dent, white kernels and is being improved as an option to farmers that prefer to use maize with white kernels.

CMS 477

CMS 477 is a normal experimental population selected for high gamma-zein content. Gamma-zein is a storage protein whose accumulation parallels *o2* endosperm modification. This protein is rich in cysteine and its primary structure resembles that of gliadin, a wheat prolamin that has been implicated in breadmaking quality. Since modified *o2* have been shown to have better breadmaking quality in mixtures with wheat, when compared to normal maize, there is a possibility that gamma-zein is a factor that affects the functional properties of its flour. To generate this population the normal inbred line W64A was crossed with the population BR 451 QPM and from the segregating population seeds displaying the normal, non-opaque phenotype were selected. Afterwards, five cycles of backcrossing with BR 451 were carried out with selection for normal, non-opaque seeds for every cycle. The functional properties of CMS 477 flour will be evaluated to investigate if gamma-zein content affects the breadmaking quality of maize flour.

CMS 478

CMS 478 is an experimental population synthesized to study the possibility of combining high lysine and high methionine contents in modified *o2* backgrounds. High methionine content can be achieved through the overproduction of a storage protein, known as delta-zein, that contains 23% of this essential amino acid. The mechanism involved in the regulation of delta-zein overproduction is partially known and characterized. We crossed the inbred line BSSS 53, that overproduces delta-zein, with the population Pool 23 QPM. From the segregating F2 population we derived semi-opaque F3 families that were recombined to generate CMS 478. This population is being selected to increase seed modification. During the process of selection the seeds will be biochemically screened to verify if segregation for high delta-zein and methionine contents occur.

HYBRID DEVELOPMENT PROGRAM

The maize hybrid seed industry is well developed in Brazil. In 1992/93 about 147,933 tons of improved seed were produced (ABRASEM, 1994), a volume sufficient to plant an area of 7.4 million

ha. One of the objectives of the QPM hybrid program at CNPMS is to develop high yielding QPM hybrids with a potential to compete in the market. QPM will achieve general use if hybrids are produced that have agronomic performance similar to normal hybrids and retain an enhanced nutritional quality.

Besides CNPMS/EMBRAPA, private seed companies have been working with QPM and there is a great possibility that after release of the first QPM hybrid other companies will also invest in QPM hybrid development.

The main activities of the QPM hybrid program of CNPMS/EMBRAPA are geared towards development of single-, double- and three-way cross hybrids that are able to compete agronomically with normal endosperm hybrids. Also, emphasis is directed towards development of stablely modified, high yielding, and high quality synthetic varieties of different heterotic patterns, with the objective of overcoming specific QPM problems and deriving new sources of inbred lines.

Table 1. Means and general combining ability estimates for ear weight and means for protein, tryptophan and kernel density of a diallel between five QPM populations evaluated in eleven environments of Brazil during 1990 and 1991.

Material	Ear weight		Protein[2]	Tryptophan[2]	Kernel
	Mean (t/ha)	GCA[1] (t/ha)	%	(%)	Density[3] (g/cm^3)
Population 65	5.2	0.2	8.0	1.00	1.28
65 x 66	4.8		8.1	1.02	1.25
65 x P 25	5.0		8.1	0.98	1.25
65 x P 26	5.1		8.2	0.90	1.24
65 x Am. Crist.	4.7		8.3	0.98	1.24
Population 66	4.8	0.1	8.7	1.02	1.26
66 x P25	4.1		8.9	0.94	1.25
66 x P26	4.6		8.9	1.02	1.24
66 x Am. Crist.	4.9		9.0	0.98	1.24
Pool 25	4.7	0.0	7.9	1.09	1.26
P 25 x P 26	4.9		8.7	1.02	1.26
P 25 x Am. Crist.	4.7		8.7	0.95	1.23
Pool 26	4.9	-0.1	8.6	0.96	1.25
P 26 x Am.Crist.	4.7		8.2	1.06	1.24
Am. Crist.	4.5	-0.2	7.5	1.08	1.25
BR 451	5.2		8.5	1.06	1.25
LSD (0.05)	0.7		1.2	0.17	0.05

[1]- General combining ability effects (Griffing,1956); [2]- From two environments
[3] - From one environment, method of Wessel-Beaver et al., 1984.
Source: Guimarães et al., 1994f.

Heterosis of QPM Populations

In order to determine heterotic patterns and combining abilities of the populations to be used in the QPM hybrid program, a series of diallel trials were evaluated in eleven environments of Brazil (Table 1). There were no significant specific combining ability effects for ear weight, protein content in the endosperm, tryptophan content and kernel density. Significant general combining ability was found only for ear weight. The lack of heterosis among these materials indicated the necessity of developing heterotic synthetic varieties to be used as sources of inbred lines in our hybrid program.

Depression Due to Inbreeding

In a hybrid program, source populations are chosen based on the level of heterosis they present and on the potential they have to generate inbred lines with vigor sufficient for seed production, especially if the goal is to develop three-way or one-way cross hybrids. Therefore, before choosing the populations to be incorporated, they should be evaluated for inbreeding depression.

One such evaluation is shown in Table 2, where comparisons of several traits evaluated in 4 different environments have been made for the generations S_0 and S_1 of 5 QPM populations. The data show that depression due to inbreeding is variable in function to the population and the trait evaluated. Tryptophan content in endosperm protein and kernel density have not been significantly affected by inbreeding. The S_1 generations of three populations have significantly higher percentages of ear rot when compared to the S_0 generations. The reduction in ear weight in S_1 generations was significant relative to S_0 generations, but the decrease was comparable to results obtained with similar studies for 28 normal populations utilized in the breeding program of CNPMS (Santos et al., 1994). These results indicate the possibility of utilizing these populations as sources of inbred lines for the hybrid program.

QPM Inbred Line Development and Evaluation

The main emphasis of the program is on development of inbred lines with a kernel phenotype similar to that of normal maize and a protein quality similar to that of *o2*. The QPM populations being selected at CNPMS are still segregating for seed modification. When we examined 1000 kernels from flint and dent types for degree of softness, we found that 50% of the dent type kernels had 50% or more opacity, while only 34% of the flint types kernels were in the same category (Table 3). During the process of inbred line extraction, only the most vitreous seeds (a maximum of 25% of the endosperm with an opaque texture) are selected. In each generation of selection, lines that show less than fifteen

Table 2. Comparison of S_0 and S_1 generation of five QPM populations for ear weight (ton/ha), ear rot (%), tryptophan content in protein of endosperm and kernel density (g/cm^3). Materials evaluated in four environments during the 1993/94 season.

Material	Ear Weight			Ear Rot			Tryptophan[2]			Kernel Density[2]		
	S_0	S_1	D	S_0	S_1	D	S_0	S_1	D	S_0	S_1	D
Pop 65	6.9	4.2	-39**	6.5	13.8	112	1.09	1.18	8	1.28	1.25	-2
Pop 66	7.0	4.1	-42**	5.9	15.3	159*	1.09	1.19	9	1.26	1.24	-2
Pool 25	7.1	3.9	-45**	6.7	18.5	176*	1.20	1.12	-7	1.26	1.23	-2
Pool 26	7.1	3.4	-48**	7.3	18.1	147*	0.97	1.01	4	1.25	1.21	-4
A. Cristal.	6.7	4.4	-34**	5.0	10.6	112	1.20	1.08	-10	1.25	1.24	1
Mean	7.0	4.0	-43**	6.3	15.3	142	1.11	1.12	1	1.26	1.23	-2

[1] $D = (S_1-S_0)\ 100/S_0$
[2] From one environment
* Significantly different at 0.05 level of probability
** Significantly different at 0.01 level of probability
Source: Guimarães et al., 1994g.

Table 3. Evaluation of 6 QPM populations according to frequency of kernels with different levels of softness in samples of 1000 kernels.

Material	Kernel type	Percentage of kernels per class of softness					
		percentage of softness					
		0%	25%	50%	75%	100%	>50%
Pop 65	flint	6	62	21	12	0.1	33
Pool 25	flint	8	61	21	9	0.2	30
A. Cristalino	flint	12	49	24	13	2	39
Mean	flint	9	57	22	11	0.8	34
Pop 66	dent	5	44	22	20	10	52
Pool 26	dent	5	31	22	36	6	64
BR 451	dent	7	62	21	10	2	33
Mean	dent	6	46	22	22	6	50

Source: Guimarães et al., 1994k.

Table 4. Kernel density and weight of 25 kernels of 22 QPM hybrids segregating for kernel modification. Materials evaluated during the 1991/92 season.

Kernel trait	Kernel phenotype		Difference	
	Vitreous	Opaque	(V-O)	%
Density (g/cm^3)	1.25	1.20	0.05^{**}	4
Weight (g)	7.73	6.87	0.86^{**}	11

Source: Guimarães et al., 1994k.

more vitreous seeds per ear are discarded, to reduce the probability of hybrid production with undesirable *o2* characteristics.

If careful selection of endosperm modification is not done during the development of inbred lines, there is a risk that the resulting hybrids will have undesirable kernel phenotypes, as shown in Table 4. Twenty-two QPM hybrids segregating for endosperm modification were evaluated for kernel characteristics and the results showed that opaque kernels were 4% less dense and 11% lighter when compared to vitreous kernels. Even if segregating hybrids show excellent agronomic performance they have little chance of being successful in the Brazilian market.

The effect of selection for kernel modification in quality traits of inbred lines have also been evaluated. Table 5 shows this type of evaluation by comparing kernel phenotype and quality of a group of 47 S_1 lines extracted from the population CMS 453. The correlation values for lysine and protein were high and significant, and there were small mean differences for these traits in endosperms of more vitreous and more opaque kernels. These results indicate the possibility of selecting inbred lines with a more vitreous kernel phenotype and adequate protein quality and quantity, in this population. Since protein quantity and quality can be affected by the environment, evaluation of lines "per se" is done in comparison to an intercalary check. Variations in the

Table 5. Quality traits comparison for vitreous and soft kernels in 47 segregating S_1 lines derived from the population CMS 453. Materials evaluated during the 1991/1992 season.

Endosperm trait	Kernel		Difference		Correlation
	Vitreous	Opaque	(V-O)	%	
Modification[1]	1.7	3.1	-1.40		
Protein	7.24	7.02	0.22**	3	0.93**
Lysine[2]	4.29	4.49	-0.20**	-4	0.70**

**significant at 0.01 level of probability
[1] Scale of 1 (completely modified) to 5 (soft), Vasal et al, 1984
[2] % protein
Source: Guimarães et al., 1994k.

Table 6. Performance of selected QPM inbred lines crossed to two testers, in two topcross trials evaluated in four locations during the 1993/1994 season.

Line	Yield[1] (%)		Grain quality[2] (%)	
	Tester 1	Tester 2	Tryptophan	Protein
1	110	123	93	86
2	105	97	107	113
3	103	117	99	102
4	102	112	99	95
5	94	112	114	117
6	93	111	98	122

[1] - Related to the mean of the QPM hybrid check of the trial
[2] - Related to the mean of the intercalary check (BR 451) mean grown between 6 rows in the selfing plot.

performance of the reference genotype are used to infer environmental variations, especially those due to heterogeneity in soil fertility.

To direct the formation of synthetic varieties and high yielding hybrids, the inbred lines with good performance "per-se" and acceptable seed phenotype are evaluated in crosses with two divergent testers of narrow genetic basis. Table 6 exemplifies this type of evaluation, showing performance in crosses with two testers, of six inbred lines selected for yield and other agronomic traits. The results indicate that lines number 2 and 5 show higher probability of producing superior QPM hybrids. Based on a visual scale, crosses from selected lines have stability for modifier genes in several different environments. With this methodology it is possible to discard germplasm with serious problems for modification (Guimarães et al. 1994h).

Our experience shows that it is necessary to evaluate a great number of QPM lines to increase the chance of overcoming problems associated with the usual agronomic traits as well as problems with specific QPM traits. Up to now, four sets of QPM inbred lines have been evaluated in top crosses and diallel trials (Guimarães et al., 1992a, 1992b, 1994i, and

1994j). Inbred lines developed at CIMMYT have also been introduced and evaluated for combining ability. It is important to point out that with the formation of new sources of inbred lines, such as divergent synthetics with stable vitreous kernels, high protein value and nutritional quality, a QPM hybrid program can be as expensive as a normal maize program. We suggest that inbred lines and single crosses should be identified to be used as international checks to compare the quality of QPM lines developed in different parts of the world. This germplasm with stable vitreous kernels and high protein quality and quantity could also be used as donor stocks in conversion of normal to QPM material.

Ear Diseases

One of the main problems of non-modified *o2* materials is the high incidence of ear rots. Levels of ear rot susceptibility of several experimental QPM have been evaluated since 1989. Table 7 shows comparisons of ear rot levels in ten different trials of QPM hybrids and normal checks.

The results summarized in Table 7 show a wide range of performance for ear rot susceptibility among the QPM hybrids. The mean for the QPM hybrids computed from eight trials was similar to or even smaller than the mean of the normal hybrids. The two highest yielding QPM hybrids in each trial had smaller or similar levels of ear disease incidence, when compared to the mean of the QPM hybrids and the mean of the normal hybrids. Trials 9 and 10 correspond respectively

Table 7. Comparison of QPM and normal hybrids for ear rot percentage in ten trials.

		Ear rot (%)			
		QPM hybrid			Normal hybrid
Trial	Location	Range	Mean	2 top yield	Mean
01	2	0-25	07(96)[1]	04	12(4)[1]
02	3	8-57	28(30)	13	17(6)
03	3	8-47	24(61)	08	22(3)
04	4	12-33	22(22)	15	15(3)
05	6	3-07	05(10)	06	07(5)
06	3	4-14	07(14)	06	10(6)
07	3	6-17	09(19)	07	10(6)
08	3	5-13	08(17)	10	09(8)
09	3	0-20	09(135)	05	12(4)
10	3	0-16	05(134)	05	11(10)

Source: Guimarães et al., 1994l.

[1] - Number of entries for each mean (in parenthesis).

to 135 and 134 QPM lines tested for ear disease tolerance in two different topcross trials evaluated in the 1993/94 season. The results indicated that the top-crosses showed smaller mean ear rot values (9% and 5%) than the normal checks (12 and 11%). These results suggest that with the available germplasm it is possible to develop QPM hybrids with low incidences of ear rots.

Grain Quality Evaluations

The materials developed by the QPM breeding program of CNPMS have been continuously selected for protein content and quality levels on the basis of whole grain analysis. Protein and tryptophan content has been determined at CNPMS's laboratory following the procedure described by Villegas et al. (1984). Lysine concentration has been estimated by the method of Hernandez & Bates (1969).

Table 8 exemplifies the means of several traits related to grain quality in 49 QPM hybrids and 11 normal hybrids grown in the same environment. When we consider levels of protein and oil as well as grain density it is apparent that we can select QPM hybrids capable of competing with the normal hybrids used as checks. Due to the predominance of flint and semi-flint kernels in the QPM hybrids, the weight per one thousand kernels is generally inferior when compared to normal hybrids. However, selection of QPM materials with flint or semi-flint kernel texture is advantageous since our experience shows that they usually have a more modified kernel phenotype when compared to dent types.

With the objective of generating information to better direct the efforts of the breeding program towards quality maintenance and improvement, correlation studies were developed for several traits involved in the determination of grain quality. Table 9 exemplifies one such evaluation carried out on 43 QPM hybrids grown in two environments. The results indicated that grain density has a low, non-significant correlation value with traits related to protein quality,

Table 8. Comparison of whole grain quality in 49 QPM hybrids and 11 normal hybrids.

Grain traits	Hybrid		
	QPM		Normal
Protein	10.50	(99%)[1]	10.60
Tryptophan	0.09	(150%)	0.06
Lysine	0.39	(144%)	0.27
Oil[2]	4.13	(106%)	3.91
Density	1.22	(98%)	1.25
Weight (1000 kernels)	281	(92%)	305

[1] In relation to normal mean; [2]Analysis made at ESALQ/USP

Table 9. Correlation studies for quality traits of 43 QPM hybrids evaluated in two environments during the 1993/1994 season.

Trait Correlations	Correlation Coefficients (r)
Protein x tryptophan in the protein	-0.42**
Protein x tryptophan in the grain	0.48**
Tryptophan in the protein x tryptophan grain	0.59**
Protein x Density	0.06
Tryptophan in the protein x Density	-0.14
Tryptophan in the grain x Density	0.20

**Significant at 0.01 level of probability

indicating that it is possible to select hybrids with higher grain density and higher protein content and quality. Protein content was negatively correlated with tryptophan content in the protein and tryptophan in the grain was positively correlated to both protein content and tryptophan in the protein. These results indicate that tryptophan in the grain is better suited to select QPM hybrids with higher protein content and quality.

Identifying Competitive QPM Hybrids

Since 1984 the QPM breeding program of CNPMS has been actively searching for high yielding hybrids with good general agronomic performance and quality traits. The program was initiated with development of hybrids from full-sib families (Magnavaca et al., 1988), but soon it was determined that it was necessary to develop inbred lines and synthesize experimental hybrids with higher agronomic potential. In 1989 the first group of yellow S_3 lines derived from several populations of CIMMYT were evaluated in a topcross (Parentoni et al., 1992). From 1990 to 1995, six groups of double-cross and three-way experimental hybrids were evaluated in several locations of Brazil (Guimarães et al., 1992c, 1994h, 1995). In order to increase program competitiveness, each year new hybrids are synthesized in winter nurseries based on information from the trials conducted during the previous growing season. Thus, every year new information on inbred line combinations and performance in specific environments are being incorporated for production of new hybrids and synthetic varieties.

Evaluation of the first three sets of hybrids developed by the program did not reveal materials with agronomic performance sufficient to compete with the normal maize hybrids grown in Brazil. However, in the 1992/1993 season, some experimental hybrids proved to be agronomically competitive with top normal hybrids. One of these was the double-cross experimental yellow hybrid 92HD1QPM and based on its performance it could be commercially released in 1996. This hybrid

Table 10. Results from the best four experimental yellow double cross QPM hybrids and six normal endosperm double cross checks. Materials evaluated in 8 locations during the 1993/94 season.

Hybrid	Ear Weight (ton/ha)	Lodging (%)	Ear[1] Rot (%)	Whole Grain Traits[2] Density (g/cm^3)	Lysine (%)	Oil (%)
QPM						
92HD1	7.9	18	10	1.23	0.38	4.5
93HD3	7.5	22	8	1.27	0.37	4.2
93HD1	7.4	26	7	1.19	0.36	4.5
93HD12	7.2	26	11	1.22	0.36	4.4
NORMAL						
BR 201	6.8	34	10	1.25	0.21	3.4
BR 205	6.7	20	9	1.22	0.25	3.9
BR 206	7.5	22	8	1.22	0.24	3.3
AG 122	8.0	18	13	1.25	0.24	3.9
C - 435	9.1	11	9	1.28	0.25	3.2
G - 600	7.7	20	15	1.24	0.23	4.0
LSD (0.05)	1.7	8	5			

[1] - means of five locations
[2] - means of one location
Source: Guimarães and Lopes, 1995.

yielded an average of 8.1 ton/ha in trials conducted in 32 environments representing the major growing regions of Brazil. The normal check used in these trials, BR 201, a widely planted double-cross hybrid of EMBRAPA, yielded 7.5 ton/ha (Guimarães and Lopes, 1995). Table 10 summarizes data for the four best yellow, double-cross QPM hybrids compared with six top normal double cross hybrids used as a check. On average, QPM hybrids are competitive with normal hybrids for yield, lodging, grain density and ear diseases, and superior in lysine and oil content.

Also, the QPM hybrid program of CNPMS has generated three-way hybrids competitive with top normal maize (Table 11). The market for three way hybrids in Brazil has been growing steadily among the more progressive farmers.

CONCLUDING REMARKS

Utilization of QPM in Brazil can have a significant social impact since malnutrition remains a major problem that plagues a portion of the rural and urban populations. Also, widespread use of high-quality maize could result in economic gains to the country since a large and efficient swine and poultry market could benefit from production of feed with reduced use of soybean meal.

Table 11. Comparison of the best five experimental yellow three-way cross QPM hybrids and three normal three-way checks. Materials evaluated in 9 locations during the 1994/95 season.

Hybrid	Ear Rot[1] (%)	Lodging[2] (%)	Ear weight (ton/ha)
QPM			
94HT33	13	19	8.3
94HT41	15	15	8.0
94HT37	17	20	8.0
94HT40	21	10	7.8
93HT44	12	16	7.7
NORMAL			
P 3041	16	12	8.6
BR 3123	11	15	8.4
AG 5011	16	19	8.1
LSD (0.05)	9	13	1.2

[1] From five locations
[2] From eight locations

Since 1983, CNPMS/EMBRAPA has developed QPM germplasm adapted to the environmental conditions prevailing in the tropical belt of the world, where the intense climate, low soil fertility (associated with soil acidity) and high pressure of insect and diseases generally limit maize production. The CNPMS's program has a multidisciplinary group of researchers involved in genetics, breeding, biochemistry, molecular biology, human and animal nutrition, and extension. Several government and private institutes such as county governments, NGO's, cooperatives, universities, research and extension institutes, and private companies involved in seed production, processing and food production, etc., are involved in all steps leading to development and utilization of QPM.

CIMMYT's maize populations have demonstrated excellent adaptation to the conditions prevailing in the main maize growing areas of Brazil, making it possible to develop QPM cultivars in shorter periods of time which are capable of competing with the normal maize cultivars. QPM cultivars have been tested in all 27 states of Brazil and besides EMBRAPA/CNPMS, other public and private companies are developing QPM improvement programs. Up to now, two open-pollinated QPM varieties of EMBRAPA have been released to the farmers and some experimental double-cross and three-way hybrids have been identified which are agronomically competitive with top normal maize hybrids cultivated in Brazil. A high-yielding, yellow double-cross QPM hybrid has been evaluated with possibilities of release in 1996. Through a

franchising scheme, the seed will be produced by 28 seed commercial companies.

Besides cultivar development, the CNPMS program has been generating and making knowledge available on breeding strategies and utilization of QPM for both human and animal nutrition. Multimedia strategies such as TV, radio, newspapers, magazines, field demonstrations, and meetings have been utilized to promote QPM and to educate people about its potential. Knowledge and the available germplasm has been shared with national and international groups interested in QPM development. Cooperation in several fields of investigation has been developed with international institutes such as CIMMYT, the Grain Crops Institute of South Africa, the Crops Research Institute of Ghana, the Sasakawa Global 2000 Program and the University of Arizona.

We believe that the development of an international network to promote QPM development and utilization would be of great value to QPM researchers, as well as to the general public which could benefit from the greater availability of high-quality maize. A start could be the production of an international QPM newsletter and a video showing the QPM experiences throughout the world. We also suggest, as a marketing strategy, that a commercial name should be found to better identify QPM grain and QPM products.

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