Quality protein maize for nutritional security: rapid development of short duration hybrids through molecular marker assisted breeding

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Quality protein maize (QPM) originally developed in the late 1990s at CIMMYT, Mexico possesses roughly twice as much usable protein as normal maize grown in the tropics. The improved quality of the protein in QPM is due to enhancement in lysine and tryptophan – the two limiting amino acids that are known to be regulated by *opaque*2 gene and associated modifiers. QPM has widely been adopted for cultivation in the developing world to fight protein malnutrition. In India, QPM was released for commercial cultivation almost a decade ago by introducing QPM lines from CIMMYT. However, all these inbred lines are of longer duration and thus, give rise to QPM hybrids of full season maturity. Utilizing marker assisted selection we transferred *opaque*2, a recessive gene, to two early maturing Indian inbreds that were, in turn, crossed to give rise to an early duration QPM hybrid, Vivek QPM 9, with 30% higher lysine and 40% more tryptophan while retaining the same level of productivity. Vivek QPM 9 yielded at par with Vivek Maize Hybrid 9 in the multilocation yield trials. Vivek QPM 9 has further been found suitable for cultivation under organic farming.

Keywords: Marker-assisted selection, molecular breeding, *opaque*2 gene, quality protein maize.

CEREALS supply more than half of the dietary protein to human being, yet their proteins are nutritionally imbalanced as the most abundant storage protein of cereals, prolamin, is devoid of several amino acids essential for the monogastric animals, lysine being the most limiting. Maize is a globally important crop and preferred staple food for more than 1 billion people in Sub-Saharan Africa and Latin America, where animal source of protein is not affordable by the common people[1]. Maize is an important cereal in Asia too, but here more than half of the produce is used for livestock feed, primarily due to strong economic growth and rapid urbanization experienced by many countries of the subcontinent, including India[2]. A typical mature maize kernel contains a small embryo and a much larger endosperm, which is 90% starch and 10% protein. Approximately 70% of this protein is composed of several types of prolamin known as zeins that are alcohol-soluble. Four types of zeins, viz. α, β, γ and δ are found in maize and they are distributed in a distinctive pattern. These proteins are rich in glutamine, leucine and proline[3]. In normal maize, all protein fractions except zeins are balanced in the amino acid content and are rich in lysine as well as tryptophan. Normal maize protein is known to have a biological value of 40% that of milk[4] and therefore, needs protein supplementation from legumes and animal products. The essential amino acids like lysine, tryptophan and threonine are found in reduced quantities, lysine being the most limiting followed by tryptophan. In contrast, quality protein maize (QPM) has nearly twice the amount of lysine and tryptophan, which make the protein of QPM equivalent to 90% of the milk protein[5]. The nutritional quality of normal maize grain can, therefore, be improved substantially by altering the composition of the zeins present in the endosperm. This has so far been done by deployment of mutants through conventional breeding, but it can now be accomplished more precisely and rapidly by applying molecular breeding tools. We present here a brief account of QPM in conjunction with the deployment of DNA marker technology for accelerating the pace of development of a QPM hybrid, its evaluation and release for commercial cultivation.

*opaque*2 – a gene for improving quality of protein in maize

A natural spontaneous maize mutant with soft and opaque grain was found in a Connecticut maize field in USA during the 1920s, which was later named as *opaque*2 (*o*2) maize[6] by Singleton. The mutant was passed onto Mertz at Purdue University, USA, who, in turn, reported that the *o*2 homozygous maize contained substantially higher lysine (+69%) in the grain endosperm compared to normal maize[7]. The increase in lysine content doubled the biological value of the *o*2 maize protein and this increase in protein quality is due to increase in the ratio of non-zein

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to zein proteins[3]. Further, reduction of leucine in these mutants is considered desirable since it makes the leucine–isoleucine ratio more balanced and helps in liberating more tryptophan for niacin biosynthesis. Although the *o*2 mutant had better lysine content, the pleiotropic effects of this gene manifested in the form of soft endosperm, increased susceptibility to insect-pests and fungal diseases, inferior food processing and reduction in grain yield, discouraged its acceptability. Therefore, other mutants[8,9] were subsequently developed. However, all of them suffered from disadvantages, the details of which are described elsewhere[2].

Quality protein maize

Soon after the discovery of the nutritional benefits of *o*2 mutations, several breeding programmes were initiated to incorporate the gene aiming at conversion of normal endosperm populations and inbreds to *o*2 versions through direct backcrossing. However, the soft endosperm of the *o*2 maize coupled with reduced grain yield and susceptibility to pests did not allow its widespread adaptation[10]. During this process of conversion, partially hard endosperms (vitreous) were noticed. Meanwhile, endosperm modifications in *o*2 kernels with much less negative pleiotropic effects were reported, which opened the door for introducing selection of hard endosperm modifications in the *o*2 breeding programme[11]. Consequently, now the approach for selection of *o*2 plants at the phenotypic level for the modifiers became a viable approach. The resultant genotypes with elevated lysine and tryptophan levels and without the negative effect of soft endosperm were termed as 'quality protein maize' by CIMMYT, Mexico. QPM, thus, looked and performed like normal maize, except that its nutritional value got elevated.

Development of QPM genotypes through conventional breeding

The most important aspect in developing acceptable QPM lines is to combine the nutritional advantages offered by the *o*2 mutation with the *o*2 modifiers along with the acceptable agronomic traits like grain yield, resistance against diseases and grain vitreousness. During the 1980s, CIMMYT took initiatives to convert a number of non-QPM genotypes to QPM genotypes, representing tropical, subtropical and highland maize germplasm with different maturity durations. They followed a 'modified backcrossing-cum-recurrent selection' and during the conversion process, they also emphasized grain yield, kernel modification, reduced ear rot incidence and other agronomic traits. In a short span of 5–6 years, CIMMYT could convert many normal germplasm into QPM, which were as good as their non-QPM counterparts for grain yield and other agronomic traits. Thereafter, CIMMYT initiated development of QPM hybrid in 1985, since hybrid maize occupies a significant percentage of the total maize area and the grain yield of hybrids in maize is significantly higher. They identified a number of lines with better combining ability[12,13]. In many cases the test-hybrids outperformed the local hybrids. After three decades of intensive research, the team led by Vasal developed a number of QPM lines/hybrids that revolutionized maize cultivation around the world. This contribution was later recognized by conferring the 'World Food Prize' on Vasal and Villegas in 2000. India is one of the first few countries to focus on *o*2 maize[14] and released three *o*2 composites, namely Shakti, Rattan and Protina in 1970 followed by one modified superior *o*2 composite 'Shakti 1' in 1997. Later, India released eight QPM hybrids, seven of which were developed from the QPM inbreds of CIMMYT as parental lines and are of full season maturity (Table 1)[15].

Development of QPM hybrid through marker assisted selection: conversion of normal maize inbreds into QPM

In order to shorten the period normally required for development of QPM hybrids through the conventional method of backcrossing, marker-assisted selection (MAS) was the method of choice, as a few molecular markers were already known within the *o*2 gene and these makers were capable of detecting the *o*2 gene even in heterozygous state. Utilizing this method, we have reported rapid conversion of normal maize inbred into QPM inbred[16].

To convert normal maize hybrid into QPM hybrid, a promising hybrid, viz. Vivek Maize Hybrid 9 (developed by Vivekananda Parvatiya Krishi Anusandhan Sansthan, Almora) was selected for converting into QPM. The hybrid matures in 85–90 days and yields 50–60 q/ha maize grain. The hybrid was released for commercial cultivation in zone I (Himalayan states) as well as zone IV comprising the states of Andhra Pradesh, Tamil Nadu, Karnataka and Maharashtra by the Central Seed Subcommittee on Crop Standard and Notification in the year 2000. This hybrid was developed by crossing two inbreds, viz. CM 212 and CM 145, which were used as recipients of the *o*2 gene. Donor inbred line; CML 180 and CML 170 were obtained from CIMMYT and utilizing the method developed in our laboratory[16], we converted CM 212 and CM 145, the normal maize inbred lines into QPM inbreds, VQL 1 and VQL 2 respectively. VQL 1 showed 92.0% of the recipient genome (CM 212), whereas VQL 2 possessed 94.44% genome of the recipient parent (CM 145). The two converted QPM inbreds were crossed to recover QPM hybrid, Vivek QPM 9. The quantitative analysis of tryptophan was done using colorimetric estimation and lysine was measured with HPLC.

Table 1. QPM cultivars released for commercial cultivation in India

Culture	Pedigree	Year of release	Centre	Maturity group
Shakti	Composite	1970	AICRP	Full season
Rattan	Composite	1970	AICRP	Full season
Protina	Composite	1970	AICRP	Full season
Shakti 1	Composite	1997	DMR	Full season
Shaktiman 1	(CML 142 × CML 150) × CML 186	2001	Dholi	Full season
Shaktiman 2	CML 176 × CML 186	2004	Dholi	Full season
HQPM 1	HKI 193-1 × HKI 163	2005	Uchani	Full season
Shaktiman 3	CML 161 × CML 163	2006	Dholi	Full season
Shaktiman 4	CML 161 × CML 169	2006	Dholi	Full season
HQPM 5	HKI 163 × HKI 161	2007	Uchani	Full season
HQPM 7	HKI 193-1 × HKI 161	2008	Uchani	Full season
Vivek QPM 9	VQL 1 × VQL 2	2008	Almora	Extra early

Table 2. Comparison of QPM, non-QPM inbreds and hybrids – agronomic traits and reaction to major diseases and insect-pests in the NW Himalayas

Trait	CM 212	VQL 1	CM 145	VQL 2	CML 170	CML 180	Vivek Maize Hybrid 9	Vivek QPM 9
Plant height (cm)	144	155	144	135	190	180	195	195
Reaction to turcicum blight (scale 1–5)	1.5	1.3	1.5	1.5	1.5	1.8	1.0	1.0
Days to silking	53.0	53.5	53.2	53.7	62.0	60.0	51.0	52.0
Days to maturity	85–90	85–90	85–90	85–90	110–112	108–110	85–90	85–90
Protein content (%)	9.01	8.1	9.8	8.4	8.9	8.7	9.5	8.5
Tryptophan (%)	0.42	0.52	0.55	0.58	0.87	0.9	0.59	0.83
Kernel hardness	Hard	Hard	Hard	Hard	Hard	Hard	Hard	Hard
Grain yield (t/ha)	4.03	4.07	3.39	3.44	4.1	4.5	5.9	5.8

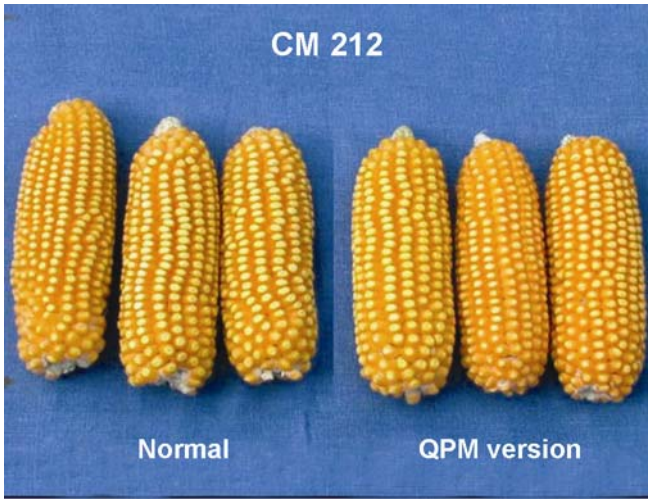

Figure 1. Normal and QPM version of CM 212 (VQL 1).

Field evaluation of the MAS-converted QPM inbreds and hybrid

The two QPM inbreds were evaluated in the field. The agronomic characteristics, viz. days to 50% silking, days to pollen shed, grain yield, total protein and tryptophan content in the endosperm along with reaction to major diseases and insect-pests of these two lines along with their parents were recorded and are presented in Table 2. The newly converted QPM inbreds were almost similar to the original inbreds, except that the QPM inbreds, VQL 1 (Figure 1) and VQL 2 (Figure 2) showed 6–24% gain in tryptophan over the respective normal inbreds (Table 3), without any loss in yield. The agronomic and biochemical attributes of the reconstituted QPM hybrid (Vivek QPM 9) and the non-QPM hybrid (Vivek Maize Hybrid 9) are also presented in Table 3, which shows that the QPM hybrid contains 41% higher tryptophan and 30% more lysine compared to the non-QPM hybrid. The appearance of the kernel is yellow, semi-flint with cap as in Vivek Hybrid 9, with straight rows and low tip sterility (Figure 3). The hybrid was tested under the All India Coordinated Research Project (AICRP) on maize for two years. It was also tested in the 'State Varietal Trial' under organic conditions in Uttarakhand. The results of these multilocation trials are discussed below.

Multilocation trials of the MAS-converted QPM hybrid under AICRP

Vivek QPM 9 was evaluated during Kharif 2005 and 2007, under the AICRP on Maize at seven locations in zone I (comprising Jammu and Kashmir, Himachal Pradesh, Uttarakhand and Meghalaya) and thirteen

Table 3. Amino acid profile of non-QPM (Vivek Maize Hybrid 9) and QPM hybrid (Vivek QPM 9)

Hybrid	Vivek Maize Hybrid 9	Vivek QPM 9	Percentage increase/ decrease over Vivek Maize Hybrid 9
Protein (%)	9.5	8.5	
Tryptophan (% protein)	0.59	0.83	41
Lysine	3.25	4.19	30
Leucine	14.10	12.36	–12
Histidine	2.57	3.15	23
Methionine	1.84	1.91	3.8

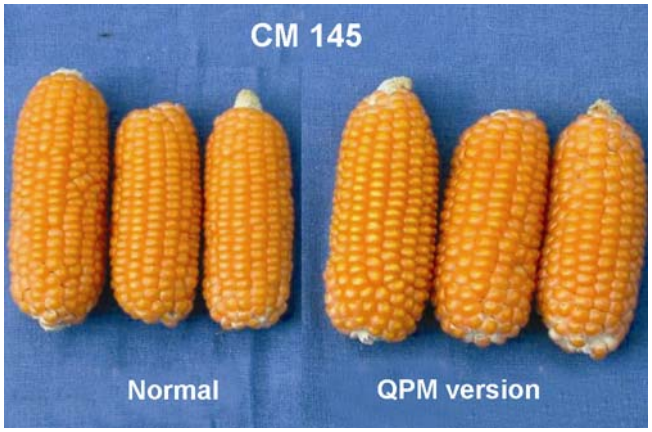

Figure 2. Normal and QPM version of CM 145 (VQL 2).

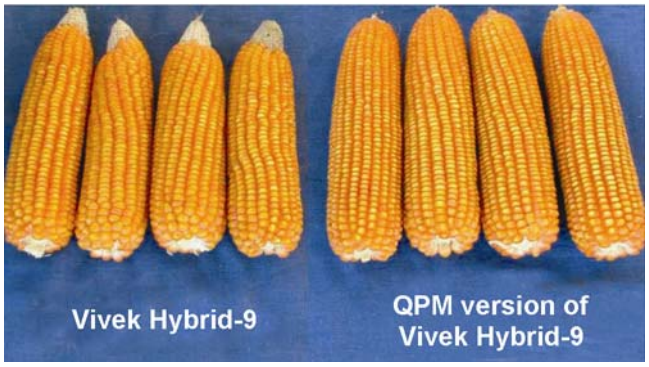

Figure 3. Cobs of Vivek Maize Hybrid 9 and Vivek QPM 9.

locations in zone IV (comprising Andhra Pradesh, Maharashtra, Karnataka and Tamil Nadu). The average productivity of the QPM hybrid (5843 kg ha^{-1} in zone I and 5435 kg ha^{-1} in zone IV) was at par with Vivek Maize Hybrid 9 (5931 kg ha^{-1} in zone I and 5404 kg ha^{-1} in zone IV) in both the zones over the years (Table 4). Besides, this hybrid showed 41% higher tryptophan in the endosperm compared to Vivek Maize Hybrid 9 (Table 3). In addition, the new QPM hybrid showed equal level of resistance to turcicum blight, the most important disease of maize crop (Table 2). Based on the performance for two years in zones I and IV, Vivek QPM 9 was released in 2008 for commercial cultivation in zones I and IV in India[17].

Table 4. Grain yield (kg/ha) of Vivek QPM 9 in zone I (Himalayan states) and zone II (Peninsular India)

	Zone I			Zone IV		
Hybrid	2005	2007	Mean	2005	2007	Mean
FQH 4567	6118	5567	5843	3531	7338	5435
Vivek 9	6360	5502	5931	3502	7306	5404
CD 5%	638	998		488	863	

Multilocation testing under organic farming in Uttarakhand

Vivek QPM 9 was also evaluated in Uttarakhand during *Kharif* 2006 and 2007 under organic farming. Table 5 shows that the mean yield of Vivek QPM 9 for two years was 4575 kg ha^{-1}, which is on par with that of Vivek Maize Hybrid 9 (4422 kg ha^{-1}). The productivity of Vivek QPM 9 was even numerically superior to Vivek Maize Hybrid 9 at four out of the six locations over two years (*Kharif* 2006 and 2007). Considering the yield performance and better quality protein, Vivek QPM 9 was released by the 'State Varietal Release Committee' of Uttarakhand in 2007 for commercial cultivation under organic farming.

Table 5 shows that Vivek QPM 9 yields at par with normal maize hybrid (Vivek Maize Hybrid 9) as well as composite (Vivek Sankul Makka 11) under organic condition. Thus, QPM hybrid can replace normal maize hybrid as well as composites without any yield penalty in these areas. Domestic consumption of QPM will thus help in reducing protein malnutrition in the hills and mountains. In view of this, F1 hybrid seeds of Vivek QPM 9 are being produced in large scale for distribution in Uttarakhand and other parts of the country. Few villages in Uttarakhand have also been identified for converting them into QPM villages.

Genetic systems and their role in enhancing the level of limiting amino acids in QPM

Development of QPM involves three genetic systems, viz. (i) recessive homozygous allele of the *o*2 gene,

Table 5. Grain yield (kg/ha) of Vivek QPM 9 in 'State Varietal Trial' of Uttarakhand under organic condition

Location	Vivek QPM 9	Vivek Maize Hybrid 9	Vivek Sankul 11	CD at 5%	CV %
Kharif 2006					
Hawalbagh	4503	3965	3344	1249	15.67
Majhera	4633	4800	4700	1160	19.60
Thal	1944	1204	1713	NS	27.80
Ranichauri	6020	5740	5084	1073	12.15
Mean (4)	4275	3927	3710	–	–
Kharif 2007					
Hawalbagh	4738	4493	3827	731	9.74
Majhera	5611	6333	5444	808	727
Mean (2)	5175	5413	4636	–	–
Weighted mean (2 yrs)	4575	4422	4019	–	–
Rank	1	3	4		
Superiority of Vivek QPM 9 (%)		3.46	13.83		

(ii) modifiers for kernel hardness, and (iii) amino acid modifiers, which affect the relative level of lysine and tryptophan content in grain endosperm. The recessive *o*2 allele is the central component of the QPM. This gene codes a transcription factor, which is a regulator for zein synthesis[18]. Zeins, in particular α-zeins, are the most abundant proteins in the maize endosperm, but they are known to be poor in amino acids like tryptophan and lysine. The *o*2 allele when present in homozygous condition reduces production of zeins, particularly the α-zeins, and triggers increase in the level of lysine and tryptophan[3]. This allele is also known to be involved in the synthesis of the enzyme that is associated with free lysine degradation. As a consequence, in the grain with *o*2 mutation a dramatic reduction in this enzyme leads to a corresponding increase in free lysine in the endosperm[19]. The second component of QPM breeding is the hardness of the grains. Increased level of the gamma zein is likely to contribute to the recovery of hard endosperm. The *o*2 modified (QPM) grains have approximately double the amount of gamma zeins in the endosperm compared to the *o*2 mutants[20]. Two genes responsible for the grain hardness[21], have been mapped to the long arm of chromosome 7 and one of them is located near the gamma zein gene *gzr*1. Proteomic analysis of several QPM lines[22] indicated increased levels of granule-bound starch synthase I in the soluble non-zein protein fraction of these genotypes. Increased amount of this enzyme reflected in the form of a change in starch structure, which was manifested as shorter amylopectin branches and increased swelling of starch granules. In mature kernels, these alterations in starch structure were associated with interconnections between starch granules that resulted in a vitreous kernel phenotype.

Many more genes are likely to be associated with the grain hardness and thus, they need to be understood. This character can be visually selected under a light box, where white light is projected through the grains and completely hard seeds are selected. The third component for QPM is the set of amino acid modifiers which affect the relative level of lysine and tryptophan content. The lysine content of normal maize is around 2%, whereas it is approximately 4% (of the total protein) in QPM, with a range 1.6–2.6% in normal maize and 2.7–4.5% in QPM[23]. Three genes associated with lysine level have been mapped[24,25] to locations on chromosome 2, 4 and 7. Apart from this, several major *o*2 modifier-QTLs on chromosomes 1, 7 and 9 have been recently mapped[26]. In addition, endosperm traits such as texture, opacity and vitreousness have been reported to be influenced by the genetic background of the inbred, which exhibit high broad-sense heritability. The relative content of the essential amino acids – lysine, tryptophan and methionine is also known to be affected by the inbred line genotype. However, a negative correlation was observed between endosperm texture trait and amino acid content[27]. In our opinion, favourable responses to selection can be expected for both endosperm texture modification and relative content of the essential amino acids if they are monitored efficiently.

Enhancement of limiting amino acids in the MAS-converted QPM inbreds and hybrids

During the process of conversion of normal maize inbred lines into QPM through MAS, we monitored the presence of *o*2 gene through the molecular markers located within the gene. In addition, kernel hardness was monitored through light box and the level of tryptophan was measured through biochemical method following Babu *et al.*[16]. After recovery of the homozygous lines (for the *o*2 gene) containing more than 90% genome of the recurrent parent, the tryptophan level was measured. This was done to ensure that we are advancing with the *o*2*o*2 lines having hard endosperm and high tryptophan. It has been reported that if lysine or tryptophan levels are not continuously measured during the breeding process, the additional

gains in protein quality may be lost even though the *o*2*o*2 genotypes are maintained[10]. We noted similar effect here and found that despite the presence of *o*2 in the homozygous state (*o*2*o*2) in VQL 1 and VQL 2, the level of enhancement in tryptophan was significantly different in both the QPM inbreds, VQL 1 and VQL 2 (0.42 in CM 212 and 0.52 in VQL 1; 0.55 in CM 145 and 0.58 in VQL 2; Table 2). This significant difference in the level of increase in tryptophan in the two recipient (of *o*2 gene) inbred lines (CM 212 and CM 145) is due to the fact that we did not continuously monitor tryptophan level during the selection. The results of the present investigation are in conformity with those of Krivanek *et al.*[10] and Danson *et al.*[28], who deployed MAS to introgress *o*2 gene for developing QPM inbred lines at CIMMYT. Following the strategy developed in our laboratory, we recovered inbred lines homozygous for *o*2 gene with more than 90–95% recurrent parent genome coupled with 6–24% higher tryptophan within a short span of three years, which would otherwise require 10 generations (five for backcrossings followed by five for selfings), if the conventional backcrossing method is adopted for transferring a recessive gene. In our experiments, we recovered QPM hybrid (Vivek QPM 9) with 44% higher tryptophan, 30% more lysine, 23% histidine and 12% less leucin. Another important outcome of the conversion process was marginal increase (3.4%) in methionine content and maintenance of the yield and pest resistance at the same level as in the original hybrid, Vivek Maize Hybrid 9.

Since the quantity of tryptophan and lysine in the QPM hybrid did not double in our case, we modified the selection strategy such that we screened tryptohan level in the *o*2*o*2 homozygous lines (containing >90% recurrent parent genome) and advanced only those lines possessing >40% tryptophan compared to the non-QPM original inbred. Following this approach, we have now developed another elite QPM hybrid-FQH 38, the QPM version of Vivek Maize Hybrid 21. The new QPM hybrid contains more than 72% increase in tryptophan over Vivek Maize Hybrid 21 (in which the tryptophan level was 0.49% of the total protein). The modified approach has helped in significantly increasing the tryptophan content in the new QPM inbreds as well as the hybrids. Another important aspect of this investigation was the development of QPM hybrids in four years, if we grew two crops per year. On the contrary, conventional breeding will require 8–9 years out of which six years will be needed just for conversion of normal inbreds to QPM inbreds because each backcross has to be followed by selfing for recovery of the *o*2*o*2. Availability of a combination of molecular probes that would allow selection of endosperm modifiers in *o*2 genotypes, prior to selection of agronomic characters, would further facilitate rapid and efficient conversion of normal maize inbred lines into QPM lines. The utility of three maize SSR markers (*umc* 1066, *phi* 057 and *phi* 112) present within the *o*2 gene coupled with a set of markers spread over the entire genome has been successfully demonstrated by us in the conversion of normal maize inbred lines to QPM lines.

Nutritive value of QPM and its effect on monogastric animals

The superior protein quality and digestibility has been demonstrated in QPM by many researchers[5,6]. The QPM protein in general contains 55% more tryptophan, 30% more lysine and 38% less leucine than that of normal maize. Besides, the biological value of normal maize protein is 40%, while that of *o*2 maize protein is 80%. Only 37% of the common maize protein intake is utilized in monogastric animals compared to 74% of the same amount of *o*2 maize protein. The nitrogen balance index for skim milk and *o*2 maize protein is 0.80 and 0.72 respectively, which indicates that the protein quality of QPM is 90% that of milk. Besides, around 24 g of normal maize per kg of body weight is required for nitrogen equilibrium, compared to only around 8 g for QPM[4–6]. In QPM maize, the niacin availability is higher due to higher tryptophan and lower leucine content[29] and carotene utilization[30]. QPM maize can also be transformed into edible products without any deterioration in its quality and acceptability.

Among the QPM hybrids that were released recently for commercial cultivation in India, Vivek QPM 9 developed by our group shows 41% increase in tryptophan, 30% in lysine and 23% in histidine coupled with 12% reduction in leucine. Therefore, its protein is likely to have better biological value than that of recently released HQPM 7, which is reported to contain 0.72% tryptophan of the total protein (9.42%); however, Vivek QPM 9 will be marginally inferior to HQPM 5 that contains 0.76% tryptophan of the total protein (9.8%). The nutritional and biological superiority of QPM has been studied in many systems like rats[30], pigs[31,32], infants and small children as well as adults[6,33]. QPM has been shown to have a better conversion ratio compared to normal maize in the monogastric animals like pigs and chickens[34]. QPM maize can also be used as an ingredient in the preparation of composite flours to supplement wheat flour for bread and biscuit preparation. Ten per cent maize flour has been used in composite flours in many countries such as Brazil, Zambia, Zimbabwe and Ghana. QPM can, thus, play an increasingly important role in reducing protein malnutrition in humans and help in reducing the cost of feed supplement in monogastric animals.

New QPM hybrids in pipeline

We have converted many promising inbred lines of maize into QPM line following the MAS method developed in our laboratory. In the process, we have so far recovered

15 QPM inbred lines and reconstituted more than 50 hybrids from them. These hybrids are at different stages of evaluation. The present emphasis is on enhancing the quantity of limiting amino acids, viz. lysine and tryptophan. One of the new hybrids, FQH 38 (QPM version of Vivek Maize Hybrid 21) shows >70% enhancement in tryptophan over the original hybrid, Vivek Maize Hybrid 21, released in 2006 for commercial cultivation in zones I, II and IV. The tryptophan content of FQH 38 is 0.85, whereas it is 0.49 for Vivek Maize Hybrid 21. FQH 38 was tested in the All India Coordinated Trial of *Kharif* 2007, in which it performed equally well in respect of grain yield and other agronomic traits over the non-QPM national check, Vivek Maize Hybrid 17.

In addition, new QPM hybrids are being produced at maize breeding stations in India, viz. Haryana Agricultural University's research station at Uchani; Rajendra Agricultural University, Dholi; Directorate of Maize Research, New Delhi; Indian Agricultural Research Institute, New Delhi, and several research institutions in Africa, Latin America and at CIMMYT. However, all the new QPM hybrids will be tested under the AICRP on Maize for their suitability in various agroclimatic conditions before release for commercial cultivation.

Concluding remarks

For a country like India, with diverse agroclimatic and soil situations, we need to develop a number of QPM hybrids of different maturity groups, viz. early, medium and late (full season), so that farmers can select the right hybrids which fit in their cropping sequence. Recovery of high yield from Vivek QPM 9 under organic condition indicates that QPM hybrids can be grown in hilly areas where farmers do not apply chemical fertilizers and consequently, the agriculture in these areas is organic by default. Thus, QPM can successfully replace normal maize in these areas too. However, the major constraints in adoption of the QPM hybrids in these areas are the non-availability of hybrid seeds and lack of incentives like premium price for the QPM over normal maize grains. There is also a need to create awareness among the consumers and industry for its use in food and feed. It is equally important to involve private players for seed production and link the industry with the farmers, so that the latter get an assured premium for their QPM produce. We are developing a linkage between the seed producers, farmers and the industry to bring about the much needed synergy in development and utilization of QPM that will help in reducing protein malnutrition.

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MEETINGS/SYMPOSIA/SEMINARS

National Symposium on 'New Vistas for Mycology in Meeting Global Challenges' and the 35th Annual Meeting of the Society

Date: 29–30 January 2009
Place: Chennai

The symposium is organized in honour of late Prof. K. Natarajan, who served as Editor for many years, of *Kavaka*, the official journal of MSI.

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Advancement of Nanotechnology in Physics

Date: 7–8 February 2009
Place: Rourkela

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