Review Paper:

Impact of diverse climate variables on the lysine and tryptophan quantity and quality of quality protein maize (QPM) hybrids

Kumar Saket[1]*, Sarkar Abhijit[2], Singh Rajeev Pratap[1] and Singh Rajesh[3]
1. Department of Environment and Sustainable Development, IESD, Banaras Hindu University, Varanasi, UP, INDIA
2. Laboratory of Applied Stress Biology, Department of Botany, University of Gour Banga, Malda – 732 103, West Bengal, INDIA
3. Department of Genetics and Plant Breeding, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi, UP, INDIA
*saketjntradelink@gmail.com

Abstract

Quality Protein Maize (QPM) hybrid is a beneficial crop. It showed better tolerance and resistance in different environmental condition growing across a wide range of agro ecological zones. QPM produced double amount of tryptophan and lysine than normal maize that which is more beneficial for supplement amount as required human. QPM hybrid is also easily developed from inbred through conventional breeding during Rabi (winter) and Kharif (summer) season in a year.

Higher level of tryptophan and lysine was produced from the influences of zein protein in QPM under diverse environment. Therefore, understanding key aspect of zein biosynthesis of QPM and control regulatory aspect of lysine and tryptophan synthesis are major requirements for human nutrition in globalization.

Keywords: Lysine, non QPM, different environment, QPM, Tryptophan and Zein protein.

Introduction

Over the last decades, maize (*Zea mays* L) has been recognized amongst the most extensively adapted cereal crops with the highest genetic yield potential and is cultivated approximately in 150 m ha of land in about 160 countries with a wide and diverse range of soil, climate, biodiversity and management practices. In India, maize ranks as the third most vital food crops after rice and wheat and contributes almost 9 % of the country's food basket.[30,40] The grain of maize serves almost 15 % of the total calorific value of the rural and malnourished population of underdeveloped and developing countries.[71]

Maize contains about 10% of protein, 72% of starch, 1.4% of oil and 1.7% of ashes[62]. In human, the deficiency of any essential amino acid limits the ability of the body to acquire immunity and make proteins[36]. Among all the amino acids, tryptophan and lysine are two of the most essential amino acids for humans whose deficiency can create crisis to meet the daily balanced nutrition, protein requirements and immunity[41,59]. Around the globe, about 32% of pre-school children are stunted and 20% are underweight due to protein malnutrition in most of the developing and underdeveloped countries including India[41].

As compared to the normal maize hybrids, the Quality Protein Maize (QPM) hybrids have almost doubled the lysine and tryptophan quantity, which makes QPM protein equivalent to around 90% of milk protein[59,65]. The grain flour contains 0.4% of tryptophan in common maize and 0.8% in QPM and 2 % of lysine in common maize and 4% in QPM. Tryptophan range varies from 0.2 to 0.5% in common maize and 0.5 to 1.1% in QPM hybrids and lysine levels are across genetic background from 1.6 to 2.6% in common maize and 2.7 to 4.5% in the O_2 converted QPM genotypes[18] under some fluctuation. Therefore, QPM has a better nutritional value and can be used as raw material for manufacturing many industrial products and also a nutritive component[2].

Amaya et al[3] demonstrated the superior protein quality of QPM over normal maize because it is superior in production than normal hybrids[16]. Contrary wise, the embryo of maize contains both zein and the non-zein fractions (60% albumins) as mainly structural and storage protein[72]. Zein protein is the main storage protein and usually accounts for 50% –70% of the endosperm proteins but contains low levels of lysine with an approximate value of $0.1g.100g^{-1}$ whereas glutelins are rich in lysine with an approximate value of $2g.100g^{-1}$.[35]

In non-QPM hybrids, all the protein fractions, except for zeins, are balanced with essential amino acids and contents a biological value of 40% as compared to milk protein[23]. It was also observed that the insertion of α-lactalbumin in maize hybrids raised the proportions of the essential amino acids without any associated pleiotropic effects[10]. These insertions increase lysine and tryptophan concentration by reducing zein synthesis and affect several other biochemical changes. This increase is explained by the decrease in zein fraction and an increase of non-zein proteins in the endosperm proteins[65].

The endosperm maize contains α -zeins which are the most abundant proteins; but they are poor in amino acids like tryptophan and lysine. The presence of O_2 allele in homozygous conditions reduces the production of zeins, particularly the α -zeins and triggers an increase in the level of lysine and tryptophan[22].

The background

The International Maize and Wheat Improvement Center (CIMMYT) in Mexico selected hard endosperm (vitreous) o2 mutants to develop new maize hybrids named QPM which in general contains 55% and 30% higher amount of tryptophan and lysine as compared to common maize hybrids[48,52].

The opaque2 gene was first mentioned by Singleton and Jones[61] and reported by Emerson et al1[19], but the nutritional significance of mutant was first demonstrated by Mertz et al[39] for the increase of lysine content and development of QPM hybrid. Opaque2 mutants increase maize resistance to disease and increase the utilization of superior maize[67]. CIMMYT introduced high yield QPM maize but in lower yield and in need for breeding efforts. Interdisciplinary research team converted the floury soft endosperm kernels in harder grain yield potential to normal maize hybrids[65].

'Shaktimaan-1' (a three-way cross hybrid) and 'Shaktimaan-2' (a single-cross hybrid) are average yield maize crops but Shaktimaan-3 and Shaktimaan-4 produced a higher amount of tryptophan in protein[52]. Shaktimaan-3 and Shaktimaan-4 are particularly suitable for cultivation in Bihar. Nkongolo and Mbuya[47] observed the changes of amino acid level during early generations of maize inbred lines. This study revealed a significant decrease of 33% and 38% of tryptophan in S1 and S2 inbred lines compared to t he original parent of the MUDISHI-3 population respectively. There was a decrease 15% of lysine in S2 inbred lines compared to the parental MUDISHI-3, then a similar level of lysine compared to the genetically improved normal maize (Salongo-2) was observed. Further it is possible to develop effective complement through the breeding program and provide a greater thrust of QPM hybrids.

It expresses significant nutritional and economic benefits for human cultural society development. Banisetti et al[12] selected 22 maize inbred lines in which 8 are normal inbred lines, 7 QPM inbred lines from Vivekananda Institute of Hill Agriculture (VPKAS), ICAR, Almora, India and 7 exotic QPM inbred lines from CIMMYT, Mexico, were used for the study of the biosynthesis of zein protein for an increment of tryptophan and lysine development[13]. These are briefly explained in table 3 recording for yield, protein content and tryptophan production.

Biosynthesis of amino acid in maize

Protein quality of normal maize grain is poor due to the presence of the largest concentration of an alcohol-soluble protein fraction prolamine known as zein obtained in the endosperm. Particular α -zeins are the most abundant proteins found from maize endosperm, but these are poor in amino acid production like tryptophan and lysine.

Table 1
Eight years maize production records in 16 countries according to FAS/USDA, Office of Global Analysis.

World Maize Production in Thousand Metric Tons								
Country	**2011-12**	**2012-13**	**2013-14**	**2014-15**	**2015-16**	**2016-17**	**2017-18**	**2018-19**
Argentina	21,000	27000	26000	28700	27000	28000	28700	2900
Brazil	73000	81500	80000	85000	84000	84000	84000	85000
Canada	11359	13060	14194	11487	13600	13600	13800	14000
China	192780	205614	218490	215646	224580	224580	224850	224929
Egypt	5500	5800	5800	5960	6000	6000	6400	7000
Europeon Union	68123	58896	64635	75499	57751	57465	57648	58973
India	21759	22258	24259	24170	21000	21000	22000	23000
Indonesia	8850	8500	9100	9000	9400	9400	9900	99800
Mexico	18726	21591	22880	25480	23500	24000	26000	27000
Nigeria	9250	76591	22880	25480	23500	24000	27000	28000
Philipines	7130	7261	7532	7671	7500	7500	78000	78200
Russia	6962	8213	11635	11325	13000	13168	13273	13300
South Africa	12759	12365	14925	10629	6500	6500	6800	6810
Turkey	3600	4400	5100	4800	6100	6200	6400	6400
Ukraine	22838	20922	30900	28450	23300	23333	24363	25000
US	312789	273192	351272	361091	345486	345486	357484	360000
Others	93164	91287	96052	100418	93918	94902	98988	99000
World total	889589	869489	990474	1012841	969635	972134	974356	980000

Table 2
Selected QPM hybrids for higher tryptophan production in protein

QPM Hybrids	Pedigree	Centre of Origin	Characters	Yields q/ha	Protein Content (gm)	Tryptophan (%)
HQPM-1	HKI-193-1xHKI163	CCSHAU, Karnal (2005)	Late maturity, yellow, dent.	62	9.36	0.94
HQPM-5	HKI 163x HKI 161	CCSHAU, Karnal (2007)	Late maturity, orange, flint.	58	9.80	0.76
HQPM-7	HK1-193-1xHKI-161	CCS HAU Karna (2008)	Late maturity, Yellow, semi-flint	72	9.42	0.72
VivekQPM-9	VQL1 x VQL2	VPKAS Almora (2008)	Extra early maturity, dent, yellow.	52	8.46	0.83
Shaktiman -1	CML-142 xCML-150	RAU Dholi	Late maturity, orange-yellow, flint.	60	9.60	1.01%
Shaktiman -2	CML-176 xCML-186	RAU Dholi	Semi flint, Resistance to MLB	60	9.30	1.04%
Shaktiman -3	CML-161 xCML-163	RAU Dholi	Orange yellow, late maturity, semi flint, tall.	62	9.63	0.73%
Shaktiman -4	CML-161 xCML-169	RAU Dholi	Semi flint, tall	62	9.98	0.93%

Table 3
Major classes of zein proteins

S.N.	Zein Class	Molecular Mass	Lysine content
1	α	19-kDa-22-kDa	No Lysine
2	β	14-kDa	No Lysine
3	γ	16-kDa-27-kDa	No Lysine
4	δ	10-kDa-18-kDa	18-kDa zeinalon with one lysine codon

The amount of this alcohol-soluble protein fraction zein is low in immature maize grains and increases after grain matures. These genes have been selected from the metabolic pathways of lysine and tryptophan and opaque2 modifiers in maize as previously reported by Wang and Larkins. The high quality of protein fractions becomes recessive under control some parts of maize kernel are due to the dominance of zein in normal maize.

Endosperm modifiers are the third genetic system consisting of amino acid modifier genes from the addition of O_2 affecting relative levels of lysine and tryptophan[29]. These genes are associated with lysine metabolism identified by Wang et al[70] and found lys-sensitive Asp kinase is better for the quantitative trait locus and affecting free amino acid content than thr-sensitive. AK- homo-Serdehydrogenase-2 (HSDH-2) and enzyme activities were measured. The o2 gene encodes endosperm-specific basic leucine zipper (b-ZIP) transcription factors that regulate the transcription of genes encoding 22-kDa α-zeins and other proteins such as the cytoplasmic pyruvate orthophosphate dikinase (CyPPDK1), the lysine-ketoglutaratereductase/saccharopine dehydrogenase (LKR/SDH).

Significantly from the decreases of 22-kDa α-zeins produce higher lysine content[59]. The δ2-endosperm genetic modifier genes are capable of altering the expression of other genes at different loci in the genome and alter the undesirable correlated effects of δ2 gene[63]. Insertion of α-lactalbumin in maize raised proportions of essential amino acids in maize without any associated pleiotropic effects. These mutants alter lysine and tryptophan concentration by reducing zein synthesis and some biochemical changes[15]. The δ2 gene increases lysine and tryptophan in the endosperm[46] by acting on the four types of storage proteins (albumins, globulins, zeins and glutelins) in maize endosperm. This value was less in wheat, rice, barley, oats, sorghum and common maize[67].

The amino acid is a key enzyme involved in the metabolism and alters from O_2 mutation. Aspartate kinase (AK) activity is regulated by opaque2 (O_2) mutation in the synthesis of essential amino acids including lysine. O_2 allele present in the homozygous condition in maize reduces the production of zeins from the α -zeins and triggers increase in the level of lysine and tryptophan production[22]. Aspartate kinase 2 (Ask2) is a good gene that regulates the reaction of aspartate to aspartate 4-semialdehyde (figure 1) which in turn is the source for lysine production[70]. The o2 mutation in maize is associated with an increased level of free amino acids in the mature endosperm. O_2 mutant regulates lysine and tryptophan pathway enzymes that produce higher lysine and tryptophan in the QPM hybrids.

The O_2 has decreased the synthesis of prolamine (zein) protein, thereby increasing the lysine and tryptophan content of maize. The O_2 mutant is the down-regulated activity of lysine ketoglutaratereductase dehydrogenase.

Reduction of lysine ketoglutaratereductase dehydrogenase is an important factor responsible for increase free lysine in the maize endosperm o2 mutant leading to the regulation of lysine and tryptophan pathway enzymes, while homozygous O_2 α-zein fraction of endosperm protein increases the proportion of non-zein proteins that naturally contain higher levels of lysine and tryptophan[22].

RNA interference induced down regulation of 22 KDa a-zeins[58] and 19 KDa zeins[25] due to produce higher lysine content (up to 16-20%) much below 02 mutants in maize. The control of essential amino acids like lysine and tryptophan is synthesized in all higher plants from the aspartic acid pathway. Maize increased 2 to 30% expression of the total amino acid pool of DHPS from free lysine content[74].

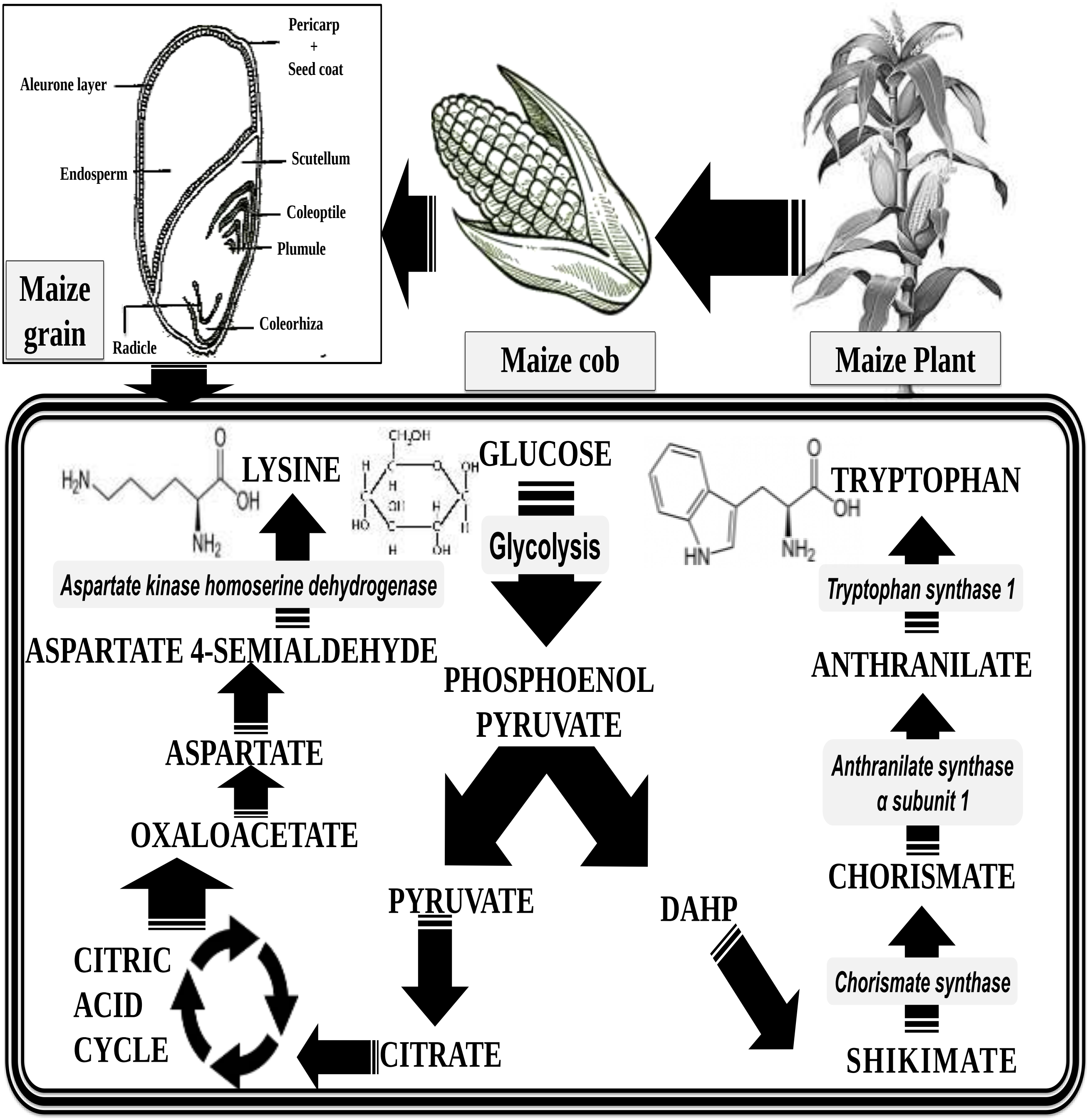

Figure 1: Lysine and tryptophan biosynthesis mechanism in maize

Synthesis of lysine and tryptophan

Quality protein maize (QPM) was developed by combining genetic systems[52] through gene mutant opaque-2 (δ2) and genetic endosperm modifiers[67]. The amino acids are synthesized as lysine threonine and methionine (figure 2) from aspartic acid pathways[60]. Increase lysine and tryptophan was controlled from a set of genes called amino acid modifier genes[29]. The o2 mutation is associated with an increased level of free amino acid in the mature endosperm. Maize grain protein is made up of five different fractions. The percentage of different fractions to total nitrogen in maize kernel is albumin 7 %, globulin 5 %, non-protein nitrogen 6 %, prolamine 52 % and glutelin 25 % and the leftover 5 % is residual nitrogen[34].

Some mutations are the formation of Floury-1 (fl1) and Opaque-1 (o1) prolamin protein body, therefore typical mature maize grains contain a small embryo and much larger endosperm with 90 % starch and 10 % protein[72]. Other proteins are unrelated to prolamin protein bodies[43] such as zmAroDH-1 (mto140), Opaque-5 (o5) and Opaque-7 (o7)[44].

Protein body formation of maize is controlled by the regulation of zein expression in different zein components[24]. The zein fraction in normal maize usually contains a higher proportion of leucine (18.7%), phenylalanine (5. 2%) isoleucine (3.8%), valine (3.6%) and tyrosine (3.5%). Four types of zeins (α, β, γ and δ) are found in maize and they are distributed in a distinctive pattern (Table 4). Recently, α-zeins were proofed to restore protein body and starch grain interaction and activities for modification of QPM.

In normal maize, proportions of various endosperm storage protein fractions such as globulins (3%), glutelins (34%) and albumins (3%) are collectively called non-zeins. The non-zein protein fraction is balanced and rich in lysine and tryptophan[66]. The lysine was determined in most external layers (10% endosperm and consecutive 10%) and the remaining endosperm (80%) to determine the synthesis of lysine in the maize endosperm. However, the zein dry matter percentage was estimated by the formula suggested by Drochioiu et al[20] given as:

% Zein in dry matter = % crude protein x 0.386-2.22

Some conventional breeding programs are improved incensement and developed varieties with high protein value in QPM[52]. Therefore QPM can be developed by combining genetic systems of opaque-2 (δ2) mutant gene and genetic endosperm modifiers[68] with some phenotypic changes such as the appearance of soft, chalk and dull traits of maize. Kernel modification is influenced by a complex genetic system that acts as additive and non-additive manner, observed at various levels of kernel modification. These were mapped from modifier loci at chromosomes 1 and 4 in maize[22].

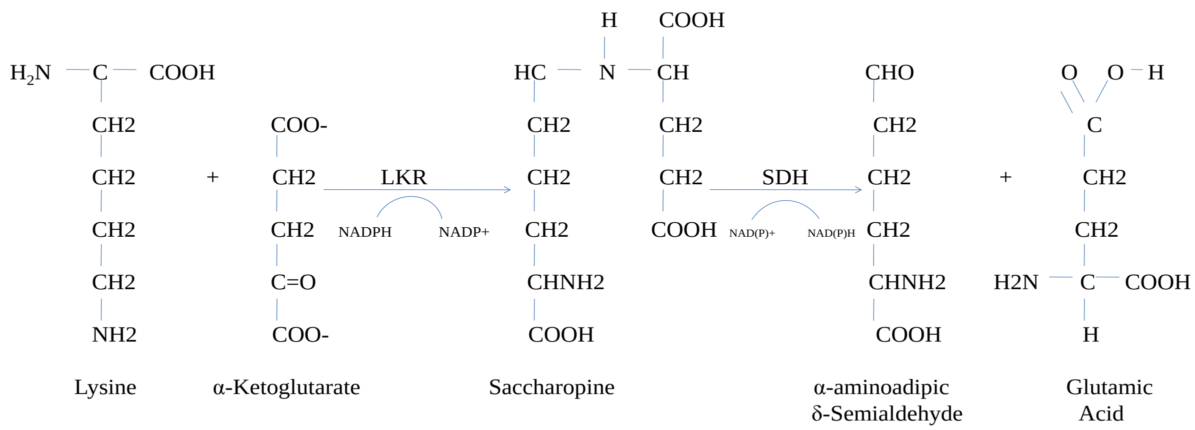

Figure 2: Conversion of Lysine to α- Ketoglutarate into Sacchropine under control of maize crop

Table 4
Dominance models are scaling adequate data set of protein quality traits in maize[26]

Plant Characters	Trials	R^2 Values	b- values		Remarks
			b=0	b=1	
Protein Percentage	Normal	4.90ns	9.730	2.758	Partial adequate model
	Drought	4.76 ns	6.197	2.997	Partial adequate model
Tryptophan percentage	Normal	0.05ns	3.875	0.482	Adequate model
	Drought	2.21ns	5.534	2.184	Partial adequate model
Lysine percentage	Normal	8.72ns	7.020	3.933	Partial adequate model
	Drought	1.75ns	3.701	2.253	Partial adequate model

Table 5
Details of the maize inbred lines used in the study along with range of tryptophan content[18]

S.N.	Genotypes	Normal/QPM Hybrids	Released From	Tryptophan content (% Protein)
1	V25	Normal	India	≤0.50
2	V335	Normal	India	≤0.50
3	V353	Normal	India	≤0.50
4	V358	Normal	India	≤0.50
5	V359	Normal	India	≤0.50
6	V369	Normal	India	≤0.50
7	V370	Normal	India	≤0.50
8	CM145	Normal	India	0.50
9	VQL2	QPM	India	0.51
10	VQL4	QPM	India	0.75
11	VQL8	QPM	India	0.94
12	VQL20	QPM	India	0.52
13	VQL21	QPM	India	0.54
14	VQL26	QPM	India	0.60
15	VQL27	QPM	India	0.71
16	CML170	QPM	CIMMYT, Mexico	0.95–1.05
17	CML173	QPM	CIMMYT, Mexico	0.95–1.05
18	CML176	QPM	CIMMYT, Mexico	0.95–1.05
19	CML180	QPM	CIMMYT, Mexico	0.95–1.0
20	CML184	QPM	CIMMYT, Mexico	0.95–1.05
21	CML189	QPM	CIMMYT, Mexico	0.95–1.05
22	CML193	QPM	CIMMYT, Mexico	0.95–1.05

V = Vivek; VQL = Vivek QPM line; CM = Coordinated maize

Maize genotypes stability in different environment

The improved early maturity maize varieties produce assurance for increased maize productivity in the sub-regions of India. QPM is partly attributed to global climate change variable environments due to more complexity in the survival of yielding crops and declining soil fertility from the less water holding capacity[5]. Early maize hybrids are usually grown in seasonal variation. Maize was fully established and shortly matured in all environments in comparison to traditional crops. Therefore, early maize hybrids are self-protected to drought and tolerate reduced moisture supplement in flowering and drought-affected environments[26]. The relative performance of genotypes is across environments and raises challenging issues among plant breeders and agronomists[6].

The environmental interaction is great concern to plant breeders in the presence of genotypes because large interaction can reduce yield and make a selection of superior cultivars[53]. The evaluating cultivars were superior interactions in selected environments that exhibit significant genotypes[50].

Arusleivi and Selvi[1] reported environmental factors as more affected by quantitative traits than qualitative traits in evaluating potential performance under multiple environments[8]. Many abiotic factors such as temperature, seasonal rainfall, seasonal length of drought, sub-soil pH and socio-economic factors and biotic stresses such as diseases, insect pests and weeds have been causes of environmental interaction for different genotypes[5].

Maize breeders were developing different maize varieties from the partnership of national maize program. These are helpful for adaptation of different agro-ecological farming systems[9]. Maize hybrids are regarded as stable yield performance of targeted environments. These genotypes responded in different locations and form a combination of maturity group with high and stable yielding traits[54]. The ability of genotypes was referred stability in breeding programs, if the regression coefficient is about 1[73], for high or low yield levels across a wide range of populations[28]. The ability of a hybrid is to be stable in various environments and give higher yielding under the inherent genetic system[73].

Maize hybrids' adaptability is to perform a pattern of development to adjust in the provided environment. Many genotypes produce high yields under certain change environmental conditions but lass yield in a controlled environment[7]. Stability measurements express survivability of genotypes to maintain maize crop yield[49]. Maize crop yields are increasing gradually in some arid regions due to the changes in agricultural patterns under different seasons.

The food production systems are now under the confluence of a number of biotic and abiotic stresses including climate change. The impacts of climate change are likely to be severe for countries like India that have limited arable land but heavy dependence on agriculture[48] and also have poor technological and financial capabilities for mitigation and adaptation to climate change. In the past four decades (1969-2005), India's surface temperature has increased by 0.3 °C or by 0.08 °C per decade.

In recent years, climate change has been accompanied by an increased incidence of natural calamities such as droughts, floods, cyclones and heat waves[21]. Such extreme events are causing a drastic decline in the agricultural output and exacerbating problems of food insecurity in rural poverty. Breeding under stress-tolerance is an important thrust of agricultural research[51]. Therefore, return investment of drought-tolerant breeding is estimated to be attractive, ranging from 29 to 167 percent[42].

Efficacy of maize under diverse climate variables

Temperature and sunlight*:* Maize is a subtropical crop, through its adaptation of a crop always responds to higher temperature under different environment. Maize is physiologically damaged to 5-7^oC followed by photo-inhibition that may reduce photosynthesis rate.

Photosynthesis rates of sun adopted maize do not saturate until light intensity approaches sunlight. Photosynthesis captured sunlight energy driving force of maize growth and development. Maize plant has maximum leaf photosynthesis rates in temperature of 32-35^oC. Threshold temperature is ±10^oC for maize crop seed germination. The maize crop is relatively sensitive and does not acclimatize to low temperatures under the coolest temperature.

Soils and their effect: Maize is growing best in sandy clay (loams), silty clay soils, it is less adopted to compact clays and sands. Sandy (loamy) soils having low water retention capacity due to maize give poor yield while loamy and clay soils have high moisture. Maize has a stronger deep root system; it is about 2m deep root in some cases and these help in space development. Normal root development of maize crop is 80-100cm minimum soil depth but critical root development expresses smaller yields under the rain-fed condition. For more water retention, green manures and fodder are mostly used. The soil is the main factor for water storage and helps for maize growth, it is determined by texture and structure. Availability of soil moisture is a major element of success in rain-fed maize production mainly where the rain is not uniformly distributed in whole season.

In such cases plant has stored moisture in root zones to overcome the temporary water deficit[45]. Soils of the major maize growing areas in India are inherently low in soil organic matter and nitrogen is the major limiting plant nutrient with N availability being routinely supplemented through the application of fertilizers. Application of large amounts of N, P and K is to achieve higher yield and stimulates the deficiency of secondary and micronutrients.[27]

Moisture content*:* Maize is a fairly tolerant crop under dry soil and moisture stress condition during the early vegetative stage of pollination. The maize crop is more beneficial from a greater amount of sunlight and dry weather but during pollination, condition maize is very sensitive to drought and dry soils which causes yield losses. These yield losses increase due to failure pollination. Recently some hybrid maize cultivars are tolerated; water stress is more effectively than normal maize and produces more amount of proteins. The hybrids have variable sensitivity to both heat and drought tolerance through genetic variations.

Water requirements and irrigation

Maize is a water-efficient crop, a considerable amount of water requirements for high yields. Maize crop showed significantly higher under receiving 5-6 irrigations compared to less number of irrigations[31]. Maize requires 500-600mm water use during one season in temperate environments but its requirements are increased as 900mm or more under irrigated environments of the dry climate depending upon crop evaporation. From the sufficient use of water, 2.5 kg of grains produced per m^3 of maize crop. The success of Rabi maize crops under rainfed conditions depends upon the conservation of moisture in the soil surface. The maximum plant height of winter maize was recorded under an irrigation ratio of 1.2[14].

Therefore, deep soil and high organic matters are more helpful to maintain the water availability of crops and form suitability of maize production. Maize crop gradually increases water uptake from the germination during the vegetative growth stage. Water shortages reduce grain yield. The seed yield of spring maize was higher with the application of nitrogen at 225 kg ha^{-1} with a spacing of 75 × 20 cm[64].

Conclusion

Maize is an important cereal crop in our country; more than half of the people are used as livestock resulting in the rapid increase in economic growth and poultry products in particular hilly ecologies (North Eastern Himalayas, Uttarakhand, Himachal Pradesh) and rain-fed and tribal states (Madhya Pradesh, Chhattisgarh, Rajasthan, Orissa, Bihar and West Bengal), a large area under maize production with untreated fertilizers. India is the first country to focus on the improvement of maize quality after the nutritional benefits incensement in the world. Therefore, maize is a heterogeneous crop, that cannot be directly improved through selecting desirable plants but the selection of agronomic traits will certainly boost grain yield.

Different field condition changes the proportions of genetic effects and suppresses maternal component for protein concentration. Its main contributions fulfill the dietary requirements of the country especially in the summer season due to short duration crop and large production of grains per unit area.

In most developing countries, about 77 % of maize is used as food for humans, but in industrialized countries, about 70 % of this crop is used as cattle feed either in the form of fodder, grazing and forage; only 3 % is used as food for human while the remaining is used for biofuel, industrial products and seed. About 85% of the maize production is used for human consumption in India, particularly it is beneficial for deprived areas where protein malnutrition and hunger are present. In addition, maize is used as animal feed and continues to grow at fast rate. It is estimated that production will be increased from 165 to 400 metric tons under up to year 2030. The Quality Protein Maize (QPM) is manifold for both human nutrition and animal feed. QPM is considered as a bio-fortified food because its nutritional profile has been improved using the conventional breeding program.

Tryptophan and lysine are essential amino acids. Humans cannot synthesize any essential amino acids, these need to be supplied through foods. Absence of any of these amino acids limits the ability of the body to make proteins despite the presence of all other amino acids. The nutritive compositions are fully potential for mono-gastric animals that balanced nutritive elements in humans. A number of studies have proved the impact of QPM increases in body growth in poultry and pigs. Chicken body weight increased 50% from QPM fed compared to normal maize.

Children fed were healthier with lysine and tryptophan maize supplements with better growth capabilities compared with children fed with normal maize porridge. Therefore, QPM has superior biological value evaluated under dry environments for protein and tryptophan concentrations as used sources of amino acid. QPM substitutes are used in the production of animal feed components.

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