CIMMYT

QUALITY PROTEIN MAIZE (QPM)

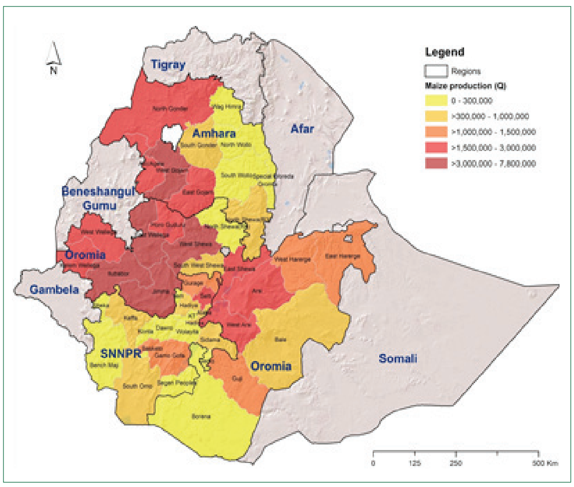
NUTRITIONAL WELLBEING FOR THE POOR AND VULNERABLE

For children in the developing world, QPM offers significant promise: a marked improvement in the quality of the diet, with little or no change in buying power and eating habits. It offers the possibility of markedly altering diet in the direction urged by healthy authorities, without sacrificing growth.”

Graham et. al. 1990

Maize in Ethiopia

Maize is the most commonly grown cereal in Ethiopia; of 12 million cereal-growing households, 8.6 million choose to cultivate maize on a total of 2.1 million hectares. With average yields of 3.4 tons/hectare, it is not only the most popular cereal, but also the most productive. According to farmer best practice data from the Federal Ministry and the Regional Bureaus of Agriculture, average farm level productivity exceeds 10 t/ha in some of Ethiopia's most favorable maize growing areas.



Maize production (Q) in Ethiopia by zones

Maize is the lowest cost source of cereal calories, providing 1.5 to 2-fold more calories per dollar than wheat and teff, respectively. The bottom 40 % income group of rural inhabitants are among the foremost consumers of cereals in general and of maize in particular.

Ethiopia's major staple foods (teff, wheat, maize, sorghum, barley, and enset) provide approximately 68% of the total calories consumed. Of these, maize contributes the most calories per capita (24.6%), followed by sorghum (21.7%). In rural Ethiopia, the calorie contribution of maize can be as high as 26.1% (436 of 1668 calories/day).

Ethiopian diets generally lack diversity and contain few non-cereal grains or animal products. Pulses and animal products contribute just 6.9% and 2.5%, respectively, to total per capita calorie intake. As a result, protein energy malnutrition is a major health problem in Ethiopia. In some parts of the Southern Nations, Nationalities and Peoples Region, where maize contributes more than 60% of dietary protein intake, an estimated 85-90% of the population is at risk of inadequate lysine intake.

Protein is made up of building blocks called amino acids. There are 20 amino acids, of which 11 are considered 'non-essential' because they can be manufactured within the body (as long as the diet is adequate). The other nine are 'essential' as they can only be obtained through a person's diet. The protein quality of a food is quantified based on its content of essentialamino acids such as lysine, tryptophan, and methionine.

The endosperm protein of conventional maize (CM) is comprised of 50-70% zein, a protein fraction with low levels of lysine and tryptophan. Due to these deficiencies, most maize varieties fail to meet the protein quality requirements for human growth and development, as established by the World Health Organization. Unless daily lysine and tryptophan requirements are met through other lysine- and tryptophan-rich foods, a reliance on maize as the principal daily food greatly increases the risk of protein malnutrition in humans, especially among children.

What is QPM?

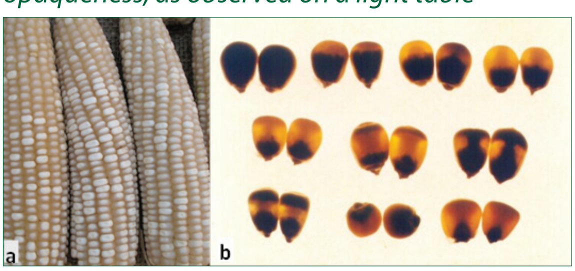
Quality protein maize (QPM) is a maize type based on genetic modification by the *o2* mutant gene along with numerous modifiers that enhance kernel hardness and the tryptophan and lysine content of the endosperm and kernel hardness. The presence of *o2* in the homozygous recessive *(o2o2)* state is a prerequisite for obtaining maize with high levels of lysine and tryptophan. Transferring the *o2o2* gene by breeding, selecting, and pyramiding amino acid modifier genes ensures that concentrations of these amino acids are at the high end of the range of variation observed in the *o2* mutants. The *o2* mutant reduces synthesis of the alpha-zein protein (which is poor in lysine and tryptophan) and enhances the synthesis of non-zein fractions that are rich in these amino acids.

Lysine and tryptophan levels as % of total protein in whole grain flour of conventional maize (CM) and QPM (o2o2) genotypes. From Vivek et al. (2008).

Traits	CM	QPM
Protein	>8	>8
Lysine in protein	1.6-2.6 (mean 2.0)	2.7-4.5 (mean 4.0)
Tryptophan in protein	0.2-0.6 (mean 0.4)	0.5-1.1 (mean 0.8)

The *o2* mutant confers a starchy opaque endosperm phenotype. This makes the kernels unattractive to producers and consumers; moreover, the soft opaque kernels make it susceptible to mechanical damage and storage-pest attack. Breeders were able to ameliorate the negative features of the *o2* mutant by selection for *o2* modifier genes that convert the starchy endosperm to a vitreous phenotype, typical of conventional *non-o2* maize.

a) Ears segregating for chalky and normal kernels; and b) QPM kernels with varying levels of kernel opaqueness, as observed on a light table



It is important to note that the total protein content of a QPM variety is the same as the isogenic CM variety. The presence of the *o2* gene reduces the synthesis of zein protein (with low levels of lysine and tryptophan) but increases the synthesis of non-zein components (albumin, globulin, and glutelin protein fractions), which are rich in lysine and tryptophan.

Advantages of QPM

The development of QPM has been driven by the need to provide an affordable source of balanced protein to the millions of rural poor families that relay largely on maize for their daily dietary calorie intake and who have limited access to other protein sources such as poultry, dairy, and meat products. Young children who require more and better-quality protein for body growth and development are especially vulnerable.

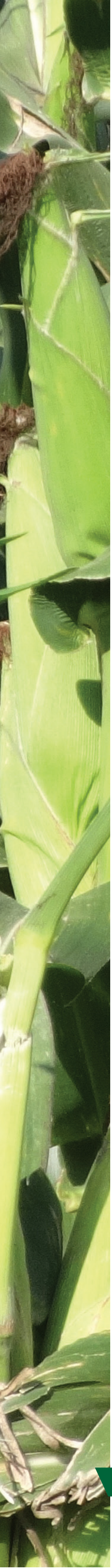
Several nutritional studies in different regions and with different populations have demonstrated the potential of QPM to reduce or alleviate the risk of protein malnutrition in the maize consuming populations. The production and consumption of QPM has the following advantages:

1. QPM proteins have higher levels of lysine and tryptophan and are more easily digested, making the nutritional value of protein from QPM closer to milk, compared to CM.

Nutritional value of QPM and CM compared to milk. From Bressani et al. (1969); Viteri et al. (1972).

Food	Nitrogen balance	Protein quality (% of milk)
CM	0.31	39
QPM	0.72	90
Milk	0.80	100

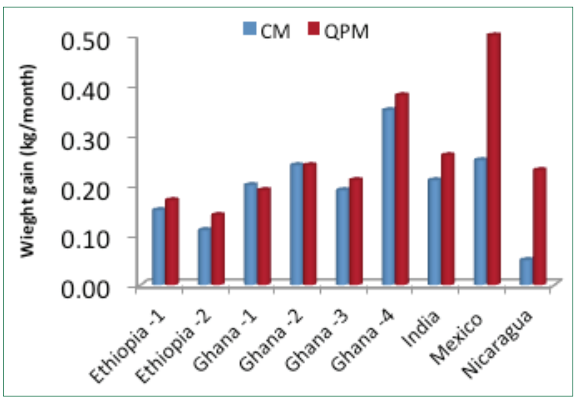
2. Protein quality of QPM is highest among all cereal staple foods consumed by humans.



Protein quality of QPM maize and other cereals from miko et al. (2001)

Cereal crop	QPM (% Casein)
QPM	82.1
Rice	79.3
Oats	59.0
Barley	58.0
Pearl millet	46.4
Wheat	38.7
Finger millet	35.7
Sorghum	32.5
CM	32.1

3. Consumption of QPM increases the growth of infants and young children with mild to moderate undernutrition among populations where maize is the staple food.



Rate of weight increase among children receiving QPM versus CM. Modified from Gunaratna et al. (2010).

4. The yield and other agronomic characteristics of improved QPM varieties are competitive with those of CM varieties of similar maturity groups.

5. QPM may also help other vulnerable groups – such as pregnant and nursing women, the elderly or the sick – who have increased protein requirements.

6. Consumers have found different common and traditional foods, including injera, prepared with QPM acceptable and even preferable to those prepared with CM.

Rolled and sliced injera made from QPM.

7. In addition to their nutritional advantages, QPM foods have similar or better functional properties compared to food prepared with CM.

A field day participant enjoying a QPM based dish

8. QPM in foods prepared from fresh immature (e.g. roasted or boiled green cobs) or mature grain maintains its protein quality and nutritional advantage relative to CM.

9. Monogastric livestock (pigs, broiler chickens; not ruminants such as cattle or sheep) fed on QPM grow faster and mature earlier than those fed on CM.

Pig (Q4) fed with QPM compared to its sibling (N4) fed with CM. From Vivek et al.(2008) (Courtesy: Crops Research Institute, Kumasi, Ghana; Animal Science Department, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana; Sasakawa Global 2000)

10. Compared to CM, it is possible to meet targets for lysine and tryptophan intake by consuming 40% and 20% less maize, respectively.

Complementary QPM benefits

Besides doubling the amount of biologically useable protein in a maize diet, QPM also provides higher niacin availability, higher carotene bio-utilization in yellow QPM, higher carbohydrate utilization, and stimulates the appetite.

Other considerations

- QPM is not to replace animal protein sources such as meat and milk, or legume protein such as beans. It can be used as part of a strategy to diversify and improve the diet quality of vulnerable groups, particularly infants, young children, and women in rural communities who consume maize as a primary food source.
- QPM increases protein quality (by improving amino acid balance) but not protein quantity. The total amount of protein in QPM is the same as in CM.

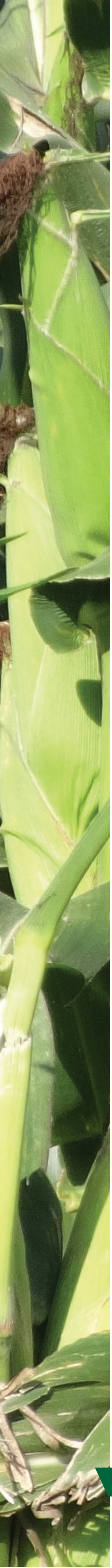
Development of QPM varieties

The physical and agronomic characteristics of maize containing the *o2* gene have been steadily improved to compete with standard hybrids through the painstaking manipulation of diffrent genetic systems by breeders at CIMMYT over a period of four decades. The resultant germplasm – QPM – is physically and agronomically similar to CM varieties. QPM was the first bio-fortified crop offered by CIMMYT to global maize consuming communities. QPM open-pollinated varieties (OPVs) and hybrids based directly or developed from CIMMYT germplasm have been released and are grown in 39 countries across Africa, Latin America, and Asia, where the risk of protein under-nutrition is high and where maize is the dominant dietary source of energy and protein. By 2015, there were about *90* recorded releases of QPM varieties (both OPVs and hybrids) in Africa alone, of which many share the same pedigree indifferent countries. In Ethiopia,seven QPM varieties have been released so far and promising candidate varieties are in the pipeline.

QPM development work in Ethiopia began in 1994 with the objective of fast-tracking the release of best-bet QPM varieties developed from QPM germplasm bred at other CIMMYT stations. QPM breeding was later developed into a fully-fledged program with funding from the Government of Canada through the Quality Protein Maize Development (QPMD, 2003-2010) and Nutritious Maize for Ethiopia (NuME, 2012-) projects. The programfocuses on three strategies: short-, medium-, and long-term, as follows:

QPM varieties released in Ethiopia and their important agronomic and adaption characteristics.

Variety name	Adaptation		Days to maturity	Potential Yield (q/ha)		Type
	Altitude (masl)	Rain fall (mm)		On-station	On-farm	
BHQP548	1000-1800	1000-1200	145	75-85	65-75	Hybrid
BHQPY545	1000-1800	1000-1200	144	80-95	55-65	Hybrid
BHQP542	1000-1800	1000-1200	145	80-90	50-60	Hybrid
AMH760Q (Webi)	1700-2200	1000-1500	160	90-120	60-80	Hybrid
Melkasa6Q	1000-1750	500-800	120	45-55	30-40	OPV
MH 138Q	1000-1800	600-1000	135	70-80	55-60	Hybrid
Melkasa 1Q	800-1500	400-700	90	30-45	25-35	OPV

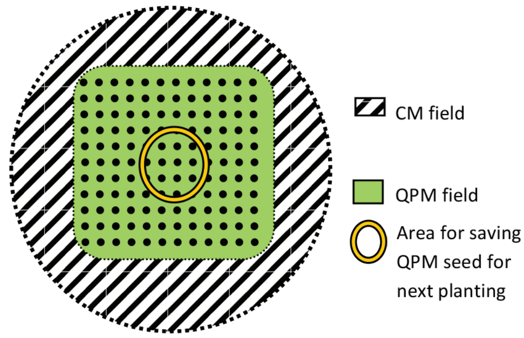


- Screening of QPM varieties introduced from elsewhere for adaptation to local conditions.
- Conversion of popular and farmer-preferred CM cultivars into QPM versions.
- Development of QPM source germplasm through mass conversion of elite non-QPM inbred lines or pedigree breeding with proven QPM lines.

QPM seed production

Production of QPM seed is no different from non-QPM seed production. The same strict standards for the different classes of seed must be followed to ensure good quality seed reproduction. Because QPM trait is conferred by a single recessive gene *(o2o2)*, coupled with many complementary modifier genes, it is vulnerable to genetic contamination through outcrossing. Therefore, in QPM seed production, laboratory analysis for tryptophan and protein determination is essential to ensure that the content of the two amino acids, lysine and tryptophan, are above the required minimum. In foundation seed multiplication (particularly breeder and pre-basic seed), checking the protein quality every two years is highly recommended. QPM seed produced from pure seed stocks under strict regulatory standards should retain the protein quality characteristics of the variety.

When a farmer intends to recycle seed of a QPM OPV, both the genetic purity and the protein quality can depreciate through contamination by pollen from non-QPM plants growing in the vicinity, if the flowering periods overlap. To maintain the original quality and reduce the risk of contamination from non-QPM pollen, farmers should select about 300 relatively pure QPM seed cobs from a subplot in the center of the field, at a minimum of 15 m from each side of the field.



Schematic representation of a QPM OPV field surrounded by CM fields under small-scale farm conditions

Outcrossing studies have shown that the maximum level of contamination due to cross-pollination from adjacent non-QPM and QPM fields is 11%. Studies have also shown that as long as QPM grain is not contaminated by more than 20%, its nutritional value is not significantly affected. Thus there are no losses in nutritional benefit when QPM plots experience pollen outcrossing from neighboring non-QPM fields.

The following measures are advised for reducing contamination and protein quality loss:

1. Plant QPM in relatively square plots to minimize the length of the perimeter with CM plots;
2. Plant QPM plots upwind of CM plots;
3. Plant QPM buffer rows (5-10 m width) adjacent to the other fields and treat them as non-QPM when harvesting; and
4. Where the length of the season permits, stagger the planting time of QPM and non-QPM varieties in adjacent fields to avoid overlapping of flowering periods and pollen contamination.

Where to get QPM seed?

Early generation QPM seeds are available from the Ethiopian Institute of Agricultural Research (Bako, Ambo, and Melkasa Research Centers), Tigray Agricultural Research Institute, and Ethiopian Seed Enterprise (ESE). Certified seed of QPM varieties are available from public and private seed companies and farmers' cooperative unions, such as the ESE, Oromia Seed Enterprise, Amhara Seed Enterprise, Ethio Agri-CEFT Plc, Gadisa Gobena Agro-Industry, Meki-Batu Union, etc.

Contact details for some of the institutions involved in QPM seed multiplication and distribution are as follows:

1. **Bako National Maize Research Center, EIAR**

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3. **Ambo Plant Protecion Research Center, EIAR**

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4. **Crop Research Process, TARI**

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5. **Ethiopian Seed Enterprise (ESE)**

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   Email: tafesseg004@yahoo.com

6. **Amhara Seed Enterprise**

   Contact: Demelew Abebe (Agronomist)

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   Email: demelewabebe@yahoo.com

7. **Oromia Seed Enterprise**

   Contact: Ato Kedir Nefol (General Manager)

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8. **Ethio Agri-CEFT PLC**

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9. **Meki Batu Cooperatives Union**

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10. **Gadissa Gobena Commercial Farm PLC**

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CIMMYT

International Maize and Wheat Improvement Center

CIMMYT - the International Maize and Wheat Improvement Center - is the global leader in publicly-funded maize and wheat research and related farming systems. Headquartered near Mexico City, CIMMYT works with hundreds of partners throughout the developing world to sustainably increase the productivity of maize and wheat cropping systems, thus improving global food security and reducing poverty. CIMMYT is a member of the CGIAR Consortium and leads the CGIAR Research Programs on MAIZE and WHEAT. The Center receives support from national governments, foundations, development banks and other public and private agencies.

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