CURRICULUM AND MODULES FOR QUALITY PROTEIN MAIZE (QPM) TRAINING



Prepared for Agricultural Technical and Vocational Education and Training Colleges in Ethiopia

Adefris Teklewold (PhD), Kaleb Kelemu, Abraham Tadesse (PhD) and Dagne Wegary (PhD)

> May 2017 Addis Ababa, Ethiopia



CURRICULUM AND MODULES FOR QUALITY PROTEIN MAIZE (QPM) TRAINING

Prepared for Agricultural Technical and Vocational Education Training Colleges in Ethiopia

Adefris Teklewold(PHD), Kaleb Kelemu, Abraham Tadesse(PHD) and Dagne Wegary(PHD)

May 2017

Addis Ababa, Ethiopia







CIMMYT – the International Maize and Wheat Improvement Center – is the global leader in publicly-funded maize and wheat research-for-development. Headquartered near Mexico City, CIMMYT works with hundreds of partners worldwide 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.

© 2017. International Maize and Wheat Improvement Center (CIMMYT). All rights reserved. The designations employed in the presentation of materials in this publication do not imply the expression of any opinion whatsoever on the part of CIMMYT or its contributory organizations concerning the legal status of any country, territory, city, or area, or of its authorities, or concerning the delimitation of its frontiers or boundaries. CIMMYT encourages fair use of this material. Proper citation is requested.

Correct citation: CIMMYT. 2017. Adefris Teklewold, Kaleb Kelemu, Abraham Tadesse and Dagne Wegary. Curriculum and Modules for Quality Protein Maize (QPM) Training. CIMMYT: Addis Ababa, Ethiopia.

Abstract: This QPM course curriculum has been prepared to acquaint ATVET students on the production and benefit of quality protein maize. It is presented under three competencies describe the basic features of QPM (genetics, history and nutritional benefits of QPM); characteristics and adaptation of QPM varieties released in Ethiopia; and QPM seed maintenance procedures and preventing grain contamination. By learning this course, the graduates can get the wisdom and means to stand against the pervasive menace of undernutrition in Ethiopia using a very cheap and simple approach, biofortification.

Table of Contents

List of Tables	ii
List of Figures	ii
Preface	iii
SECTION I: CURRICULUM	1
Brief description of the quality protin maize (QPM) curriculum	2
Summary of competencies, learning outcomes and total credit	
hours to be allocated for each competency	3
SECTION II: LEARNING GUIDE	5
MODULE 1: Understanding Basic Features of Quality Protein Maize and its Nutritional	
Benefits	6
1.1 Understanding the historical development of QPM	7
1.1.1 What is QPM?	7
1.1.2 QPM genetics and breeding	8
1.2 Historical development of QPM	11
1.3 Nutritional benefits of QPM	12
Learning Activity 1	16
MODULE 2: Characteristic and Ecological Adaptation of QPM Varieties Released in	
Ethiopia	17
2.1 QPM germplasm development	17
2.2 Released QPM varieties and their Characterstics	19
2.2.1 Open pollinated varieties	19
2.2.2 Hybrid QPM varieties	23
Learning Activity 2	31
MODULE 3: Seed Maintenance and Prevention of Grain Contamination	32
3.1 Principles of QPM seed multiplication	32
3.2 Preventing QPM grain contamination in farmers' fields	33
3.3 Recycling of QPM seeds	35
Learning Activity 3	36
REFERENCES FOR FURTHER READINGS	37
Glossary	41

List of Tables

Table 1. Lysine and tryptophan levels as percentages of total protein in whole	
grain flour of conventional and QPM genotypes	7
Table 2. QPM varieties released in Ethiopia and their agro-ecological adaptations,	
disease reactions, and agronomic characteristics	20

List of Figures

Figure 1. Simple recessive inheritance of the o2 gene	9
Figure 2. Variation for endosperm in QPM and CM	10
Figure 3. Varying degrees of opaqueness indicate varying	
levels of endosperm modification	10
Figure 4. Rate of increase in weight (kg/month) among children	
receiving CM versus QPM	13
Figure 5. Rate of increase in height (cm/month) among children	
receiving QPM versus CM	14
Figure 6. Average weight gain (g) of rats fed on	
QPM and CM for 28 days	15
Figure 7. Plant and ear morphology of BHQP542	24
Figure 8. Plant and ear morphology of BHQPY545	26
Figure 9. Plant and ear morphology of AMH760Q	27
Figure 10. Ear and plant morphology of MHQ138	28
Figure 11. Ear and plant morphology of BHQ548	29
Figure 12. Plant and ear morphology of AMH852Q	30
Figure 13. Schematic representation of a QPM OPV field surrounded by	
CM fields under small - scale farming conditions	33

i

Preface

With technical and material support from CIMMYT and other partner organizations, significant efforts have been made to develop, release, and disseminate QPM varieties in developing countries where maize is the dominant dietary source of energy and protein, to address the problem of protein under nutrition. More than 167 QPM varieties have so far been released across 39 countries. In Ethiopia, QPM research was started in 1994 with evaluation of varieties introduced from CIMMYT. However, a concerted effort in QPM research and dissemination was only started in 2003 with the launching of the Quality Protein Maize Development (QPMD) project funded by the Government of Canada. Subsequently, commencing in 2012, a more comprehensive research for development project called Nutritious Maize for Ethiopia (NuME), funded by the same donor, was initiated by CIMMYT and its partners in 36 focal Woredas of Amhara, Oromia, SNNP and Tigray Regions where impact is expected to be greatest. The project includes dissemination, research and seed system components with gender equality, capacity building, communications and M&E forming cross-cutting activities across all the components. The project has been implemented in partnership with about 17 institutions (GOs, NGOS, Universities, private companies and farmers' unions). The major implementing partners are: the Ethiopian Institute of Agriculture Research, the Ministry of Agriculture and Natural Resources and Regional Bureaus of Agriculture, Sasakawa Global 2000, Farm Radio International, the Harvard School of Public Health, the Ethiopian Public Health Institute, the Ethiopian Seed Enterprise, Hawassa University, and World Vision Ethiopia.

The project uses different mechanisms for disseminating knowledge and information about QPM among which developing and distributing different training and course materials is one. Therefore, this QPM course curriculum has been prepared to equip ATVET students, the future agricultural professionals working at grassroots level, with the basic knowledge about QPM, its nutritional benefits, characteristic feature of QPM varieties released in Ethiopia and QPM seed production and maintenance procedures. This module is prepared following ATVETs' module preparation format in the country.

iii

SECTION I CURRICULUM

Brief description of the QPM curriculum

Maize is first in terms of total production and second in area of production of cereal crops produced in Ethiopia. Most people in the Ethiopian maize belt rely on maize for their daily calorie intake. Although maize contains different macro and micronutrients, since long its protein is known to be of poor quality due to the deficiency of two essential amino acids: tryptophan and lysine. As a result, in areas where maize is the staple food protein malnutrition predominates. Substituting the conventional maize (CM) varieties with quality protein maize (QPM) varieties would substantially improve the protein malnutrition. QPM contains double amount of these two essential amino acids that increase the biological value of maize protein to 90% of milk while the CM is only 39%. Various nutritional studies on animal and human showed that the higher lysine and tryptophan contents of QPM varieties, compared to CM, provide a more balanced protein for humans and other monogastric animals and improves growth rates and nitrogen metabolism. The development of QPM took nearly half a century of research dedicated to reduce malnutrition in the maize consuming populations.

Maize is one of the strategic food security crops in Ethiopia. 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 highest consumers, in terms of budget share, of cereals in general and of maize in particular. Of the major staples (teff, wheat, maize, sorghum, barley and enset) that together contribute to about 68% of the calories to the national food basket, maize has the highest share of 24.6% per capita calorie consumption, followed by sorghum with 21.7%. In rural Ethiopia, maize is the primary source of calories contributing about 26.1% (436 of the average 1668 calories/day intake) of the total per capita calorie consumption of the above mentioned six staples.

In Ethiopia, the food supply lacks diversity, and the share of animal products in the diet is very limited. Cereals constitute more than 80% of the total grain production with the highest proportion coming from maize. Pulses and animal products contribute, respectively, only 6.9% and 2.5% of total per capita calorie consumption. Protein energy malnutrition has been identified as a major health and nutritional problem in Ethiopia. In some parts of the Southern Nations, Nationalities and Peoples Region, where maize contributes more than 60% of the dietary protein intake, an estimated 85-90% of the population is at risk of inadequate lysine intake. Severe deficiency of protein especially in children causes Kwashiorkor which manifests from chronic protein and energy imbalance and increases susceptibility to life-threatening diseases, such as tuberculosis and gastroenteritis. QPM which is being promoted by the NuME (Nutritious Maize for Ethiopia) Project funded by the Government of Canada aimed at improving

household food and nutritional security, especially for young children and women, through the adoption of QPM with appropriate crop management practices that increase farm productivity.

This module is, therefore, developed to acquaint the future cadre of agricultural extension with QPM and its contribution to the food and nutrition security from the beginning, the college level, and make ready them to play a decisive role in fighting malnutrition among rural farm families that prevailed for long in different parts of the country.

This QPM training module covers the following competencies:

- understand the basic features of QPM (genetics, history and nutritional benefits of QPM);
- understand characteristics and adaptation of QPM varieties released in Ethiopia; and
- apply QPM seed maintenance procedures and preventing grain contamination.

Summary of competencies, learning outcomes and total credit hours to be allocated for each competency

S.N	Competencies	Learning out comes	Hour
	Understand the basic	Understanding the historical development of	
	features of QPM (genetics,	QPM	
1	history and nutritional	Understand the genetics and breeding of	2 h
	benefits of QPM)	QPM	3 nrs
		• Understanding the nutritional superiority of	
		QPM	
	Understand characteristics	Understanding the characteristics of the	
2	and adaptation of QPM	different QPM varieties	2 h
2	varieties released in	Understand agro-ecological adaptations of	3 nrs
	Ethiopia	the different QPM varieties	
	Apply QPM seed	knowing QPM seed maintenance procedures	
2	maintenance procedures	Undertaking necessary precautionary) hure
5	and preventing grain	measures to prevent seed and grain	2 nrs
	contamination	contamination	

Total credit hours:	8 hrs
Target trainees:	This training moduleis meant to train agricultural development
	agents that are enrolled in the ATVET colleges.
Training method:	The training will be given in lectures, practical session,
	audio-visual aids, documentary films, field visits, and group
	discussion.
Performance assessment	Learning activities, self-check exercises, oral questioning, and
method:	observation upon demonstration will be used to assess the
	performance of the target groups that takes this course.

Additional notes to the instructor/lecturer

4

This module is prepared to provide practical experiences and detail about QPM genetics, breeding, seed and grain production, nutritional advantage and the different QPM varieties released for different agro-ecologies. The instructor is expected to try its level best to make the delivery of the information about QPM contained in this module as plausible as possible so that learners could appreciate and grasp important ideas, concepts and facts about QPM easily. Instructors are advised to motivate the learners to attentively follow up lectures and carefully exercise practical sessions. As most ATVET students are adults and have rich life time experience, it is essential to make the session participatory.

SECTION II LEARNING GUIDE

MODULE 1

Understanding Basic Features of Quality Protein Maize and its Nutritional Benefits

Nominal Hours:	3 hrs
Module Description: This module provides the historical process involved	
	development of QPM both in the international as well as local
	context. It describes the characteristics of QPM and compares
	the basic difference with the CM. The nutritional advantages
	of QPM in Ethiopian context is explained and learners will gain
	understanding on the rationale behind the need to promote
	QPM in Ethiopia.
Module Learning	Knowing the historical development of QPM; and
Outcomes:	 Understand the nutritional attributes of QPM based on the
	proportion of their lysine and tryptophan content.

INSTRUCTION

6

Dear Instructor, as this module primarily focus on introducing nutritionally different type of maize called QPM, it is essential to use pictorial presentation of the different aspects of QPM as provided in the module. It is essential to make sure that learners have got clear understanding of the difference between the QPM and CM. Therefore the following are advised to be used:

- use pictures to illustrate the similarity and difference of QPM and non-QPM seed, how grain endosperm modification is associated with the inheritance of *opaque-2* gene;
- deeply explain the different genetic system involved in breeding QPM varieties and compare it with breeding for any other trait controlled by simple Mendelian genetics;
- explain them the difference between protein quality and quantity; difference between essential and non-essential amino acids;
- encourage learners to do the exercises given at the end of this module; and
- ask learners if they already know about QPM or might have heard about it before lecturing.

1.1 Understanding the historical development of QPM

1.1.1 What is QPM?



What do you know about QPM? Have you heard anything about QPM in radio, TV or from any other sources?

The term QPM refers to maize genotypes whose lysine and tryptophan levels in the endosperm of the kernels are 2-3 times higher than in CM varieties. Lysine levels in CM and QPM average 2.0% and 4.0% of total protein in whole grain flour, respectively. These levels can vary across genetic backgrounds with ranges of 1.6-2.6% in CM and 2.7-4.5% in converted QPM counterparts. Similarly, tryptophan content of CM and QPM average 0.4% and 0.8% of total protein in whole grain flour, respectively (Table 1). Despite the nutritional differences, QPM varieties look and perform like CM varieties and one can't usually distinguish between the two by the physical appearance of the plants or their ears and grains alone. Rather, biochemical analysis is required to determine the lysine and tryptophan content of the seed and confirm whether or not it is OPM.

Remember!

- ✓ The total quantity of kernel protein content in both QPM and CM is usually the same.
- It is only the quantity (percentage share) of lysine and tryptophan in the endosperm protein that is increased in QPM.
- ✓ Therefore, the nutritional advantage of QPM is due to the increase in protein quality or amino acid balance, but not due to the increase in protein quantity.

7

Table 1. Lysine and tryptophan levels as percentages of total protein in whole grain flour of conventional and QPM genotypes.

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

1.1.2 QPM genetics and breading



8

Dear learner, do you know how traits are inherited from parents to offspring (Mendelian genetics)?

Understanding the genetic background of QPM is important for QPM breeding, seed maintenance and production of grain with acceptable lysine and tryptophan content. The component of the QPM genetics system is the recessive *opaque-2* natural mutation. The presence of the *opaque-2* gene in homozygous recessive (*o2o2*) state 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 proteins), which are rich in lysine and tryptophan.

QPM development involves manipulating three distinct genetic systems:

- a) The simple recessive allele of the opaque-2 gene;
- b) Modifiers/enhancers of the *o2*-containing endosperm to confer higher lysine and tryptophan levels; and
- c) Genes that modify the *o2*-induced soft endosperm to hard endosperm.

The *opaque-2* allele is inherited in a simple recessive manner. The presence of *opaque-2* in the homozygous recessive (*o2o2*) state is a prerequisite for the entire process of obtaining high-lysine/tryptophan maize (Fig.1). However, the presence of the *opaque-2* allele in the recessive condition (*o2o2*) alone does not ensure high lysine and tryptophan levels.

In order to confer higher levels of these amino acids in the *o2o2* genetic background, the presence of another set of genes, called amino acid modifiers, are required. These are a distinct set of minor modifying loci (more than one) critical to enhance lysine and tryptophan levels in the endosperm. Therefore, if lysine or tryptophan levels are not properly monitored while developing new cultivars, one could end up with a maize cultivar having the *o2o2* genotype but with lysine and tryptophan levels similar to those in CM. This is because the lower limits of lysine and tryptophan in *o2o2* maize overlap with the upper limits in CM.

CM Dominant (o2o2)



Opaque -2 Recessive (o2o2)

F₁ (*o2o2*) CM phenotype

Segregating F₂

9

Figure 1. Simple recessive inheritance of the *o2* gene. Source Vivek et al. (2007)

The *o2o2* gene and the modifiers/enhancers of lysine and tryptophan are, by themselves, not sufficient to develop agronomically acceptable maize with high lysine and tryptophan. Due to a genetic phenomenon in which one gene controls more than one trait (pleiotropy), the presence of the *o2o2* gene makes the maize endosperm soft and opaque, often making the kernels susceptible to cracking, ear rots, and weevils (Fig.2C).



Figure 2. Variation for endosperm in QPM & CM: (A) Normal endosperm flint type maize; (B) normal endosperm dent type maize; (C) *opaque-2* maize; and (D) QPM. Source: Krivanek et. al. (2007)

The opaqueness of the kernel can be clearly viewed on a light table (Fig. 3). Therefore, breeding maize for high lysine and tryptophan content requires selection for hard kernel texture or vitreousness controlled by modifier genes with a distinct genetic system. The modifier genes convert the soft/opaque endosperm to a vitreous phenotype similar to that of CM.



Figure 3. Varying degrees of opaqueness indicate varying levels of endosperm modification: A = opaque; B = 25% modified; C = 50% modified; D = 75% modified; and E = 100% modified. Source: Kassahun and Prasanna (2004)

1.2 Historical development of QPM

QPM development dates back to the 1920s when a natural spontaneous mutation of maize with soft and opaque grains was discovered in a maize field in Connecticut, USA. The salient events of this discoveryare summarized as follows:

- Kernels of the mutant maize were delivered to the Connecticut Experiment Station and the mutant was eventually named *opaque-2 (o2)* but received little further attention.
- In 1961, researchers at Purdue University, USA, discovered that maize homozygous for the *opaque-2 (o2o2)* recessive mutant allele that had substantially higher levels of lysine and tryptophan in the endosperm, compared to CM with the dominant *O2* allele (*O2O2 or O2o2*).
- Further experimentation in the 1980s demonstrated that the increased tryptophan content in *o2* maize effectively doubled the biological value of the maize protein, thus reducing by half the amount of maize that needs to be consumed to get the same amount of biologically usable protein in a maize diet.
- Breeding programs worldwide started converting CM to *opaque-2 (o2o2)* versions through a direct backcross approach. However, serious negative secondary (pleiotropic) effects of the mutation were soon discovered which severely limited the practical use of the mutation in the field. These negative effects included:
 - o yield loss of up to 25% due to the lower density of the soft endosperm of *o2o2* grains, as well as increased susceptibility to fungal ear rots and storage pests; and
 - o unacceptability of the soft endosperm texture to consumers who are accustomed to harder grain types.
- The pleiotropic effects, especially the low yield and soft kernels of the *opaque-2* mutation, restricted the usefulness of this mutation in breeding programs. However, screening of hard kernels in some of the backcross-derived populations at CIMMYT paved the way for developing *opaque-2* varieties with hard kernels.
- CIMMYT's QPM breeding efforts focused on:
 - o converting a range of subtropical and tropical lowland adapted CM populations to *o2* versions through backcross recurrent selection;
 - o regaining the original hard endosperm phenotype of the converted populations/ lines; and

11

o maintaining protein quality while increasing yield and resistance to ear rot.

The resulting genotypes developed by CIMMYT's breeding program that retained the *o2* mutation and the quality protein trait but lacked the accompanying unfavourable agronomic characteristics were termed quality protein maize (QPM). QPM germplasm is characterized by having higher lysine and tryptophan content than CM, as well as normal vitreous endosperm, reduced susceptibility to post-harvest insect pests and diseases such as ear rots, as compared to their *o2o2* predecessors, and its yield is comparable to or higher than that of CM grown by farmers. QPM looks and performs like CM and can be reliably differentiated only through laboratory tests. Several QPM populations and pools possessing different ecological adaptation, maturity, grain color, and texture were developed. A number of advanced maize populations in CIMMYT's Maize Program were successfully converted to QPM populations. QPM development took over three decades of painstaking research; two CIMMYT scientists, maize breeder Surinder K. Vasal and cereal chemist Evangelina Villegas received the 2000 World Food Prize for their significant contributions to QPM development.

Current QPM breeding strategies at CIMMYT focus on pedigree breeding wherein the best performing inbred lines with complementary traits are crossed to establish new segregating families. Both QPM × QPM and QPM × non-QPM crosses are made depending upon the specific requirements of the breeding project. In addition, backcross conversion is used to develop QPM versions of parental lines of popular hybrid cultivars that are widely grown in CIMMYT's target regions. Significant strides have also been made with regard to molecular marker-assisted selection (MAS) for generating QPM versions of elite inbred lines. Microsatellite markers located within the *o2* gene made it possible to accelerate the pace of QPM conversion programs through MAS. Recent technological developments, including high-throughput, single seedbased DNA extraction, coupled with low cost, high density SNP genotyping strategies and breeder-ready markers for some key adaptive traits in maize, promise to enhance the efficiency and cost effectiveness of MAS in QPM breeding programs.

1.3 Nutritional benefits of QPM



12

Dear learner, based on the definition of QPM you learnt in the preceding sections, can you say something about nutritional (protein) benefits that QPM can provide?

Nutritional benefits of QPM's emanated from *opaque-2* mutation. The higher lysine and tryptophan contents of QPM, compared to CM, provide a more balanced amino acid profile for humans and other monogastric animals' nutrition. There is an overwhelming amount of data demonstrating the nutritional superiority of QPM over CM. The nutritional benefits, especially for people who depend on maize for their energy, protein, and other nutrients intake, are sufficient to justify its wide scale production and promotion.

Numerous QPM feeding trials have been undertaken in areas where participants, most often children, are undernourished. Graham et al. (1990) reported that malnourished children who were fed QPM as the only source of protein and fat, recovered well and showed the same growth as those that were fed a modified cow milk formula. Meta-analysis of nine experiments, carried out independently in different countries also indicated that children consuming QPM instead of CM had a 12% weight increase (Fig. 4).



Figure 4. Rate of increase in weight (kg/month) among children receiving conventional maize (CM) versus QPM. Source: modified from Gunaratna et al. (2010)

The same authors also showed a 9% increase in the growth rate in height of children who received QPM food over those who ate CM (Fig. 5). Except in one case, where consuming CM and QPM was statistically not significant in terms of rate of height increase, the other experiments considered in the meta-analysis proved the superiority of QPM over CM in terms of increase in the rate of weight or height of infants and young children. As in the case of infants and children, QPM had equally beneficial effects on adults. Overall, these studies concluded that consuming QPM improves growth rates and nitrogen metabolism, suggesting that it may be as efficacious as consuming casein. Due to the significantly enhanced levels of tryptophan and lysine it contains, QPM also reduces by half the amount of maize that needs to be consumed to get the same amount of biologically usable protein from a maize diet.

Besides, doubling the biologically usable protein in a maize diet, QPM also confers the following nutritional benefits: better leucine to isoleucine ratio; higher niacin availability; higher calcium availability when eaten in the form of lime-treated maize; higher carotene bio-utilization in yellow QPM; and higher carbohydrate utilization.



Figure 5. Rate of increase in height (cm/month) among children receiving QPM versus CM. Source: modified from Gunaratna et al. (2010)

A study conducted by Akalu et al. (2010) in Ethiopia, Sibu Sire Woreda, East Wollega where maize is a dominant crop, demonstrated the positive effect of QPM on both height and weight of children aged 7 - 56 months. Children consuming CM showed a decrease in both height-forage and weight-for-age over time, while children fed QPM did not show significant change in height-for-age but their weight-for-age increased marginally.

Based on information collected from a focus group discussion in the same place, traditional foods prepared with QPM were appreciated by the farmers for their taste and cooking qualities. Farmers preferred injera made from QPM over CM injera due to its softness and longer shelf life. Mothers noted that QPM developed less of a sour taste when fermented than CM, making it more palatable to children. QPM porridge was also described as smoother than porridge prepared with CM. Most people also liked the taste of "green" QPM grain over the taste of "green" CM because of its perceived sweetness. Also, children did not feel hungry for a longer time after consuming QPM-based food. Designed experimental studies in eastern African countries (De Groote et al., 2014) also indicated that QPM is more acceptable and even preferred over CM for preparing widely consumed food products such as *ugali* in Tanzania, githeri in Kenya, and injera in Ethiopia. Accordingly, in a study conducted recently in Jimma Zone of Oromia Region, consumers expressed willingness to pay a premium for QPM over the conventional maize, and the premium was higher for yellow QPM. These should be additional bonuses for farmers to produce and consume QPM and mitigate malnutrition, specifically in communities with poor quality protein intake and lysine deficiency, commonly associated with cereal-based diets.



Dear learner, why do you think QPM can be an important feed ingredient for monogastric animals?

The nutritional and biological superiority of QPM has also been amply demonstrated in model systems such as rats and pigs. The superior quality of QPM protein was first demonstrated in feeding trials with rats. Growth in rats that were fed a diet of 90% QPM (97 g) increased more than three-folds (Fig. 6) over the growth of rats fed CM (27 g). The nutritional advantage of QPM over CM was most extensively demonstrated on pigs. Generally, at suboptimal protein levels, feeding pigs with QPM instead of an equal amount of CM resulted in significant growth increase. Some studies indicated that pigs fed a diet of QPM alone, except for vitamins and minerals, grew twice as fast as those fed CM. A series of experiments on the nutritional value of QPM in poultry feed (broilers and laying hens) and pigs at the Chinese Academy of Agricultural Sciences (CAAS) proved the superiority of QPM over CM in terms of amino acid balance and nutrient composition, by improving their growth and performance. Diets incorporating QPM are also more economical, as they can lead to a progressive reductions in the use of fishmeal and synthetic lysine additives.



Figure 6. Average weight gain (g) of rats fed on QPM and conventional maize (CM) for 28 days. Source: modified from Mertz et al. (1965)

Learning Activity 1

- 1. Explain the need for breeding and producing QPM.
- 2. Which are the basic sources of nutritional benefit of QPM?
- 3. Which farming system/areas of the country can most benefited nutritionally from QPM?
- 4. Which gene is primarily responsible for obtaining higher level of lysine and tryptophan; and what is its mode of inheritance?
- 5. Describe the three genetic systems essential to breed for QPM varieties.



MODULE 2: Characteristic and Ecological Adaptation of QPM Varieties Released in Ethiopia

Nominal Hours:	3 hrs
Module Description:	This module provides when and how QPM breeding was started in Ethiopia and the number and types of QPM varieties (OPV and hybrid) released in Ethiopia. It also describes the agronomic characteristics and agroecological adaptation of the varieties.
Module learning outcomes:	 Understand the historical development of QPM breeding in Ethiopia; Know the number and types of QPM varieties released in Ethiopia; and Understand the characteristics and agroecological adaptations of QPM varieties released

INSTRUCTION

Dear instructor, please explain learners thoroughly the difference and similarities of QPM and CM breeding procedures from different reference materials. Compare and contrast the agronomic characteristics of CM and QPM varieties released in Ethiopia. You are advised to give more emphasis to the three maize growing agro - ecologies of the country.

in Ethiopia.

Dear instructor, if resources are available please show learners how QPM and CM varieties perform by planting well ahead of time.

2.1 QPM germplasm development



Dear learner, do you know how many QPM varieties are developed and released in Ethiopia and which institute has released them?

17

With technical and material support from CIMMYT and other organizations such as SG-2000, great stride have been made to develop, release, and disseminate QPM varieties in developing countries where maize is the dominant dietary source of energy to address the issues of protein

undernutrition. The Quality Protein Maize Development (QPMD) project funded by the then Canadian International Development Agency, CIDA, supported QPM germplasm development and dissemination in four eastern African countries, including Ethiopia, during 2003-2010. The support to Ethiopia has continued under the Nutritious Maize for Ethiopia (NuME) project since 2012.

The QPM development program in Ethiopia was launched in 1994 with the evaluation of openpollinated varieties (OPVs) and pools introduced from CIMMYT. The main objective of the program was fast-tracking the release of best-bet QPM varieties developed in different CIMMYT maize breeding hubs and elsewhere in the world. It was through this process that the first commercial QPM variety, BHQP542, was identified and released for commercial cultivation in the mid-altitude areas of Ethiopia in 2001. Subsequently, with support from the QPMD project, a full-fledged QPM development program was initiated for the highland, mid-altitude, and moisture-stressed maize agro-ecologies of Ethiopia, with emphasis on the following:

- Screening QPM varieties introduced from elsewhere for adaptation to local conditions: the introductions were either already commercialized in other countries of similar agro-ecologies or consisted of elite germplasm from CIMMYT breeding programs in Mexico and other regions. Introduced varieties that showed better or comparable performance to the standard checks, with respect to grain yield, other agronomic traits, and reaction to major diseases were proposed for commercial release.
- 2) Conversion of popular and farmer-preferred CM cultivars into QPM versions: this strategy was aimed at incorporating the *opaque-2* gene into parental lines of popular Ethiopian hybrids using the backcross breeding method. In the backcross program, parents of popular hybrids such as BH660 (A7033, F7215 and 142-1-e) were used as recurrent parents, while proven CIMMYT QPM lines (CML144, CML159 and CML176) were used as donor parents. F₁ crosses were made between donor and recurrent parents to transfer the *o2* gene from the donor to the recurrent parents. In the following season, F₁ seeds are advanced to F₂ by selfing the F₁ plants to allow the expression of the target recessive gene. Using a light table, only F₂ kernels that carried the *o2* gene (i.e., kernels that were opaque to light) were selected and then crossed back to the recurrent parent (the parents of the CM). In subsequent years, three backcrosses were followed by advancing each backcross to F₂ generation, where selection for endosperm modification and monitoring the level of tryptophan was carried out on a regular basis.

3) QPM source germplasm development through mass conversion of elite non-QPM inbred lines or pedigree breeding with proven QPM lines: unlike the second approach, which targeted only parental lines of popular hybrids, this strategy aimed to convert a broad selection of elite conventional inbred lines into QPM versions through backcrossing. In addition, the pedigree method of inbred line development was used to develop inbred lines, i.e., through repeated selfing of the F₁ (obtained by crossing popular QPM parental lines) for 6-7 generations to select QPM inbred lines from the segregating progenies. After each selfing, kernels were selected for endosperm modification using the light table, followed by tryptophan analysis to identify promising QPM versions of the conventional inbred lines.

Following these three strategies, the EIAR National Maize Research Program, in close partnership with CIMMYT, developed and released eight QPM varieties until 2014 adapted to the three maize agro-ecologies of Ethiopia. A detailed description of the characteristics and adaptation of these varieties is presented in the next section.

2.2 Released QPM Varieties and their Characterstics

Eight QPM varieties (six hybrids and two OPVs) have been released for commercial cultivation in the three major maize agro-ecologies of Ethiopia (Table 2).

2.2.1 Open pollinated varieties



Dear learner, do you know what an open pollination refers to?

An OPV is a genetically heterogeneous population maintained by open-pollination and when reproduced or reconstituted retains most of its distinguishing features. Seed of an OPV is produced by random cross-pollination, i.e., there is no controlled pollination; instead, pollination occurs naturally without restriction within the population under isolation (place or time isolation).

19,

Table 2. QPM varieties released in Ethiopia and their agro-ecological adaptations, disease reactions, and agronomic characteristics.

20

Maniatur.	Year of	A destation	Plant	Ear height		To see the second s		Grain		Yield (c	tt/h)	Disease	e reactic	L
variety	Release	Adaptation	height (cm)	(cm)	MO	lassel color		texture	Ргошпсасу	RS*	FF+	GLS	TLB	CLR
Open Pollinated	/arieties													
Melkasa-6Q	2008	Low moisture stress	165-175	70-75	120	White	White	Semi-flint	Non-prolific	40-50	30-40	I	F	F
Melkasa-1Q	2013	Low moisture stress	140-160	65-70	90	White	Yellow	Flint	Non-prolific	35-45	25-35	I	⊢	⊢
Hybrid Varieties														
BHQP542	2001	Moist mid-altitude	220-250	100-120	145	Dark pink	White	Semi flint	Prolific	70-90	50-60	Т	МТ	MS
BHQPY545	2008	Moist mid-altitude	250-260	120-140	144	Pinkish	Yellow	Semi flint	Prolific	80-95	55-65	⊢	МТ	MT
AMH760Q	2011	Highland	245	143	183	50% white								
& 50% purple	White	Semi flint	prolific	85-95	75-80	Т	S	MT						
MH138Q	2012	Low moisture stress &moist mid-altitude	200-235	100-120	140	white	White	Semi-flint	Prolific	75-80	55-65	F	F	MS
BHQP548	2015	Moist mid-altitude	229	109	145	Purple	White	Semi flint	Prolific	75-85	55-70	F	MT	F
AMH852Q	2016	Highland	250	145	183	Purple	White	Semi flint	Prolific	90-100	75-85	⊢	н	ī

* 1 ton = 10 quintals (qt)

DM=days to maturity; RC=research center; FF=farmers' field ;T=tolerant; MT=moderately tolerant; MS=moderately susceptible; S=susceptible. Source: Ethiopian National Maize Research Program, EIAR



Dear learner, can you describe the possible advantages of OPVs compared to hybrids?

Compared to hybrids (discussed in Section 3.2), OPVs have the following advantages:

- they are relatively easy to develop;
- the seed is simple and inexpensive to produce (it does not have distinct male and female parents and as a result there is no need for detasseling and planting in isolation);
- farmers can save their own seeds for replanting in the following season, thus reducing their dependence on external seed sources (although it is recommended that farmers purchase fresh seed every 3 seasons); and
- seed can easily be transferred from farmer to farmer.



Dear learner, what disadvantages can you think that OPVs have as compared to hybrids?

However, OPVs also have the following disadvantages, as compared to hybrids:

- they produce relatively lower yields and are not as uniform as hybrids; and
- because of their less uniformity, OPVs are not suitable for mechanized harvesting compared to hybrids.

So far, the EIAR National Maize Research Program had released two improved QPM OPVs for commercial cultivation, mainly for moisture-stressed maize agro-ecologies. The names of the varieties and their target production zones are indicated in Table 2. Seeds of an OPV can be recycled with little or no yield penalty for a few (optimally three) years. However, it should be noted that small plots of QPM OPVs that are surrounded by CM fields are easily contaminated and hence will not maintain the required protein quality. Some important aspects of the QPM OPV varieties released in Ethiopia are presented on the subsequent pages.

A. MELKASSA-6Q

Vear of Poleace and Description	• 2008
Tear of helease and Description	 early maturing open pollinated variety
	• central rift valley area of Oromia, Southern Nations,
	Nationalities and Peoples (SNNP) and Somali
Agro-ecological Adaptation	Regions and in some parts of Tigray due to its
	tolerance to low moisture stress
Days to Maturity	on average 120 days
Yield Potential	• 4.5-5.5 t/ha under researcher management
	3.0-4.0 t/ha under farmers` management

Note:

Currently the seed of this variety is under commercial production by different public and private seed companies and farmers' cooperative unions.

B. MELKASSA-1Q

Year of Release and Description	• 2013
	QPM version of Melkassa-1
	 extra early maturing OPV
Agro-ecological Adaptation	 best suited to the adaptation areas of
	Melkassa-1, areas with short rainfall
	duration and marginal for growing maize
Days to Maturity	on average 90 days
Yield Potential	• 3.5 to 4.5 t/ha on researcher management
	• 2.5 to 3.5 t/ha under farmers` management

Note:

- This variety and its conventional counterpart are not recommended for relatively high potential areas within moisture stress areas because of their low yield as compared to other varieties.
- Farmers should be aware that this variety is disposed to birds and wild animals because of its early maturity and shorter plant stature.

2.2.2 Hybrid QPM varieties



Dear learner, what is a hybrid variety? What makes it different from OPV?

A hybrid is the product [first filial generation (F₁)] of a cross between two unrelated (genetically dissimilar) parents, one of which is designated as female and the other male. When the hybrid is formed by crossing two different inbred parental lines, it is a single-cross hybrid. A cross of one inbred line with a single-cross hybrid parent forms a three-way cross hybrid. Other types of hybrids include double-cross hybrids (formed by crossing two different single-cross parents) and top-cross hybrids (formed by crossing an OPV to a single-cross hybrid). BHQPY545 is an example of a single-cross hybrid obtained by crossing two QPM inbred lines [CML161 (the female or "seed" parent) X CML165 (the male parent)]. Examples of three-way cross hybrids are MHQ138 [(CML 144 X CML 159) X Pool15Q] and AMH760Q [FS17Q X A7033] X 142-1-e].



Dear learner, what do you think are the advantages of hybrid varieties?

Advantages of hybrids include:

- They produce higher grain yields compared to OPVs; and
- They have more uniform characteristics (particularly single-cross hybrids), making them more suitable for mechanization.

Hybrids also have some constraints:

- They are more expensive to develop;
- The price of hybrid seed is higher compared to that of OPVs; and
- Farmers must purchase fresh F₁ seed every year as use of F₂ results in a yield reduction of as much as 30% compared to F₁ seed.

Some important aspects of the QPM hybrid varieties released in Ethiopia are presented on the following pages.

A. BHQP542 (Gabissa)

Year of Release and Description	• 2001 (the first QPM variety released in Ethiopia)
	 an intermediate maturing three way cross hybrid
Agro-ecological Adaptation	 adapted to the mid-altitude sub-humid maize agro-
	ecology (1000-1800 m.a.s.l)
	 shares the same adaptation zones with BH540 (CM
	hybrid variety released in Ethiopia)
Days to Maturity	on average 145 days
Yield Potential	• 8.0-9.0 t/ha under researcher management
	 5.0-6.0 t/ha under farmers management

Note:

Because of its susceptibility to leaf rust, this variety is now out of production.



Figure 7. Plant and ear morphology of BHQP542



B. BHQPY545 (Kello)

Year of Release and Description	• 2008
	• a yellow grain single cross hybrid with high yield and
	lodging resistance
	 a little earlier in maturity than other intermediate
	maturing varieties
	 prolific and under good management it can produce
	up to four full-sized ears
Agro-ecological Adaptation	 adapted to the mid-altitude sub-humid maize agro-
	ecology
Days to Maturity	on average 144 days
Yield Potential	• 8.0 - 9.5 t/ha under researcher management
	 5.5 - 6.5 t/ha under farmers' condition
	 up to 9.8 t/ha reported from demonstration plots
	managed by farmers in Gobu Seyo district, East
	Wollega

Although consumers generally prefer maize with white kernels, demand for BHQPY545 is expected to increase for the following reasons:

- increased awareness in the community of the nutritional advantage of QPM varieties, particularly for children, as well as pregnant and lactating women. Another nutritional factor associated with yellow kernel is its pro-vitamin A content;
- demand for yellow maize, such as BHQPY545, is increasing for making corn flakes. In recent years, farmers in Bako Tibe, Illu Gelan, Gobu Seyo, and Sibu Sire districts who cultivate this variety have received premium farm-gate prices from the FAFFA food processing factory;
- demand from the country's flourishing poultry industry for BHQPY545 grain because of its yellow color (to enhance egg yolk color) and protein quality (to supplement protein in rations); and
- its suitability, both in taste and prolificacy, for green ear consumption.

This variety is low to moderately affected by ear rot under conditions of high rainfall. To reduce the incidence of ear rot, growers are advised to apply one of the following strategies:

- Avoid growing this variety in areas where ear rot is prevalent;
- Produce the variety for the green ear market as it is sweet and prolific under optimum management conditions;
- Delay planting so that it matures late in the season when rainfall is subsiding or has ended, since ear rots are favoured by excessive moisture penetrating the ear; and

• Grow the variety during the off-season under irrigation in areas to which it is adapted, thus avoiding excessive moisture as the crop matures.



Figure 8. Plant and ear morphology of BHQPY545

C. AMH760Q (Webi)

26

Webi is the outcome of the conversion of the parental lines of BH660 (CM three-way cross hybrid popular in many parts of Ethiopia) into QPM versions through backcross breeding method. The conversion was aimed at developing QPM variety that is competitive with BH660 in terms of grain yield in the transitional and true highland areas.

Year of Release and	• 2010
Description	 a three way cross hybrid variety with mixed purple and
	white tassel and leaf sheath colour
Agro-ecological Adaptation	 adapted to highland agro-ecology of Ethiopia (1800 to
	2600 masl)
Days to Maturity	• on average 160 days
Yield Potential	 9.0-12.0 t/ha under researcher management
	 6.0-8.0 t/ha under farmers' management

Webi has some weaknesses and certain peculiar features that a grower should be aware of:

- Webi is susceptible to turcicum leaf blight (TLB). Therefore farmeres, in highland areas where TLB is a serious problem are advised to grow other QPM varieties with tolerance to the disease.
- Webi has mixed purple and white (50:50) tassels as a varietal characteristic, in contrast to BH660 which is uniformly purple. This mixed tassel color does not indicate seed contamination and has absolutely no effect on grain yield. However, if the proportion of purple and white tassels in Webi deviates significantly from 50:50, it could be due to contamination.



Figure 9. Plant and ear morphology of AMH760Q

D. MH138Q

Year of Release and Description	• 2012
	 three way cross hybrid tolerant to drought
Agro-ecological Adaptation	 adapted in dry land areas such as the central rift valley
	northern, eastern and southern parts of Ethiopia
Days to Maturity	on average 140 days
Yield Potential	 7.0-8.0 t/ha under researcher management
	 5.5-6.0 t/ha under farmers' management

Note:

This variety shares the same female parent with BHQP542 (CML144/CML159), but its male parent has been derived from POOL-15Q. It has manifested high yield on demonstration plots conducted on farmers' fields around the vicinity of Bako. Therefore, it can be used as alternative QPM variety for high potential transitional midlands areas, but one should seek advice from research centres before planting on large scale.



Figure 10. Ear and plant morphology of MHQ138



E. BHQP548

Year of Release and Description	• 2015
	 three way cross hybrid
Agro-ecological Adaptation	 adapted to the mid-altitude, sub-humid maize agro-
	ecology
Days to Maturity	 on average 145 days
Yield Potential	 75-85 t/ha under researcher management
	• 5.5-7.0 t/ha under farmers' management

This variety shares the same female single cross parent with BHQP542 and MH138Q (CML144/ CML159), but its male parent is derived from an OPV called Kuleni released for the moist midaltitude agro-ecology. The release of this variety will potentially accelerate the adoption of QPM due to: (i) higher seed yield enough to meet seed productivity threshold of seed companies; and (ii) providing a white-seeded alternative with similar maturity to the yellow-seeded QPM variety (BHQPY545).



Figure 11. Ear and plant morphology of BHQ548.

F. AMH852

Year of Release and Description	released in 2016
	 three way cross hybrid
Agro-ecological Adaptation	 adapted to highland agro-ecology of Ethiopia (1800
	to 2600 masl)
Days to Maturity	 on average 183 days
Yield Potential	 9.0-10.0 t/ha under researcher management
	• 7.5-8.5 t/ha under farmers' management

Note:

This is a very high yielding QPM variety adapted to the highland maize growing agroecology of Ethiopia. Because it shares the same ecological adaptation, it is meant to substitute AMH760Q which already has shown decline in performance and susceptibility to turcicum leaf blight.



Figure 12. Plant and ear morphology of AMH852Q



Learning Activity 2

- 1. What are the different types of breeding methodologies employed to develop QPM varieties?
- 2. Describe the QPM varieties released for drought prone areas of the country and their varietal type (OPV or hybrid)?
- 3. Which variety did you find to be very productive?
- 4. Which are the QPM varieties released for mid-altitude sub-humid maize agroecology of Ethiopia; please identify their varietal type (OPV or hybrid)?

31

5. Which variety has been used by factories to produce corn flakes and why?

MODULE 3: Seed Maintenance and Prevention of Grain Contamination

Credit HOURS:	2 hrs
Module Description:	The multiplication and maintenance of QPM seed is very similar
	to CM seed production. The only additional requirement is
	to assure with laboratory analysis the tryptophan and lysine
	contents are above the threshold levels to be branded as QPM.
	The basic procedures to be followed and precautionary measures
	in seed production and maintenance is presented in this module.
Module Learning	 Understanding QPM seed maintenance procedures;
Outcomes:	 Applying QPM seed maintenance procedures; and
	Understand and undertake necessary precautionary measures.

INSTRUCTION

Dear instructor, most of the issues presented in this section are related with seed multiplication and maintenance. It, therefore, requires presenting practical examples and exposure of the learners to the practical realities in the field how seed multiplication forms are managed and maintained. It is essential to show learners pictorially seed multiplication farms so as to enable them capture the concepts.

3.1 Principles of QPM Seed Multiplication



32

Dear learner, what do you think are the advantages of hybrid varieties?

The production and maintenance of QPM seed don't differ from those of CM seed. The same strict standards in terms of land preparation, isolation distance/time, roguing, field management and inspection, detasselling, post-harvest activities, and seed certification must be followed along the seed value chain (i.e., at the breeder seed, basic seed, and certified seed production stages) to ensure true-to-type and high quality seed. The only additional requirement for QPM seed is to perform tryptophan and protein analyses to ensure the values are above the required minimum. In principle, QPM seed produced from pure seed stocks under strict isolation should retain the protein quality characteristics of the registered variety.

When a farmer intends to recycle seeds of a QPM OPV, special attention needs to be given to maintaining the required genetic diversity, purity, and protein quality. Another important

consideration for the maintenance of an OPV is the number of plants or ears to be used. Two issues interact to determine the number:

• the number of plants or ears required to adequately represent an OPV; and.

• the amount of seed required to meet future needs, without reproducing it very frequently. The number of plants or ears that can be taken as representative of an OPV depends on the genetic variability present within the OPV. Theoretical considerations as well as the experience of national and international maize breeding programs indicate 200-300 ears harvested from different plants of the same population would be sufficient to represent an OPV. During the maintenance process, apart from maintaining its genetic variability, it is important to ensure the protein quality through lab analysis, at least after every three planting seasons.

3.2 Preventing QPM grain contamination in farmers' fields

The *opaque-2* gene must be homozygous recessive (*o2o2*) in a QPM genetic background for deriving high lysine and tryptophan content. Inadvertent pollination of a QPM cultivar by non-QPM (dominant *O2* gene) pollen makes the harvested grain non-QPM, i.e., grains on a QPM ear that are fertilized by pollen from a CM plant will not be QPM. It is very likely that a farmer's field planted with a QPM cultivar for grain production will be surrounded by plots of non-QPM cultivars (Fig.13). Therefore, QPM grain production (both hybrids and OPVs) in farmers' fields runs the risk of pollen contamination, depending upon the QPM plot size, environmental conditions (e.g. wind direction), number of surrounding plots or farms planted with non-QPM varieties, and the relative flowering dates of the adjacent QPM and non-QPM plots/farms.



Figure 13. Schematic representation of a QPM OPV field surrounded by CM fields under smallscale farming conditions

The effects and significance of outcrossing from adjacent non-QPM plots on contamination of QPM grain in plots considered representative of typical on-farm plot size were studied in Ghana and Zimbabwe. In each country, a field (0.4 ha or 0.21 ha) of a white-grained QPM variety was completely surrounded by a yellow-grained, non-QPM cultivar of the same maturity. Contamination was observed and estimated by the number and percentage of yellow kernels (evidence of pollination by yellow maize) on QPM ears at various distances from the borders. The results showed a maximum contamination of 11% of the entire grain harvest from the plot. Contamination was highest near the QPM field borders and decreased towards the middle of the field, specifically, within 12 meters of the QPM border. There was virtually no contamination in the Ghana sites, while in Zimbabwe, high outcrossing levels (63 to 83%) were observed in the peripheral areas of the QPM plots which declined to <20% within 5 m and to <10% at 10 m from the borders. While outcrossing was observed on at least 60% of each of the QPM crop areas, it was not significant enough to compromise QPM grain quality.

In practical terms, planting a QPM field next to a non-QPM field does not significantly affect the quality and nutritional benefits of the harvested QPM grain. This was demonstrated in rat feeding experiments conducted by nutritionists in Ghana. QPM and non-QPM grains were physically mixed together in varying proportions to simulate varying levels of contamination, and then assessed both in lab analyses and rat-feeding studies. It was found that contamination caused the loss of QPM benefits only after the introduction of more than 20% of non-QPM grain into the QPM grain, a contamination level higher than what was observed in the field (a maximum mean contamination of 11%). Machida et al. (2012) suggested that farmers will not lose the benefits of QPM under normal farming conditions if there are non-QPM plots in the vicinity. Nevertheless, there are precautions farmers can take to minimize contamination, including the following:

- since most contamination occurs on the border of the plot, planting QPM in relatively square plots will minimize the length of the borders facing the CM plots and therefore minimize contamination;
- plant QPM plots upwind/leewardside from CM plots;

34

- harvest the relatively pure QPM grains from the middle of the field where the proportion of QPM to non-QPM grains is higher; treat the 5 m of border rows or plants growing adjacent to CM plots as non-QPM; and
- where the length of the cropping season permits, plant QPM varieties having different maturity, so that the flowering periods do not overlap with CM varieties planted in adjacent fields.

As awareness of QPM spreads and as more farmers or entire communities start growing QPM cultivars, the problem of contamination will be significantly minimized. When QPM was first commercialized in Ghana, entire villages were covered with QPM seed such that virtually all maize producers in the community grew only the QPM variety, thus avoiding the possibility of contamination.

3.3 Recycling of QPM seeds

It is important to differentiate the issue of QPM grain contamination from QPM seed contamination. Since hybrid grain is not used as seed for planting the next season, the only major concern in hybrid grain production fields is retaining protein quality in the grain for human consumption. But in OPVs, the concern is retaining protein quality both for human consumption and for use as seed for next planting. As discussed above, an advantage of using OPV seed is that farmers can save part of their seed for the next planting for about three cycles. However, when contaminated seed is sown, the non-QPM off-types in the batch will outcross with QPM plants within the plot, generating more non-QPM plants and increased contamination. Repeated recycling will quickly multiply the effect, and the seed and grain produced will very soon fail to qualify as QPM. What should a farmer do to save seed from his/ her QPM grain production for the following cycle? The following measures should be taken when saving QPM OPV seeds for the next planting season:

- Farmers should select OPV seeds from the middle of their fields (see Fig. 13), at least 20 m away from the QPM field borders with other maize fields, including fields planted with different QPM varieties. Consequently, the QPM seed should be harvested from the middle of a relatively large field (with 20 m border areas, a minimum size of 50 m x 50 m, or 0.25 ha, is recommended).
- Farmers should save about 200-300 ears and the shelled seed from these ears should be thoroughly mixed.
- Farmers should purchase fresh QPM OPV seeds from seed producers after recycle their own seeds for not more than three times.

Note the followings:

- ✓ grains on a QPM ear fertilized by pollen from non-QPM maize are non-QPM;
- ✓ contamination from a non-QPM field planted next to a QPM field is relatively low, a maximum of 11%, and does not render the entire harvest non-QPM;
- ✓ contamination causes loss of QPM benefits only after the introduction of more than 20% of non-QPM grain into the QPM grain;
- ✓ to protect seeds from all possible sources of contamination, farmers should select their OPV seeds from the middle (>20 meters away from all sides) of their fields; and
- ✓ in the case of OPVs, farmers should purchase fresh seed from seed producers after a maximum of three planting cycles of using their own seeds in order to maintain varietal purity. In case of hybrids, they should purchase fresh seed every year to minimize contamination as well as loss of yield potential due to out-crossing.

35,

Learning Activity 3

- 1. What is the purpose of maintenance and recycling of seed?
- 2. For which type of variety can a farmer recycle QPM seed and how many times can he/she recycle it?
- 3. What should a farmer do if he/she wishes to save QPM seed from his/her grain production for the following cycle?
- 4. Could you illustrate the difference and similarity of seed recycling methods in QPM and CM OPVs?



REFERENCES FOR FURTHER READINGS

Akalu, G., Tafesse, S., Gunaratna, N.S. and De Groote, H. 2010. The effectiveness of quality protein maize in improving the nutritional status of young children in the Ethiopian highlands. Food and Nutrition Bulletin 31(3): 418-30.

Alexandra, O. 2011. Sensory evaluation of foods. FITC-SFOS, University of Alaska, Alaska, USA.

- Babu, R. and Prasanna, B.M. 2014. Molecular breeding for Quality Protein Maize (QPM). In: Tuberosa, R. and Varshney, R.K. (eds.). Advances in Genomics of Plant Genetic Resources, Springer, pp. 489-505.
- Belfield, S. and Christine, B. 2008. Field Crop Manual: Maize, a Guide to Upland Production in Cambodia. NSW Department of Primary Industries, State of New South Wales, Australia.
- Bressani, R. 1992. Nutritional value of high-lysine maize in humans. In: Mertz, E.T. (ed.), Quality Protein Maize. American Association of Cereal Chemists, St. Paul, MN, USA, pp. 205–224.
- Campbell, R.G. and Dunkin, A.C. 1983. The influence of protein nutrition in early life on growth and development of the pig. British Journal of Nutrition 50:605-617.
- CTA and ISF. 2012. Maize production and processing. Collection Pro-Agro. http://publications. cta.int/media/publications/downloads/1724_PDF.pdf [Online].
- De Groote, H., Gunaratna, N., Okuro, J., Wondimu, A., Chege, C., and Tomlins, K. 2014. Consumer acceptance of quality protein maize (QPM) in East Africa. Journal of the Science of Food and Agriculture 94 (15): 3201–3212.
- De Groote, H., Gunaratna, N., Kebebe, E., and Friesen, D. 2010. Extension and adoption of biofortified crops: Quality protein maize in East Africa. Paper prepared for submission to the African Agricultural Economics Association Meetings – Cape Town, 19-23 September 2010.
- De Onis, M., Montero, C., Akre, J., and Clugston, G. 1993. The worldwide magnitude of proteinenergy malnutrition: an overview from the WHO Global Database on Child Growth. Bulletin of the World Health Organization 71 (6): 703-712.
- Dereje, B., Mosisa, W., Hadji, T., Wonde, A., Twumasi-Afriyie, S., Mandefro, N., Leta, T., Legesse,
 W., and Abdissa, G. 2004. On-farm evaluation of CIMMYT's quality protein maize varieties
 in Ethiopia. In: Friesen, D.K and Palmer, A.F.E (eds.), Integrated Approaches to Higher
 Productivity in the New Millennium. Proceedings of the 7th Eastern and Southern Africa
 Regional Maize Conference, 5-11 February 2002. Nairobi, Kenya: CIMMYT (International Maize
 and Wheat Improvement Center) and KARI (Kenya Agricultural Research Institute).
- FAO (Food and Agriculture Organization of the United Nations). 1992. Maize in human nutrition. FAO, Rome. Available from: http://www.fao.org/docrep/t0395e/T0395 E00.htm# [Online]
- FAO (Food and Agriculture Organization of the United Nations). 2002. Protein sources for the animal feed industry. The FAO Expert Consultation and Workshop on Protein Sources for the Animal Feed Industry; 29 April to 3 May 2002, Bangkok, Thailand, FAO, Rome, Italy.
- Gezahegn, B., Dagne, W., Lealem, T., and Desta, G. 2012. Maize improvement for low moisture stress areas of Ethiopia: Achievements and progress in the last decade. In: Worku, M.,

37,

Twumasi-Afriyie, S., Wolde, L., Tadesse, B., Demissie, G., Bogale, G., Wegary, D., and Prasanna, B.M. (eds.), Meeting the Challenges of Global Climate Change and Food Security through Innovative Maize Research. Proceedings of the 3rd National Maize Workshop of Ethiopia, 18-20 April 2011; EIAR and CIMMYT, Addis Ababa, Ethiopia,

- Graham, G.G., Lembake, J., and Morales, E. 1990. Quality protein maize as the sole source of dietary protein and fat for rapidly growing young children. Pediatrics 85: 85–91.
- Guang-Hai, Q., Qi-Yu, D., Yan, T., Shu-Geng, W., and Shi-Huang, Z. 2003. Nutritional evaluation and utilization of quality protein maize (QPM) in animal feed. In: Protein Sources for the Animal Feed Industry. Proceedings of Expert Consultation and Workshop, 29 April to 3 May 2002. FAO, Bangkok, Thailand.
- Gunaratna, N.S., McCabe, G.P., and De Groote, H. 2008. Evaluating the impact of biofortification: A meta-analysis of community-level studies on quality protein maize (QPM). Paper Presented at the 12th Congress of the European Association of Agricultural Economists (EAAE), Ghent, Belgium.
- Gunaratna, N.S., De Groote, H., Nestel, P., Pixley, K.V., and McCabe, G.P. 2010. A meta-analysis of community-level studies on quality protein maize. Food Policy 35: 202-210.
- Kassahun, B. and Prasanna, B.M. 2003. Simple sequence repeat polymorphism in Quality Protein Maize (QPM) lines. Euphytica 129: 337-344.
- Kassahun, B. and Prasanna, B.M. 2004. Endosperm protein quality and kernel modification in quality protein maize (QPM) Lines. Journal of Plant Biochemistry and Biotechnology 13(1): 57-60.
- Krivanek, A.F., De Groote, H., Gunaratna, N.S., Diallo, A.O., and Friesen. D. 2007. Breeding and disseminating quality protein maize (QPM) for Africa. African Journal of Biotechnology 6:312-324.
- Lawless, H.T. and Heymann, H. 1998. Sensory Evaluation of Food: Principles and Practices. Chapman & Hall, New York, USA.
- Legesse, W., Mosisa, W., Berhanu, T., Girum, A., Wonde, A., Solomon, A., Tolera, K., Dagne, W.,
 Girma, D., Temesgen, C., Leta, T., Habtamu, Z., Alemu, T., Fitsum, S., Andualem, W., and
 Belayneh, A. 2012. Genetic improvement of maize for mid-altitude and lowland sub-humid
 agro-ecologies of Ethiopia. In: Worku, M., Twumasi-Afriyie, S., Wolde, L., Tadesse, B., Demissie,
 G., Bogale, G., Wegary, D., and Prasanna, B.M. (eds.), Meeting the Challenges of Global
 Climate Change and Food Security through Innovative Maize Research. Proceedings of the
 3rd National Maize Workshop of Ethiopia, 18-20 April 2011; Addis Ababa, Ethiopia, EIAR and
 CIMMYT, Addis Ababa, Ethiopia, pp. 24-34.
- Machida, L., Derera, J., Tongoona, P., Mutanga, O., and MacRobert, J. 2012. Geostatistical analysis of quality protein maize outcrossing with pollen from adjacent normal endosperm maize varieties. Crop Science 52: 1235-1245.

- Mahuku, G., Wangai, A.W., Sadessa, K., Teklewold, A., Wegary, D., Adams, I., Smith, J., Braidwood, L., Feyissa, B., Regassa, B., Wanjala, B., Kimunye, J., Mugambi, C., Bottomley, E., Bryce, S., Ayalneh, D., and Prasanna, B. 2015. First report of Maize chlorotic mottle virus and Maize lethal necrosis in Ethiopia. Plant Disease [http://dx.doi.org/10.1094/PDIS-04-15-0373-PDN].
- Maner, J.H., 1975. Quality protein maize in swine nutrition. In: High-Quality Protein Maize. Hutchinson Ross Publishing Co., Stroudsburg, PA, pp. 58-82.
- Meilgaard, M., Civille, G.V., and Carr, B.T. 1999. Sensory Evaluation Techniques. 3rd ed. Boca Raton: CRC Press L.L.C.
- Mertz, E.T., Vernon, O.A., Bates, S., and Nelson, O.E. 1965. Growth of rats fed *opaque-2* maize. Science 148: 1741–1744.
- Miko, S., Valencia, J.A., and Falaki, A.M. (eds.). 2001. Maize for better nutrition. Proceedings of the National QPM Production Workshop, 4-5 September 2001. Organized by SG2000 Nigeria, IAR/ ABU and FMARD, Ahmadu Bello University, Zaria.
- Mosisa, W., Bänziger, M., Friesen, D., Erley, G.S., Diallo, A.O., Vivek, B., and Horst, W.J. 2006. Protein quantity and quality, and agronomic performance of quality protein maize and normal endosperm maize under different levels of nitrogen. Proceedings of the 12th Annual Conference of the Crop Science Society of Ethiopia, pp. 156-169.
- Nuss, E.T and Tanumihardjo, S.A. 2011. Quality protein maize for Africa: Closing the protein inadequacy gap in vulnerable populations. Advances in Nutrition 2: 217-224.
- Onimisi, P.A, Omage, J.J., Dafwang, I.I., and Bawa, G.S. 2009. Replacement value of normal maize with quality protein maize (Obatampa) in broiler diets. Pakistan Journal of Nutrition 8(2): 112-115.
- Osei, S.A., Okai, D.B., Ahenkora, K., Dzah, B.D., Haag, W., Twumasi-Afriyie, S. and Tua, A.K. 1994. Quality protein maize as main source of energy and amino acids in the diets of starter pigs. In: Proceedings of Ghanan Animal Science Symposium 22: 31-36.
- Prasanna, B.M. 2015. Maize lethal necrosis (MLN) in eastern Africa: Tackling a major challenge. The African Seed (March 2015 Issue), pp. 18-21.
- Prasanna, B.M., Vasal, S.K., Kassahun, B., and Singh, N.N. 2001. Quality protein maize. Current Science 81(10): 1308-1319.
- Qi, G., Diao, Q., Tu, Y., Wu, S. and Zhang, S. 2004. Nutritional evaluation and utilization of quality protein maize (QPM) in animal feed. In: Protein Sources for the Animal Feed Industry. Expert Consultation and Workshop, 29 April-3 May 2002, FAO, Bangkok, Thailand.
- Rahmanifari, A. and Hamaker, B.R. 1999. Potential nutritional contribution of quality protein maize: A close-up on children in poor communities. Ecology of Food and Nutrition 38(2): 165-182.
- Sofi, P.A., Shafiq, W.A, Rather, A.G., and Shabir, W.H. 2009. Review article: Quality protein maize (QPM): Genetic manipulation for the nutritional fortification of maize. Journal of Plant Breeding and Crop Science 1(6): 244-253.

39,

- Teklewold A., Wegary D., Tadesse A., Tadesse B., Bantte K., Friesen D.s and Prasanna B.M. 2015. Quality Protein Maize (QPM): A Guide to the Technology and Its Promotion in Ethiopia. CIMMYT: Addis Ababa, Ethiopia.
- Twumasi-Afriye, S., Demissew, A.K., Gezahegn, B., Wonde, A., Gudeta, N., Demoz, N., Friessen, D., Kassa, Y., Bayisa, A., Girum, A., and Wondimu, F. 2012. A decade of quality protein maize research progress in Ethiopia (2001-2011). In: Worku, M., Twumasi-Afriyie, S., Wolde, L., Tadesse, B., Demissie, G., Bogale, G., Wegary, D., and Prasanna, B.M. (eds.), Meeting the Challenges of Global Climate Change and Food Security through Innovative Maize Research. Proceedings of the 3rd National Maize Workshop of Ethiopia, 18-20 April 2011, Addis Ababa, Ethiopia, EIAR and CIMMYT, Addis Ababa, Ethiopia, pp. 47-65.
- Twumasi-Afriyie, S., Dzah, B.D. and Ahenkora, K., 1996. Why QPM moved in Ghana. In: Ransom, J.K., Palmer, A.F.E., Mduruma, Z.O., Waddington, S.R., Pixley, K.V. and Jewel, D.C. (Eds.), Maize Productivity Gains through Research and Productivity Dissemination. Proceedings of the Fifth Eastern and Southern Africa Maize Conference, Arusha, Tanzania, 3-7 June 1996. CIMMYT, Addis Ababa. Ethiopia, pp. 28-31.
- Vasal, S.K. 1999. Quality protein maize story. In: Improving Human Nutrition through Agriculture: The role of International Agricultural Research. October 5-7, 1999. A Workshop Hosted by the International Rice Research Institute (IRRI), Los Banos, Philippines, and Organized by the International Food Policy Research Institute (IFPRI).
- Vasal, S.K. 2000. The quality protein maize (QPM) story. Food and Nutrition Bulletin 21(4): 445-450.
- Vivek, B.S., Krivanek, A.F., Palacios-Rojas, N., Twumasi-Afriyie, S. and Diallo, A.O. 2008. Breeding quality protein maize (QPM): Protocols for developing QPM cultivars. CIMMYT.
- Wakene, N., Tolera, A., Minale, L., Tolessa, D., Tenaw, W., Assefa, M., and Zirihun, A. 2012. Soil fertility management technologies for sustainable maize production in Ethiopia. pp. 123-127. In: Worku, M., Twumasi-Afriyie, S., Wolde, L., Tadesse, B., Demissie, G., Bogale, G., Wegary, D., and Prasanna, B.M. (eds.), Meeting the Challenges of Global Climate Change and Food Security through Innovative Maize Research. Proceedings of the Third National Maize Workshop of Ethiopia, 18-20 April 2011, EIAR and CIMMYT, Addis Ababa, Ethiopia.
- WHO (World Health Organization). 2002. Protein and amino acid requirements in human nutrition. WHO Technical Report No. 935.

GLOSSARY

Alleles: alternative forms of the same gene, located at the same locus in a chromosome. **Amino acids:** the building blocks from which proteins are constructed. Amino acids are classified either as essential or non-essential.

Backcross: a cross between a hybrid (F1) and one of its parents.

Casein: proteins commonly found in mammalian milk, making up 80% of the proteins in cow's milk and between 20% and 45% of the proteins in human milk.

Conventional maize: a term used interchangeably to describe maize that is not QPM.

Dominant allele: an allele that express itself in the heterozygous form.

Donor parent: in backcross breeding, the parent from which one or more genes are transferred to the recurrent parent.

Dough stage: the stage of maize/cereal grain development at which the kernel's milky inner fluid changes to a "doughy" consistency as starch accumulation continues in the endosperm. In maize this usually happens about 24 to 28 days after silking.

Essential amino acid: an amino acid that cannot be synthesized by the organism being considered, and therefore must be supplied in its diet; whereas non-essential amino acids can be produced from other amino acids and substances in the diet and metabolism.

F1 (1st filial generation): progeny obtained by crossing two different parents or the first generation from a cross.

F2 (2nd filial generation): progeny obtained by self-fertilization of or crossing between the same F1 individuals or F1 individuals of the same population.

Genotype: the genetic constitution of an individual organism.

Germplasm: the sum total of hereditary material or genes present in a species.

Githeri: a mixture of boiled maize kernels and beans in a ratio of 2:1.

Gotera (Amharic): a granary made by weaving elongated thin shrub stems or split bamboo sticks plastered with mud and cow dung, usually cylindrical in shape, flat or conical at the base and covered with a conical thatched roof.

Grain/endosperm modification: the extent to which the mutant maize endosperm of the soft (opaque) phenotype carrying the *o2* gene is converted through breeding selection to the hard/ vitreous phenotype similar to that of conventional maize.

Height-for-age: the age that corresponds to the child's height when plotted at the 50th percentile on a growth chart.

Heterozygous: an individual having dissimilar alleles of a gene.

Homozygous: an individual having two or more identical alleles of a gene.

Hybrid maize: maize varieties or cultivars created by crossing two different inbred parental lines (to form a single-cross hybrid) or one inbred line with a single-cross parent (to form a three-way cross hybrid). Other types of hybrids include double-cross hybrids (formed by crossing two

different single-cross parents) and top-cross hybrids (formed by crossing an OPV to a singlecross hybrid. Parents of hybrids are chosen on the basis of desired characteristics to combine into a hybrid.

Injera: a leavened bread made from fermented dough.

Lysine: a basic amino acid that is a constituent of most proteins. It is an essential nutrient in the diet of vertebrates.

Monogastric animal: an animal with a simple single-chambered stomach, as compared to ruminant animals such as cows, goats, or sheep, which have a complex four-chambered stomach. Animals with a monogastric digestive tract are less efficient than ruminants in extracting energy from cellulose digestion.

Nutrition: the process of providing or obtaining the food necessary for health.

Opaque-2 (o2) gene: a recessive gene in maize responsible for increased lysine and tryptophan contents in the endosperm protein.

Open pollination: pollination which occurs freely and naturally without restriction.

Open-pollinated variety (OPV): an assemblage of cultivated maize plants distinguished by uniform morphological, physiological, cytological, chemical or other characteristics which, when reproduced or reconstituted, retain its distinguishing features.

Phenotype: the set of observable characteristics of an individual resulting from the interaction of the genotype with the environment.

Protein: any of a class of nitrogenous organic compounds which have large molecules composed of one or more long chains of amino acids and are an essential part of all living organisms.

Quality protein maize (QPM): the term QPM refers to maize genotypes having the *opaque-2* (*o2*) gene and, consequently, contains generally higher lysine and tryptophan content as compared to conventional maize genotypes, as well as a vitreous endosperm similar to conventional maize to ensure acceptable ear characteristics.

Recessive: an allele of a gene whose action is hidden by the presence of a dominant allele of the same gene.

Recurrent parent: the parent in backcross breeding to which one or more genes from the donor parent are transferred.

Tryptophan: an amino acid that is a constituent of most proteins. It is an essential nutrient in the diet of vertebrates.

Ugali: a stiff, unfermented porridge, prepared by gradually adding maize flour to boiling water and stirring continuously until cooked.

Weight-for-age: an index of the adequacy of the child's nutrition to support growth. Standard weight-for-age is the 50thpercentile on a growth chart.



CIMMYT-Ethiopia Nutritious Maize for Ethiopia (NuME) Project Tel: +251 11 617-20 00 P.O.Box 5689 Addis Ababa Ethiopia International Maize and Wheat Improvement Center (CIMMYT) Apdo. Postal 6-641 Mexico D.F.Mexico 06600 Tel: +52(55) 58042004 www.cimmyt.org



