CURRICULUM AND MODULES FOR QUALITY PROTEIN MAIZE (QPM) TRAINING

CIMMYT

NuME
Nutritious Maize for Ethiopia Project

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

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

December 2017
Addis Ababa, Ethiopia
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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.

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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.
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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 (QPM) 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.
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

<table>
<thead>
<tr>
<th>S.N</th>
<th>Competencies</th>
<th>Learning outcomes</th>
<th>Hour</th>
</tr>
</thead>
</table>
| 1   | Understand the basic features of QPM (genetics, history and nutritional benefits of QPM) | • Understanding the historical development of QPM  
• Understand the genetics and breeding of QPM  
• Understanding the nutritional superiority of QPM | 3 hrs |
| 2   | Understand characteristics and adaptation of QPM varieties released in Ethiopia | • Understanding the characteristics of the different QPM varieties  
• Understand agro-ecological adaptations of the different QPM varieties | 3 hrs |
| 3   | Apply QPM seed maintenance procedures and preventing grain contamination | • knowing QPM seed maintenance procedures  
• Undertaking necessary precautionary measures to prevent seed and grain contamination | 2 hrs |
**Total credit hours:** 8 hrs

**Target trainees:**
This training module is meant to train agricultural development agents that are enrolled in the ATVET colleges.

**Training method:**
The training will be given in lectures, practical sessions, audio-visual aids, documentary films, field visits, and group discussion.

**Performance assessment method:**
Learning activities, self-check exercises, oral questioning, and observation upon demonstration will be used to assess the performance of the target groups that takes this course.

**Additional notes to the instructor/lecturer**
This module is prepared to provide practical experiences and details 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 in the 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 Outcomes:
- Knowing the historical development of QPM; and
- Understand the nutritional attributes of QPM based on the proportion of their lysine and tryptophan content.

INSTRUCTION
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 QPM.

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

<table>
<thead>
<tr>
<th>Traits</th>
<th>CM</th>
<th>QPM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Protein (%)</td>
<td>&gt; 8</td>
<td>&gt; 8</td>
</tr>
<tr>
<td>Lysine in endosperm protein (%)</td>
<td>1.6-2.6 (mean 2.0)</td>
<td>2.7-4.5 (mean 4.0)</td>
</tr>
<tr>
<td>Tryptophan in endosperm protein (%)</td>
<td>0.2-0.6 (mean 0.4)</td>
<td>0.5-1.1 (mean 0.8)</td>
</tr>
</tbody>
</table>

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.
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.
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).
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.
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 discovery are 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:
  - 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
  - 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:
  - converting a range of subtropical and tropical lowland adapted CM populations to o2o2 versions through backcross recurrent selection;
  - regaining the original hard endosperm phenotype of the converted populations/lines; and
  - maintaining protein quality while increasing yield and resistance to ear rot.
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 (QPM Development) 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.

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SECTION I
CURRICULUM
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 in Ethiopia.

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.

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?

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 open-pollinated 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:

1) **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, F₂ seeds are advanced to F₃ 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 F₄ 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 Characteristics

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

<table>
<thead>
<tr>
<th>Variety</th>
<th>Year of Release</th>
<th>Adaptation</th>
<th>Plant height (cm)</th>
<th>Ear height (cm)</th>
<th>DM</th>
<th>Tassel color</th>
<th>Seed Color</th>
<th>Grain texture</th>
<th>Prolificacy</th>
<th>Yield (qt/hl)</th>
<th>Disease reaction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Melkasa-6Q</td>
<td>2008</td>
<td>Low moisture stress</td>
<td>165-175</td>
<td>70-75</td>
<td>120</td>
<td>White</td>
<td>White</td>
<td>Semi-flint</td>
<td>Non-prolific</td>
<td>40-50</td>
<td>T</td>
</tr>
<tr>
<td>Melkasa-1Q</td>
<td>2013</td>
<td>Low moisture stress</td>
<td>140-160</td>
<td>65-70</td>
<td>90</td>
<td>White</td>
<td>Yellow</td>
<td>Flint</td>
<td>Non-prolific</td>
<td>35-45</td>
<td>T</td>
</tr>
<tr>
<td>BHQP542</td>
<td>2001</td>
<td>Moist mid-altitude</td>
<td>220-250</td>
<td>100-120</td>
<td>145</td>
<td>Dark pink</td>
<td>White</td>
<td>Semi-flint</td>
<td>Prolific</td>
<td>70-90</td>
<td>T</td>
</tr>
<tr>
<td>BHQPY545</td>
<td>2008</td>
<td>Moist mid-altitude</td>
<td>250-260</td>
<td>120-140</td>
<td>144</td>
<td>Pinkish</td>
<td>Yellow</td>
<td>Semi-flint</td>
<td>Prolific</td>
<td>80-95</td>
<td>T</td>
</tr>
<tr>
<td>AMH760Q</td>
<td>2011</td>
<td>Highland</td>
<td>245</td>
<td>143</td>
<td>183</td>
<td>50% white &amp; 50% purple</td>
<td>White</td>
<td>Semi-flint</td>
<td>Prolific</td>
<td>85-95</td>
<td>T</td>
</tr>
<tr>
<td>MH138Q</td>
<td>2012</td>
<td>Low moisture stress &amp; moist mid-altitude</td>
<td>200-235</td>
<td>100-120</td>
<td>140</td>
<td>white</td>
<td>White</td>
<td>Semi-flint</td>
<td>Prolific</td>
<td>75-80</td>
<td>T</td>
</tr>
<tr>
<td>BHQP548</td>
<td>2015</td>
<td>Moist mid-altitude</td>
<td>229</td>
<td>109</td>
<td>145</td>
<td>Purple</td>
<td>White</td>
<td>Semi-flint</td>
<td>Prolific</td>
<td>75-85</td>
<td>T</td>
</tr>
<tr>
<td>AMH852Q</td>
<td>2016</td>
<td>Highland</td>
<td>250</td>
<td>145</td>
<td>183</td>
<td>Purple</td>
<td>White</td>
<td>Semi-flint</td>
<td>Prolific</td>
<td>90-100</td>
<td>T</td>
</tr>
</tbody>
</table>

* 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 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

<table>
<thead>
<tr>
<th>Year of Release and Description</th>
<th>2008</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>early maturing open pollinated variety</td>
</tr>
</tbody>
</table>

| Agro-ecological Adaptation      | central rift valley area of Oromia, Southern Nations, Nationalities and Peoples (SNNP) and Somali Regions and in some parts of Tigray due to its tolerance to low moisture stress |
| Days to Maturity                | on average 120 days |
| Yield Potential                 | 4.0-5.0 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

<table>
<thead>
<tr>
<th>Year of Release and Description</th>
<th>2013</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>QPM version of Melkassa-1, extra early maturing OPV</td>
</tr>
</tbody>
</table>

| 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                 | 3.5-4.5 t/ha on researcher management, 2.5-3.5 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.


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

- Webi is susceptible to turcicum leaf blight (TLB). Therefore farmers, 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

<table>
<thead>
<tr>
<th>Year of Release and Description</th>
<th>2012</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>three way cross hybrid tolerant to drought</td>
</tr>
<tr>
<td>Agro-ecological Adaptation</td>
<td>adapted in dry land areas such as the central rift valley northern, eastern and southern parts of Ethiopia</td>
</tr>
<tr>
<td>Days to Maturity</td>
<td>on average 140 days</td>
</tr>
<tr>
<td>Yield Potential</td>
<td>7.5-8.0 t/ha under researcher management</td>
</tr>
<tr>
<td></td>
<td>5.5-6.5 t/ha under farmers' management</td>
</tr>
</tbody>
</table>

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                | • 7.5-8.5 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 mid-altitude 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](image)
### F. AMH852

| Year of Release and Description | • released in 2016  
| Agro-ecological Adaptation | • three way cross hybrid  
| | • 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.

![Image of corn plants and ears]

**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)?

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 Outcomes:
- Understanding QPM seed maintenance procedures;
- 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 farms 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

Dear learner, what do you think are the advantages of open pollinated 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 small-scale farming conditions](image)
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;
- 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.
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


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


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,


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.

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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 single-cross 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 50th percentile on a growth chart.