Extension and adoption of biofortified crops:

Quality protein maize in East Africa

By

De Groote, Hugo; Gunaratna, Nilupa; Ergano, Kebebe and Friesen, Dennis

Contributed Paper presented at the Joint 3rd African Association of Agricultural Economists (AAAE) and 48th Agricultural Economists Association of South Africa (AEASA) Conference, Cape Town, South Africa, September 19-23, 2010.

Extension and adoption of biofortified crops: Quality protein maize in East Africa

Hugo De Groote [1], Nilupa Gunaratna [2], Kebebe Ergano [3], Dennis Friesen [1]

[1] International Maize and Wheat Improvement Centre, CIMMYT, PO Box 1041-00621 Nairobi, Kenya, h.degroote@cgiar.org
[2] International Nutrition Foundation, Boston, USA
[3] International Livestock Research Institute (ILRI), Addis Ababa, Ethiopia

Paper prepared for submission to the African Agricultural Economics Association Meetings – Cape Town, 19-23 September 2010 (Contact: Prof. Nick Vink, nv@sun.ac.za)

DRAFT – June 1, 2010

Extension and adoption of biofortified crops: Quality protein maize in East Africa

Abstract

Biofortified crops, bred for improved nutritional quality, can alleviate nutritional deficiencies if they are produced and consumed in sufficient quantities. These varieties can be promoted based on their agronomic performance or based on their nutritional qualities. Quality protein maize (QPM) was the first biofortified crop and has been disseminated in Africa using both approaches. To study their effectiveness, a survey of rural households was conducted in the maize-growing areas of East Africa, comparing communities with access to QPM extension activities to control communities.
The results show that a third to one half of the farmers in project communities participated in extension activities in all countries except Kenya. In these communities, familiarity with QPM was high (74-80% of farmers), again except for Kenya (19%), but understanding of their nutritional benefits was much lower (47-55%, with 7% in Kenya). In all countries, farmers evaluated QPM varieties as good or better than conventional varieties (CV) for post-harvest characteristics. For agronomic characteristics, however, QPM varieties scored better than CV in Uganda, about the same in Tanzania, but less in Ethiopia. Adoption patterns differed widely between the countries: in the project areas it varied from 70% in Uganda, 30% in Tanzania to none in Kenya. In the control areas, adoption was only observed in Uganda (45% of farmers). Factors that significantly influenced adoption were farmers' participation in extension activities, farmers' agronomic and post-harvest evaluation of QPM vs. CM, and their understanding of the nutritional benefits of QPM. Evaluation for agronomic performance was found to be more important than knowledge of nutritional benefits, thus favoring the first approach. A reliable seed supply was, however, found to be a basic condition for adoption.

1. INTRODUCTION

(a) *Malnutrition in Africa*

Global agricultural production has grown at a tremendous rate over the last half century, not only keeping up with rapid population growth but also producing more food per person, and of better quality, than ever before. Unfortunately, this progress has not been achieved in Africa. While steady advances were made during the 1960s and 1970s, yields and production stagnated afterwards. This has often been attributed to heavy government involvement, which lead to large and costly inefficiencies (Kherallah et al., 2002; Omamo, 2003)

A wave of market liberalization and structural adjustment programs, starting in the 1990s and largely donor driven, reduced some of these inefficiencies (Crawford et al., 2003; Kelly et al., 2003), but the overall results have been disappointing, especially in food production. In East Africa particularly, food production per capita decreased from the mid-1970s to the early 1990s and has stagnated since (FAOSTAT, 2010). Despite the Millennium Development Goal to halve the proportion of people who suffer from hunger by 2015, Africa is the only region where both the proportion and the number of underweight children are increasing (Rosegrant et al., 2001; de Onis et al., 2004). Lack of access to nutritious food is, moreover, an underlying and major cause of child mortality (Caulfield et al., 2004; Black et al., 2008). In rural areas, household diets are dominated by staples such as cereals and tubers, mostly produced at the homestead, while consumption of other foods that would improve dietary quality, such as legumes, vegetables, fruits, and animal source foods, is limited by availability and price.

(b) *Biofortified crops*

Given the lack of progress in improving dietary quality in Africa, improving the nutritional quality of food crops, through a process called biofortification, would complement other agricultural and public health interventions. Some crops, such as orange flesh sweet potato (OFSP), are biofortified through conventional methods; others, such as golden rice, are biofortified through genetic engineering. Investments in biofortification research are likely to result in high returns, because of the high malnutrition rates in developing countries and their high costs to human welfare and productivity, compared with the low cost of breeding biofortified crops and the ease of disseminating them to large groups of people (Bouis, 1999).

An ex ante impact assessment of globally important staple food crops biofortified with provitamin A carotenoids, iron, and zinc for twelve countries in Africa, Asia, and Latin America indicated that the intervention can have a significant impact on the burden of micronutrient deficiencies in the developing world in a highly cost-effective manner (Meenakshi et al., 2010). Unlike other strategies to improve nutrition such as improving the diet through home gardens or education, biofortification can reach large groups of rural people cheaply, without changing their dietary habits. Unlike fortification through the addition of synthetic micronutrients and vitamins, biofortification does not require processing of food staples.

(c) *Quality protein maize*

Since maize is a major food crop worldwide but has poor nutritional quality (FAO, 1992), it is a principal target for biofortification. Maize lacks adequate levels of the essential amino acids lysine and tryptophan, thus reducing the overall biological value of its protein (Lauderdale, 2000). In the 1960s, scientists discovered the *opaque-2* (*o2*) gene, which almost doubles the lysine and tryptophan content in maize protein. The gene improves the protein quality of maize drastically (Mertz et al., 1965). Initial association of the *o*2 gene with soft kernels and poor agronomic performance was overcome and a group of new maize varieties was developed, collectively called QPM, with improved protein quality as well as and storage and agronomic qualities similar to conventional maize (Vasal, 2000; Prasanna et al., 2001). Consumption of these varieties leads to greater protein utilization (Bressani, 1992) and greater rates of growth among malnourished young children (Gunaratna et al., 2010; Akalu et al., forthcoming).

Many QPM varieties have now been released in different regions (Atlin et al., forthcoming), in particular in East Africa under the QPM Development (QPMD) project (Krivanek et al., 2007). The QPM experience, however, has shown that biofortified crops pose particular challenges that affect extension, dissemination, and likely adoption. Lessons learned could therefore be of major importance to other biofortified crops.

(d) *The challenge: Extension of biofortified crops*

The main target beneficiaries of biofortified crops are poor rural farm households: their diets depend on home grown staples with low nutritional quality, they have little access to other sources of nutritious food, and they are hard to reach through other interventions. The conditions for impact of these crops are that i) the biofortification provides a nutrient that is lacking in the diet, ii) the increased nutrient level in the crop is substantial, and iii) the beneficiaries produce and consume the crop in sufficient quantities to make a difference (Lauderdale, 2000). For QPM, the first two conditions are addressed elsewhere (Gunaratna et al., 2010; Atlin et al., forthcoming); in this paper, the extension and dissemination activities needed to meet the third condition are analyzed.

Traditional agricultural extension is based on the demonstration of the agronomic characteristics of the new varieties, lately extended to consumption characteristics. Recent consumer evaluations of new varieties for Africa included white and orange sweet potatoes in Tanzania (Tomlins et al., 2007), and rice in Ghana (Tomlins et al., 2005). The extension strategy for biofortified crops has thus far emphasized their nutritional quality. It is not clear, however, what effect this different strategy has, how it compares to the conventional strategy, or how the two can best be incorporated.

In principle, there are three possible strategies to promote the adoption of a biofortified crop. The first and classical strategy is to develop agronomically superior varieties and promote them based on these characteristics, with limited attention to their consumer or nutritional characteristics. The second strategy, long used for QPM, is to promote the biofortified varieties based on their nutritional benefit, and accept a trade-off with decreased agronomic performance. The third strategy, finally, combines developing biofortified varieties that can compete agronomically, but also promoting them on the nutritional merits.

The objective of this paper is to analyze the effect of different dissemination strategies for biofortified crops, by analyzing adoption patterns of QPM in East Africa, where it has been promoted for the last 10 years. Using farmer surveys, the effects of the different components in the extension strategy are compared, in particular farmers' participation in extension activities, their awareness of QPM, their evaluation of agronomic and consumer characteristics of QPM varieties, and their understanding of the nutritional benefits.

2. METHODS

(a) *Conceptual framework*

Extension is a critical factor in increasing the adoption of new agricultural technologies, which are typically developed to increase yields and improve the livelihoods of rural households through increased food supply and income. Biofortified crops, however, have a fundamentally different impact pathway: they are designed to reduce a nutrient deficiency and improve livelihoods through the improvement of nutritional status and health (Figure 1).

Two extension strategies can therefore be considered. The classical extension strategy (arrows with bold lines) is based on the promotion and dissemination of the varieties primarily for their agronomic characteristics. This pathway has been described extensively in the literature (Feder et al., 1985; Feder and Umali, 1993). In East Africa, classical extension was the variable most highly correlated with technology adoption (Doss et al., 2003). This strategy is also applicable to biofortified crops, since adopting households will consume the new varieties and benefit from their nutritional improvement. Apart from field characteristics, their post harvest and consumer characteristics also matter, as has been shown rice (Dalton, 2004) and bananas (Edmeades, 2007).

The alternative pathway for biofortified crops is based on increasing consumer demand (arrows with double lines in Figure 1). If public health interventions increase consumers' awareness and interest, they will increase demand, market, leading farmers to adopt the new varieties. In this pathway, two additional factors affect adoption: awareness and understanding of the nutritional value of the new varieties, which are typical increased by participating in extension activities or accessing promotion materials.

(b) *Survey Design*

The major objective of this study was to compare the effect on QPM adoption of : i) the classical pathway, in which farmers learn the new varieties from demonstrations, test and ultimately adopt them; and ii) the alternative pathway, in which farmers adopt after learning about the new varieties and their nutritional benefits. Therefore, a survey was conducted in 962 households, visited in December 2007-February 2008 in the major maize-growing areas of Ethiopia, Kenya, Tanzania, and Uganda (Figure 2).

Households were randomly selected using a stratified two-stage sampling procedure. The two strata were areas with and without access to QPMD extension activities. Primary sampling units were communities, the lowest administrative or informal unit in each country, randomly sampled with probability proportional to size, measured in number of households. Secondary sampling units where households, with about ten selected randomly within each community.

The overall impact of the project was measured by comparing areas with and without project activities. The factors in the classic pathway was measured by respondents' participation in project activities, their evaluation of the new and old varieties for agronomic and post-harvest characteristics, and their adoption. The factors in the alternative pathway were measured by respondents' awareness of QPM and their understanding of its nutritional quality. Individual characteristics can also influence adoption, as well as country specific factors such as institutions, access to seed, and policy (Feder et al., 1985), and other factors.

(c) *Site selection and sampling:*

A list of all districts where the QPMD project had been active was first assembled in all countries, and the most important districts were retained (Figure 2). In Ethiopia Because in 2007, the project was active mostly in four districts (*woredas*) in the South: Abella Tula, Dore Bafano, Badawacho, and Shashogo, these were retained, All ten Peasant Associations (PAs), the lowest administrative level, with project activities were included. From each of the four districts, three non-participating PAs were randomly selected as controls (Figure 2).

In Kenya, the project had been active in four districts in Central and Eastern Provinces, but mostly in the Embu District. To also capture lower areas, with higher poverty and food security levels, Mbeere district was also included. All four communities with QPMD activities were included in the survey, and 13 more were randomly selected along the slope.

In Tanzania, the project had QPM promotional activities in Eastern and Northern Zones but for budgetary reasons only the latter was retained for this study, where most activities took place in three districts: Hai, Babati and Karatu. In each district, the project was active in five communities, so five more were randomly selected as controls, in the same altitude range.

In Uganda, the QPMD project worked with SG2000 in four districts constituting the major maize areas: Bugiri, Iganga, Kamuli, and Kaliro. SG2000 had also been promoting the adoption of QPM in other districts since 2000. All communities with QPMD activities were first mapped, and from these four communities were selected randomly in both Bugiri and Iganga and all three in Kamuli retaine, while four more communities were randomly selected in each district as controls.

(d) *Data collection*

In each household, data were collected from both the head of the household, usually the husband, and the primary food provider, usually the wife. The head of the household was asked about agricultural production, participation in extension activities, perceptions and adoption of QPM technologies, and household wealth. The primary food provider was asked about household food consumption in the month preceding the survey.

Specifically, household heads were asked if they had participated in any QPMD project activities, and if they had grown QPM. They were also asked to score their preferred QPM and conventional maize varieties using a five-point scale (from 1=very poor to 5=very good), on different criteria including yield, other field characteristics (pest resistance, drought tolerance, and early maturity), post-harvest characteristics (resistance to storage pests, cooking qualities, and taste), and overall. They were also interviewed on their knowledge of QPM and their understanding of its nutritional quality.

As indicators of wealth, the head was asked about land area, value of agricultural production, non-agricultural income, and expenditures. Expenditures were estimated monthly for the smaller expenditures, and annually for the larger such as school fees.

(e) *Measuring the project's effect on knowledge*

In the alternative model, knowledge factors play a key role in adoption. Therefore, we first analyze the project's effect on awareness of protein (binary), awareness of QPM (binary), and understanding of its nutritional benefits. To measure understanding, the household head was asked to list QPM's advantages for humans. Responses that included benefits like improved growth, strength, increased health, improved protein quality, or substitution of QPM for other quality protein foods, were coded the response was coded "yes", all others "no".

All three dependent variables were binary, and standard analyses uses either probit or logistic regression (Maddala, 1983). Here, a mixed logistic regression model was used, including a random intercept term to account for the random selection of communities and the natural clustering of households within them. Observations from households in the same community are likely to be correlated as a consequence of the two-stage sampling and because households share information and characteristics associated with the outcomes of interest, in particular those related to infrastructure such as roads, schools, health facilities, and other services (Deaton, 1997). Such models are called mixed or random coefficient models, or also multilevel or hierarchical models (Lohr, 1999).

The exposure of farmers to the project's extension activities was measured by participation in those activities or contact with promotional materials. Participation was measured, as a binary variable, by any participation in field days, on-farm trials, demonstrations, meetings, or workshops. Contact with promotional materials was measured by having seen a QPM poster or having received any of the promotional materials such as hats, t-shirts, or pamphlets. Other factors hypothesized to influence this knowledge are individual characteristics, in particular age, and gender. Since wealthier household can have more access to information, wealth indicators were included, in particular total amount of land, ownership of livestock, ownership of durable goods (bicycle, radio, or telephone, one point for each), and housing quality (based on a metal or tile roof, walls made of concrete or mud bricks, or an improved pit or modern latrine – one point for each).

Livestock was aggregated using tropical livestock units (TLU) (1 for cattle, horses and mules; 0.25 for donkeys; 0.2 for pigs; 0.1 for small ruminants and 0.01 for poultry). Since there are differences in educational systems and extension organizations between countries, country specific binary variables were also included. All models to study the factors contributing to knowledge and adoption behavior were estimated using data from QPMD project areas only, as farmers in non-QPMD areas were unlikely to have access to QPM extension activities and seed.

(f) *The adoption models*

The main interest of this study is the effect of different strategies on adoption of biofortified varieties. Adoption can be measured as a binary variable (1 if the farmer has adopted, 0 if not) or a non-negative quantitative variable (area in the improved variety). Specific measures were adoption of QPM in the main season of 2007 (binary) and area (ha) planted to QPM in that season. For the binary variable, the same logistic model as specified above was used. For intensity of adoption, we used the area planted to QPM, a truncated variable for which the standard procedure the Tobit model (Maddala, 1983).

The independent variables, the same for both adoption models, include first the factors important in the classical impact pathway: participation in extension activities, appreciation of the new varieties, countries, and socioeconomic variables hypothesized to influence adoption. Characteristics of the household head that were considered included age, sex, years of formal education, and proportion of the working day spent on-farm, and wealth, measured as above. As seed availability appeared to be a major determinant of adoption in Ethiopia and Kenya, the adoption models included data from Tanzania and Uganda only.

Both logistic regression models were estimated using a residual pseudo-likelihood method in the GLIMMIX procedure of SAS 9.2, calculating fixed effect standard errors and degrees of freedom using the method described by (Kenward and Roger, 1997), while the Tobit regression model was estimated using maximum likelihood in the NLMIXED procedure , both using SAS 9.2.

3. THE MAIZE-BASED FARMING SYSTEMS OF EAST AFRICA

(a) *Climate and farming systems*

The climate around the Equator is driven by latitude and altitude. Rainfall increases with elevation, also depending on the direction of the slope with respect to the major wind direction. All study sites fall in the mid-altitudes (1000-1500 m) and highlands (above 1500 m) (Table 1). Average annual rainfall ranges from 742 to 1375 mm. All sites lie close to the Equator (between 5° S and 8° N) and have two rainy seasons. The rainy seasons are more distinct closer to the equator, like in Kenya and Uganda, and less distinct further away, like Tanzania and Ethiopia.

The farming systems in all sites are characterized by small holders with mixed crop and livestock production, and maize as the major food staple. Farms are generally small, especially in Ethiopia and Kenya (less than 1 ha), but larger in Tanzania and Uganda (around 2 ha). Livestock is present in all sites, but more important in Ethiopia, where almost all households own cattle, than in the other countries, where only half of them own cattle. The number of livestock per household is also much higher in Ethiopia, and that on less land. About two thirds of farmers in Ethiopia use animal traction, but only one third in Tanzania and almost nobody elsewhere. Improved dairy breeds are quite important in all countries.

Most households in the survey are male-headed, (Table 1). Almost all heads of households have gone to school. The average length of schooling is similar between countries: from six years in Ethiopia to eight years in Kenya (where the primary education cycle lasts eight years). Ethiopian households are clearly poorer than their counterparts: thatch roofs are still common in Ethiopia, while metal roofs dominate elsewhere. Few Ethiopian households own bicycles, radios, or mobile phones. In Kenya, most households have a metal roof and own a radio, but only a third have a bicycle or a mobile phone.

Both farm production and off-farm income are indicators of income, and they compare well with the estimates for expenditures (Table 1). Average income is similar between the countries, although the sources differ: Tanzanian households have very little off-farm income, while in Kenya this source provides a third of total income. The large majority of households declare agriculture as their major source of income. While most household heads in Ethiopia and Tanzania spend most of their time on the farm, less than half of those in Kenya and Uganda do so, leading to a larger off-farm income there.

(b) *Importance of maize in the system*

Maize is the dominating crop all districts, occupying the largest proportion of agricultural land in the major cropping season (Table 2). This varies from slightly less than half in Uganda, over half in Ethiopia and Kenya, to almost all in Tanzania. The Tanzanian sites, however, have a distinct second season during which other crops are grown.

In Ethiopia and Kenya, the average area under maize is small (0.4 ha), compared to Uganda (0.7 ha) and, especially, Tanzania (1.7 ha). The amounts produced and sold, per household, also vary accordingly, with particularly low yields in Kenya. Sales of maize are an important source of income in Tanzania and Uganda, but small in the other countries. In the months following the main season's harvest, however, the reverse holds for food consumption: while in Ethiopia and Kenya maize is the major component of the diet (with 600 and almost 700 grams consumed per adult equivalent (AE) per day), it is less important in Tanzania (almost 400 g/AE/day) and Uganda (less than 300 g/AE/day).

During the period that the survey was conducted, QPM accounted for two-thirds of household maize consumption in Uganda, a small portion in Ethiopia and Tanzania (14% and 6%), and none in Kenya.

4. QPM EXTENSION STRATEGIES AND ADOPTION

(a) *Project Activities*

In Ethiopia, the early maturing QPM hybrid BHQP542 was released in 2002, and seed produced by a parastatal company. The QPM variety was initially promoted both in the Western Highlands and in the southern Rift Valley, but it did not compare well with the late maturing variety BH660 which is popular in the West, so extension and promotion activities were ended there. In Kenya, three QPM varieties were developed by the Kenyan Agricultural Research Institute (KARI) and CIMMYT and released in different years, but only small quantities of one variety were ever brought to the market

In Tanzania, four QPM varieties have been released but the OPV Lishe K1, released in 2001, dominates. By 2007, it was produced by five seed companies and three farmer groups. A similar pattern emerged in Uganda, where several QPM varieties were released but the OPV Longe 5 ("Nalongo"), released in 2000, dominates and was in 2007 produced by five seed companies and one farmer group.

(b) *Farmers' participation in QPMD project activities and awareness of QPM*

The extension activities of the QPMD project reached many farmers in all countries except Kenya (Table 3). In Uganda, one third of the farmers in the project areas (35%) had participated in at least one extension activity, and about half of the farmers in in Ethiopia (41%) and Tanzania (51%). In Uganda, farmers in non-project areas also had access to QPM extension activities conducted by other agents, but participation there was lower (18%) than in QPMD project areas.

Extension activities included field days, on-farm demonstrations, meetings and workshops, but participation differed between countries. Activities in Tanzania were particularly successful, especially field days, attended by 43% of farmers in QPMD communities. In Ethiopia, a quarter of farmers attended field days (29%) or visited on-farm trials (23%). In Uganda, seminars and workshops were most popular (21%), followed by on-farm trials (19%).

Posters were fairly successful, especially in Uganda, where almost half of the farmers in QPMD communities recalled seeing them (46%), followed by Ethiopia (34%), and Uganda (21%). The number of farmers who had received promotional materials like hats or t-shirts was relatively small, including about a quarter of farmers in QPMD communities in Uganda (24%), a fifth in Tanzania (19%), and only a few in Ethiopia (4%).

In Kenya, none of the interviewed farmers, either within or outside the project areas, had participated in any of the project's activities or received any information on QPM. Informal discussions indicate that the collaborating NGOs mostly limited their dissemination activities to its members, while the research organization and seed companies were not active in the dissemination of the varieties.

The project's activities increased awareness of "protein" from one third to two thirds among the farmers in QPMD communities in Ethiopia and Tanzania. In Uganda, the increase was small (84% to 94%), largely because of the high initial awareness. In Kenya, again there was no project effect, but the awareness was nevertheless high (83%). The high awareness in the last two countries can be partly explained by the higher level of education.

In the QPMD communities, three quarters or more of respondents were familiar with the term “QPM” in all countries but Kenya (19%). QPM was also known in the control communities, albeit at a lower level (7-16%), except in Uganda, where more than half the respondents in the control group were aware of QPM. This is likely a result of SG2000’s promotion activities previous to the QPMD project or outside the project areas.

Familiarity with QPM does not, however, imply understanding of its benefits for human nutrition. In the control communities, understanding is low in all countries (under 10%) except for Uganda (45%), again likely an effect of SG2000 activities. The QPMD project’s activities raised understanding of QPM’s nutritional benefits overall and among farmers familiar with QPM in Ethiopia and Tanzania, but had no significant effect in Kenya or Uganda. Half of farmers understood QPM’s nutritional benefits in QPMD areas of all countries except Kenya.

The formal analysis, using regression, confirms these results (Table 4). Farmers who participated in QPM transfer and promotion activities, and those who saw or received promotional materials, were more likely to have heard of protein, to be aware of QPM, and to understand QPM’s nutritional benefits. Age also had a positive effect on awareness of QPM. Taking into account the other factors in the model, country differences still existed, with Tanzanian respondents less likely to have heard of protein and Kenyan respondents marginally less likely to be aware of QPM and its nutritional benefits.

(c) *Comparing QPM and Conventional maize*

Farmers were asked to evaluate both the locally available QPM variety and their preferred conventional maize variety for yield, other field characteristics (such as pest resistance, drought tolerance, and early maturity), post-harvest characteristics (such as resistance to storage pests, cooking qualities, and taste), and overall. Only farmers who knew both types are included here, which excluded all Kenyan respondents, and, in the interest of space, only the summaries are presented here (Figure 5). The difference between the countries is quite remarkable.

In Ethiopia, the local QPM variety, BHQP 542, scores lower for yield than locally preferred conventional maize varieties (Figure 5). The QPM variety is evaluated similar to conventional maize for other field traits and is rated higher for resistance to disease and field pests. Moreover, it is well appreciated for its post-harvest qualities, especially for cooking qualities and making injera, the traditional, pancake-like leavened bread. Its overall rating is therefore comparable to the conventional maize varieties.

In Tanzania, the local QPM variety, Lishe K1, scores comparably with the preferred conventional maize varieties for yield and other field characteristics. As in Ethiopia, it is better appreciated than the conventional maize varieties for its post-harvest qualities. Therefore, the QPM variety is distinctly more appreciated overall.

In Uganda, finally, the local QPM variety, Longe 5, is much more appreciated for yield and other agronomic traits than conventional maize varieties, which here are mostly local OPVs. Unlike the previous countries, it is scored comparably but not better for post harvest quality. The result, however, is a much higher overall evaluation.

(d) *Adoption*

Adoption of QPM varied greatly across the four countries, from none in Kenya to more than half of the farmers in Uganda (Figure 6). In Kenya, none of the surveyed farmers in either project or non-project areas adopted QPM in the first five years of the project (2003-2007). The factors that are likely to have influenced this outcome are the limited access to information on the new technology as well as to seed.

In Ethiopia, there was little adoption outside project areas, while in the project areas adoption varied highly between years and sites, but without any clear pattern. In Dore Bafano, all households in the project areas planted QPM in 2003, but none in the other years; in Shashogo, almost all households suddenly planted QPM in 2007, but none before that. In the other districts, there is a clear increase to about half the households adopting QPM in the project zones by 2005, but then a gradual disadoption starting in 2006. From informal discussions, it is clear that seed availability was often a problem. Alternatively, in some sites and years, only QPM seed was available. Moreover, after testing, many farmers concluded that the QPM variety did not yield as much as popular conventional varieties.

In Tanzania, on the other hand, there is a clear and logical pattern. Adoption of QPM increases steadily over time in the project areas, with little adoption in the control areas. QPM was first adopted in Hai before 2003, with support from a discontinued

SG2000 program, and by 2006-2007 it had been adopted by half of all farmers. QPM next appeared in Babati in 2004, with about a quarter of farmers growing QPM by 2006-2007. Farmers in Karatu first started growing QPM in 2006 and adoption levels were still low (8% of farmers) in 2007, when this survey was conducted. The growth pattern of 2003-2006 was, however, not continued over 2007.

Uganda, finally, is clearly the success story of the project. Adoption rates of the QPM variety, Longe 5, have been increasing steadily over the study period, with a large majority of farmers in the project areas adopting QPM in 2007, and almost half in the control area. Adoption was slowest in Kamuli, which is further north and farther from the main road to Kampala. Adoption rates in project areas also showed an impressive growth: from 9% in 2003 to 67% in 2007. Bugiri had the highest adoption rates in the project areas, growing from 30% to 78% during the study period. In the control communities, without any specific activities of the project, the adoption rate increased from 13% to almost half (45%).

(e) *Analysis of the factors that drive adoption*

A logistic model was estimated to analyze the factors influencing adoption, here defined as farmers who QPM in 2007, and a tobit model to analyze the influence of these factors on the intensity of adoption, defined as the area planted in QPM in 2007 (Table 5). Only farmers from the project areas in Tanzania and Uganda were included in these models.

Participation in extension activities, understanding of QPM's nutritional benefits, and higher evaluation of QPM relative to conventional maize all had positive effects on QPM adoption. Agronomic performance of QPM was arguably a greater factor in its adoption than understanding of its nutritional benefit: only 5% of adopters evaluated QPM less favorably than CM, while 33% of adopters were not aware of QPM's benefits for human nutrition.

Farmers who understood QPM's nutritional benefits and who rated QPM higher than conventional maize also planted larger areas in QPM in 2007. However, participation in extension activities did not have a significant effect on the area planted to

QPM. Predictably, availability of land has a positive effect on area planted to QPM, but education has, unexpectedly, a negative effect.

Taking into account all other factors in the models, farmers in Uganda were significantly more likely than farmers in Tanzania to adopt QPM and grow it on larger areas. Oxplough ownership had, surprisingly, a negative effect on both QPM adoption and QPM area planted.

5. CONCLUSIONS

(a) *Lessons learned*

The extension and promotion activities of the QPMD project reached one-third to one-half of farmers in the target areas of all countries except for Kenya. Respondents' participation in these activities had a clear and positive effect on awareness of QPM and protein, understanding of QPM's nutritional benefits, and ultimately adoption.

Farmers who evaluated QPM favorably over their preferred conventional maize varieties, as well as those who understood QPM's nutritional benefits, were more likely to adopt and to plant larger areas in QPM. Therefore, both agronomic performance and nutritional and health knowledge can drive adoption of biofortified crops, providing support for both impact pathways. The evidence, however, suggests that agronomic performance is more important.

Large differences in adoption among the four countries were also observed, likely reflecting the importance of good agronomic performance, coverage in extension activities, and a reliable and continuous seed supply. Differences in knowledge and adoption between the project and control communities can be attributed to the QPMD project. While systematic differences between project and control areas were possible, they were less likely due to random selection of communities and households within the same districts, altitude ranges, and agroecological zones.

Extension was clearly a major factor in the adoption of the new varieties. Respondents who participated in extension activities were more likely to have heard of protein, to be aware of QPM, to demonstrate understanding of its advantages for human nutrition, and to adopt. Seeing posters or receiving promotional materials has a positive effect on familiarity with QPM but only marginally significant effects on knowledge and understanding of protein or nutritional benefits, and no effect on adoption. The second factor in adoption, and likely more important in the long run, was the performance of the new varieties in farmers' fields, storage and kitchen. As the results show, good evaluation by farmers, for both agronomic and post-harvest traits, is key for farmers to adopt the new varieties.

The results of this survey further indicate that, at least in East Africa, most of the earlier concerns about the agronomic and post-harvest performance of maize varieties carrying the *opaque-2* allele have been addressed. Overall, in the study areas, many farmers see the QPM varieties as having comparable or better field and post-harvest characteristics than the conventional varieties. This cannot be generalized, however: BHQP 542 in Ethiopia is less appreciated for yield, but more for post-harvest qualities, while Longe 5 in Uganda is more appreciated for yield but does not seem to have superior post-harvest qualities.

The early maturity of BHQP 542, as compared to the late maturing conventional hybrid BH660, is clearly a factor in both its yield and adoption. It is therefore essential that the right, locally adapted germplasm is used to develop QPM varieties. QPM versions of BH660 are therefore currently in development.

As QPM germplasm becomes more diverse and varieties that are more adapted to target environments are released, the differences between QPM and CM may become variety-specific and more appropriately evaluated on a case-by-case basis rather than through anecdotal generalizations of the differences between QPM and CM.

Our results also indicate that several QPM varieties are preferred in East Africa for their processing, cooking, and sensory characteristics, although this may not be very important in Uganda's success story. Within the project, sensory evaluations have been conducted in Kenya, Tanzania, and Ethiopia with local preparations in double blind settings. Preliminary results of these tests confirm the positive evaluation of QPM for sensory characteristics by respondents from these countries.

The statistical models used to identify factors associated with knowledge and adoption used a random intercept term to account for the two-stage sampling and correlation among households within communities. Omission of this term and the associated adjustments to standard errors and degrees of freedom would result in smaller standard errors, higher degrees of freedom, and consequently a higher risk of type I errors (false positives).

(b) *Patterns of QPM adoption in East Africa*

Different countries clearly had different adoption patterns, as a result of different QPM varieties, competition with conventional varieties, extension activities, and seed availability. Except for Uganda, there was no adoption outside the QPMD areas.

Uganda showed steadily increasing adoption rates of the high-yielding QPM variety (Longe 5), clearly driven by appreciation of its higher agronomic performance. The greater adoption in the project areas suggests a positive impact of the project's promotion and transfer activities. Meanwhile, good agronomic performance, but also high levels of nutritional knowledge and the activities of SG2000 and other agents likely contributed to the increasing adoption outside the project areas.

In Ethiopia, half of all farmers participated in extension activities and understood QPM's nutritional benefits, but seed availability was likely the major determinant of adoption, as it is distributed by state agencies only. The early maturity of the local QPM variety (BHQP542) is also a factor, since it has lower yields than later maturing varieties. In districts where both types of seed were available, adoption of QPM stagnated or dropped. This suggest that farmers, even those aware of its nutritional benefits, will disadopt biofortified varieties if those are not agronomically competitive.

In the QPMD areas of Tanzania, adoption steadily increased as seed became available in each district. Again, farmers evaluated the local QPM variety (Lishe K1) favorably or comparably over conventional maize varieties and nutrition knowledge was high due to the extension activities.

In Kenya, the low coverage of extension activities led to low awareness and understanding of QPM, despite greater overall nutritional knowledge in the population, and to little or no adoption. Adoption was also hampered by unavailability of seed: only small quantities were produced by the project and its partners, and little – if any – QPM seed was available on the market.

(c) *Biofortified crops and the way forward*

Adoption of a biofortified crop is clearly a complex issue, and proper extension strategies need to take into account its many factors. Our results show that agronomic and post-harvest performance, nutritional understanding, extension, and institutional factors, particularly those that determine seed availability, all matter. Understanding the interactions among these factors is crucial as the development community is investing heavily in developing and disseminating biofortified staple crops.

Participation in a range of extension activities, as well as understanding of nutritional quality, has a positive effect on adoption. Clearly, not all extension activities are equally successful, and further research is needed to determine their effectiveness in reaching large numbers of farmers and compare it to their cost. The importance of targeting extension towards particular groups, in particular women, should also be examined.

However, to be adopted and have an impact, biofortified crops must be agronomically competitive, if not superior, to conventional varieties. The only country where QPM spread outside the project areas was Uganda, where the variety is clearly superior to the conventional alternatives. Where needed, the project should convert highly competitive conventional varieties, such as the on-going conversion of BH660 in Ethiopia. Also, in areas with high food insecurity and undernutrition, and where home production is the primary food source, promoting a variety with lower yield but higher nutritional quality does not seem justified. Apart from agronomic characteristics, post-harvest and sensory characteristics also matter. Sensory evaluation is therefore needed, and is currently being undertaken in selected project areas.

Finally, the adoption of biofortified crops can only succeed if seed availability is guaranteed, of the appropriate varieties, in sufficient quantity and quality, at reasonable price, and at the right time and place.

Acknowledgements

The authors would like to thank Florence Kyazze, James Ouma, and Frank Mmbando for organizing the survey in Uganda, Kenya and Tanzania. We also thank the CIMMYT staff in Nairobi and Addis Ababa for their logistic support, the Canadian Institute for

Development assistance for their financial support of the QPMD project. Finally, we would like to thank the enumerators for their effort, and the farmers for spending their valuable time answering our questions.

References

Akalu, G., Taffesse, S., Gunaratna, N.S., De Groote, H., forthcoming. Effectiveness of Quality Protein Maize to Improve Nutritional Status of Young Children in the Ethiopian Highlands. Food and Nutrition Bulletin,

Atlin, G.N., Palacios, N., Babu, R., Twumasi-Afriye, S., De Groote, H., Vivek, B., Friesen, D., Pixley, K.V., forthcoming. Forthcoming. Quality Protein Maize: progress, impact, and prospects. Plant Breeding Reviews,

Black, R.E., Allen, L.H., Bhutta, Z.A., Caulfield, L.E., de Onis, M., Ezzati, M., Mathers, C., Rivera, J., 2008. Maternal and child undernutrition: Global and regional exposures and health consequences. Lancet 371, 243–260.

Bouis, H.E., 1999. Economics of enhanced micronutrient density in food staples. Field Crops Research 60 (1-2), 165-173.

Bressani, R., 1992. Nutritional Value of High-Lysine Maize in Humans. In: Mertz, E. T. (ed.) Quality Protein Maize. American Association of Cereal Chemists, Minnesota. U.S.A., pp.

Caulfield, L.E., de Onis, M., Blössner, M., Black, R.E., 2004. Undernutrition as an underlying cause of child deaths associated with diarrhea, pneumonia, malaria, and measles. American Journal of Clinical Nutrition 80, 193-198.

Crawford, E., Kelly, V., Jayne, T.S., Howard, J., 2003. Input use and market development in Sub-Saharan Africa: an overview. Food Policy 28 (4), 277-292.

Dalton, T.J., 2004. A household hedonic model of rice traits: economic values from farmers in West Africa. Agricultural Economics 31 (2-3), 149-159.

de Onis, M., Blossner, M., Borghi, E., Frongillo, E.A., Morris, R., 2004. Estimates of global prevalence of childhood underweight in 1990 and 2015. Journal of the American Medical Association 291 (21), 2600-2606.

Deaton, A., 1997. The analysis of household surveys: a microeconometric approach to development policy. The World Bank. Washington, D. C.pp.

Doss, C., Mwangi, W., Verkuijl, H., De Groote, H., 2003. Adoption of Maize and Wheat technologies in East Africa: Synthesis of the Findings of 22 Case Studies. CIMMYT. Mexico, D.F., 32 pp.

Edmeades, S., 2007. A hedonic approach to estimating the supply of variety attributes of a subsistence crop. Agricultural Economics 37 (1), 19-28.

FAO, 1992. Maize in human nutrition. FAO Food and Nutrition Series No. 25. Food and Agriculture Organization (FAO) of the United Nations. Rome, 112 pp.

Feder, G., Umali, D.L., 1993. The adoption of agricultural innovations : A review. Technological Forecasting and Social Change 43 (3-4), 215-239.

Feder, G.R., Just, R.E., Zilberman, D., 1985. Adoption of agricultural innovations in developing countries: a survey. Economic Development and Cultural Change 33, 255-298.

Gunaratna, N.S., De Groote , H., Nestel, P., Pixley, K.V., McCabe, G.P., 2010. A Meta-analysis of Community-level Studies on Quality Protein Maize. Food Policy 35, 202-210.

Kelly, V., Adesina, A.A., Gordon, A., 2003. Expanding access to agricultural inputs in Africa: a review of recent market development experience. Food Policy 28, 379-404.

Kenward, M.G., Roger, J.H., 1997. Small Sample Inference for Fixed Effects from Restricted Maximum Likelihood. Biometrics 53 (3), 983-997.

Kherallah, M., Delgado, C., Gabre-Madhin, E., Minot, N., Johnson, M., 2002. Reforming Agricultural Markets in Africa. IFPRI. Washington D.C.pp.

Krivanek, A.F., De Groote, H., Gunaratna, N.S., Diallo, A.O., Friesen, D., 2007. Breeding and Disseminating Quality Protein Maize (QPM) for Africa. African Journal of Biotechnology 6 (4), 312-324.

Lauderdale, J., 2000. Issues Regarding Targeting and Adoption of Quality Protein Maize (QPM). CIMMYT (International Maize and Wheat Improvement Center). Mexico D.F., 30 pp.

Lohr, S., 1999. Sampling: Design and analysis. Duxbury Press. Pacific Grove, USApp.

Maddala, G.S., 1983. Limited-dependent and qualitative variables in econometrics. Cambridge University Press. New Yorkpp.

Meenakshi, J.V., Johnson, N.L., Manyong, V.M., DeGroote, H., Javelosa, J., Yanggen, D.R., Naher, F., Gonzalez, C., García, J., Meng, E., 2010. How Cost-Effective is Biofortification in Combating Micronutrient Malnutrition? An Ex ante Assessment. World Development 38 (1), 64–75.

Mertz, E.T., Veron, O.A., Bates, L.S., Nelson, O.E., 1965. Growth of Rats Fed on Opaque-2 Maize Science 148 (3678), 1741 - 1742.

Omamo, S.W., 2003. Policy Research on African Agriculture: Trends, Gaps, and Challenges. ISNAR Research Report 21. International Service for National Agricultural Research, The Hague.

Prasanna, B.M., Vasal, S.K., Kassahun, B., Singh, N.N., 2001. Quality protein maize. Current Science 81 (10), 1308-1319.

Rosegrant, M.W., Paisner, M.S., Meijer, S., Witcover, J., 2001. 2020 Global Food Outlook Trends,Alternatives, and Choices. International Food Policy Research Institute (IFPRI). Washington, D.C.pp.

Tomlins, K., Ndunguru, G., Stambul, K., Joshua, N., Ngendello, T., Rwiza, E., Amour, R., Ramadhani, B., Kapande, A., Westby, A., 2007. Sensory evaluation and consumer acceptability of pale-fleshed and orange-fleshed sweetpotato by school children and mothers with preschool children. Journal of the Science of Food and Agriculture 87, 2436-2446.

Tomlins, K.I., Manful, J.T., Larwer, P., Hammond, L., 2005. Urban consumer preferences and sensory evaluation of locally produced and imported rice in West Africa. Food Quality and Preference 16 (1), 79-89.

Vasal, S.K., 2000. The quality protein maize story. Food and Nutrition Bulletin 21, 445-450.

Table 1. Characteristics of the study sites, farms and households

Category	Characteristic	Ethiopia (n=217)		Kenya (n=169)		Tanzania (n=300)		Uganda (n=276)	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD
Climate	Altitude (m)*	1884	1713-2031	1358	1005-1810	1284	959-1622	1110	1016-1223
	Annual rainfall (mm)	1080	-	1304	-	742	-	1375	-
Agri culture	Total land available (hectares)	0.8	0.5	0.7	0.6	1.8	1.2	2.2	1.6
	Cultivated land (hectares)	0.7	0.5	0.6	0.5	1.7	1.3	1.6	1.2
	Tropical livestock units (TLU)	6.8	9.1	1.2	1.5	3.4	4.7	2.4	3.2
	Number of oxen	1.6	2.3	0.3	0.7	0.7	1.5	0.1	0.5
	Number of indigenous cows	2.8	4.8	0.3	0.6	0.4	1.4	1.0	2.0
	Number of improved dairy cows	0.4	1	0.3	0.6	0.7	2	0.3	0.9
	Owns cattle (%)	94	-	48	-	45	-	54	-
	Owns improved dairy cows (%)	25	-	24	-	20	-	13	-
	Owns oxplough (%)	67	-	5	-	31	-	6	-
Demo graphics	Household head is male (%)	99	-	92	-	88	-	89	-
	Hh head's education (years)	5.8	3.4	7.9	3	6.7	1.7	7.2	3.9
	Household size	8.1	2.9	5.0	2.0	5.8	2.1	8.6	3.9
Wealth	Metal or tile roof, main building (%)	35	-	96	-	83	-	87	-
	Owns bicycle (%)	10	-	36	-	57	-	84	-
	Owns radio (%)	52	-	79	-	81	-	84	-
	Owns telephone (%)	14	-	34	-	48	-	45	-
Income	Value of production of major crops (USD)	510	590	670	1148	839	880	943	1021
	Off-farm income in last year (USD)	185	563	356	1278	52	284	340	783
	Expenditure in last year (USD)	883	777	683	708	1077	660	1052	880
Off-farm work	Hh head's major source of income is off-farm (%)	6	-	10	-	3	-	12	-
	Hd head spends majority of working day on farm (%)	79	-	48	-	83	-	40	-

Table 2. Importance of maize in households of the study areas

		Ethiopia		Kenya		Tanzania		Uganda	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD
Crop	Area under maize (ha)	0.7	0.4	0.4	0.3	1.0	0.7	0.7	0.6
	Cultivated area under maize (%)	95	-	63	-	65	-	54	-
Economy	Amount produced in main season (kg/hh)	1000	940	310	299	2143	2343	1094	1402
	Amount sold in main season (kg/hh)	221	485	128	200	1119	1846	728	1187
	Value of sale (USD/hh)	77	169	45	69	389	641	253	412
Food[1]	Amount consumed (kg/hh/day)	3.1	2.1	3.1	3.7	1.6	0.7	1.8	1.9
	Amount consumed (g/AE/day)[2]	595	533	684	735	371	210	292	347
	QPM as percentage of maize consumed	14	-	0	-	6	-	66	-

[1]Measured following main harvest.
[2]AE, adult equivalent: A household member over 14 years old was assigned one adult equivalent. A household member aged 14 years
or less was assigned 0.5 adult equivalents.

Table 3. Awareness of QPM and participation in QPMD activities (2003-2007)

		Ethiopia		Kenya		Tanzania		Uganda	
		QPMD area (n=96)	Control (n=121)	QPMD area (n=42)	Control (n=127)	QPMD area (n=150)	Control (n=150)	QPMD area (n=135)	Contro (n=141
Household heads' participation in QPMD activities (%)	Any activities	41	2	0	2	51	1	35	
	Field days and farmer evaluations	29	2	0	1	43	1	6	
	On-farm demonstrations	23	1	0	1	14	1	19	
	Meetings and workshops	4	1	0	1	15	1	21	
Message received (%)	Saw QPM poster	34	7	0	0	21	1	46	
	Received promotional materials	4	1	0	1	19	1	24	
Awareness of household heads (%)	Awareness of protein	70	30	83	84	62	39	94	
	Familiarity with the term "QPM"	74	16	19	12	76	7	80	
	Understanding of nutritional benefit	55	8	7	8	47	3	53	

Table 4. Factors affecting knowledge of protein and QPM in QPMD activity areas

Category	Variable[1]	Awareness of protein		Awareness of QPM		Understanding of QPM	
Extension	Participation in activities	1.06	**	1.46	***	0.68	**
	Poster or promotional materials	0.88	*	1.51	***	0.58	*
Household head	Age	0.00		0.03	**	0.02	
	Male	0.44		-0.87		-0.30	
	Education (years)	0.09		-0.02		0.02	
Wealth	Total land available (hectares)	0.16		0.07		0.07	
	Tropical livestock units (TLU)	0.00		0.02		0.05	*
	Housing quality	0.26		-0.16		0.02	
	Durable good ownership	-0.14		0.11		-0.01	
Country	Ethiopia	-1.18		0.05		0.49	
	Kenya	-0.47		-1.53	*	-1.54	*
	Tanzania	-2.09	**	-0.18		-0.10	
	Uganda	-		-		-	
Model charactistics	N	375		375		375	
	Fit statistic[2]	1951.4		1930.0		1735.6	

[1] The table provides parameter estimates for each variable in logistic regression models of awareness of protein and QPM and understanding of QPM's nutritional benefits

[2] The fit statistic is the -2(residual log pseudo-likelihood).

* $p < 0.10$; ** $p < 0.05$; *** $p < 0.01$.

Table 5. Factors affecting adoption in QPMD activity areas of Tanzania and Uganda (2007)

Category	Variable[1]	QPM adoption (binary)		QPM area in (ha)	
Extension	Participation in activities	1.88	**	0.20	
	Poster or promotional materials	0.33		0.17	
	Understanding of QPM's advantages for human nutrition	1.17	**	0.47	**
Farmer evaluation	Difference in overall rating (QPM vs. CM)	0.93	**	0.31	***
Household head	Age	-0.01		0.00	
	Male	0.32		0.13	
	Education (years)	0.06		-0.06	*
	Proportion of working time on-farm	-0.02		-0.06	
Wealth	Total land available (hectares)	-0.14		0.17	***
	Tropical livestock units (TLU)	0.13		0.02	
	Housing quality	-0.42		-0.12	
	Durable good ownership	-0.04		0.07	
Intensification	Oxplough ownership	-1.40	*	-0.63	**
Country	Ethiopia	-		-	
	Kenya	-		-	
	Tanzania	-3.19	***	-1.09	***
	Uganda	-		-	
Model charactistics	N	164		164	
	Fit statistic[2]	879.6		369.9	

[1] The table provides parameter estimates for each variable in a logistic regression model of adoption and a tobit model of QPM area.

[2] The fit statistic is -2(residual log pseudo-likelihood) for adoption and -2(log likelihood) for QPM area

* $p < 0.10$; ** $p < 0.05$; *** $p < 0.01$.

Figure 1.

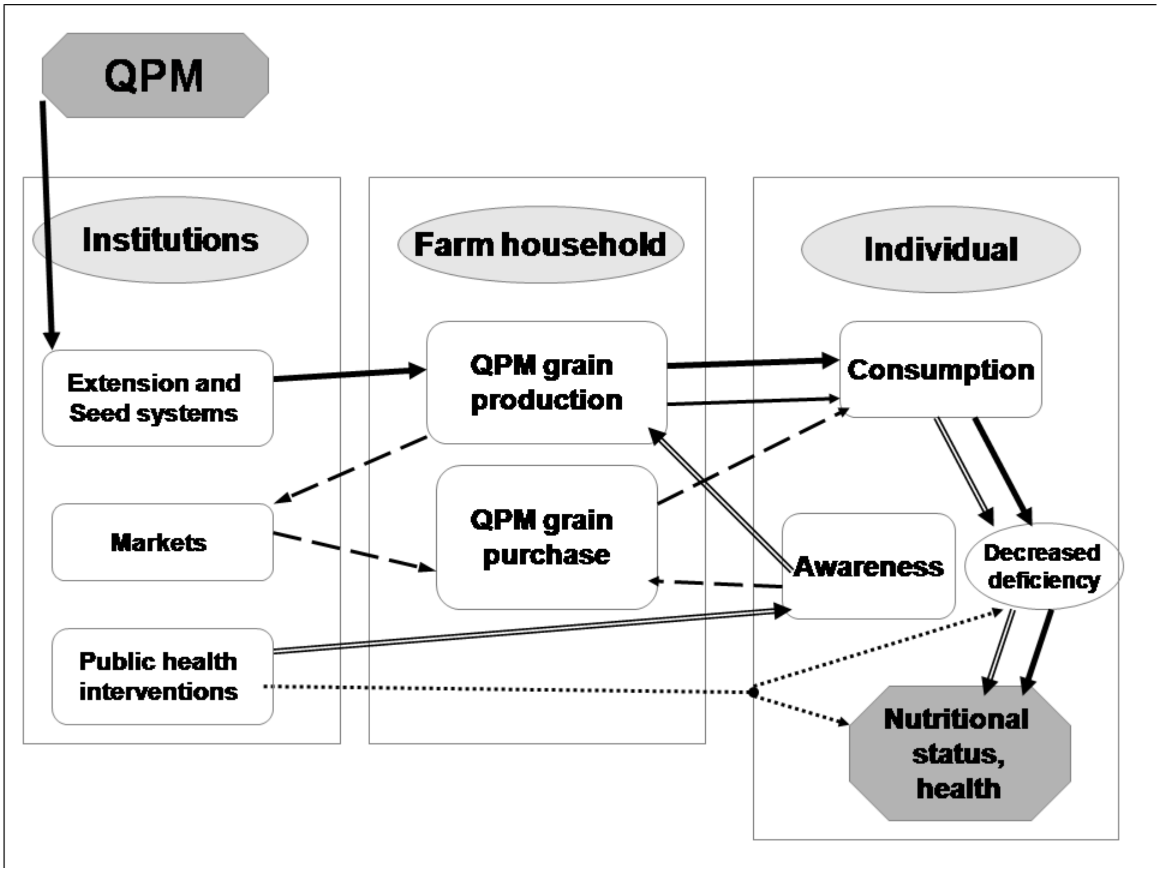
QPM
Institutions
Farm household
Individual
Extension and Seed systems
QPM grain production
Consumption
Markets
QPM grain purchase
Awareness
Decreased deficiency
Public health interventions
Nutritional status, health

Figure 2. Study countries, districts and communities

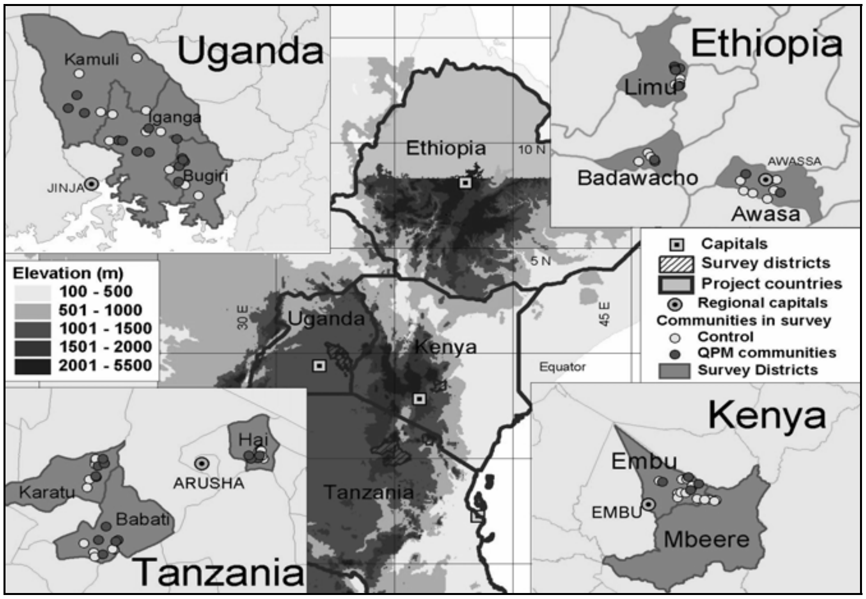

Figure 3. Farmer evaluaton of QPM and conventional maize for yield, field characteristics, post-harvest characteristics, and overall (using scores from 1=very poor, to 5=very good), only respondents who evaluated both included (n for each country as below; QPMD areas only)

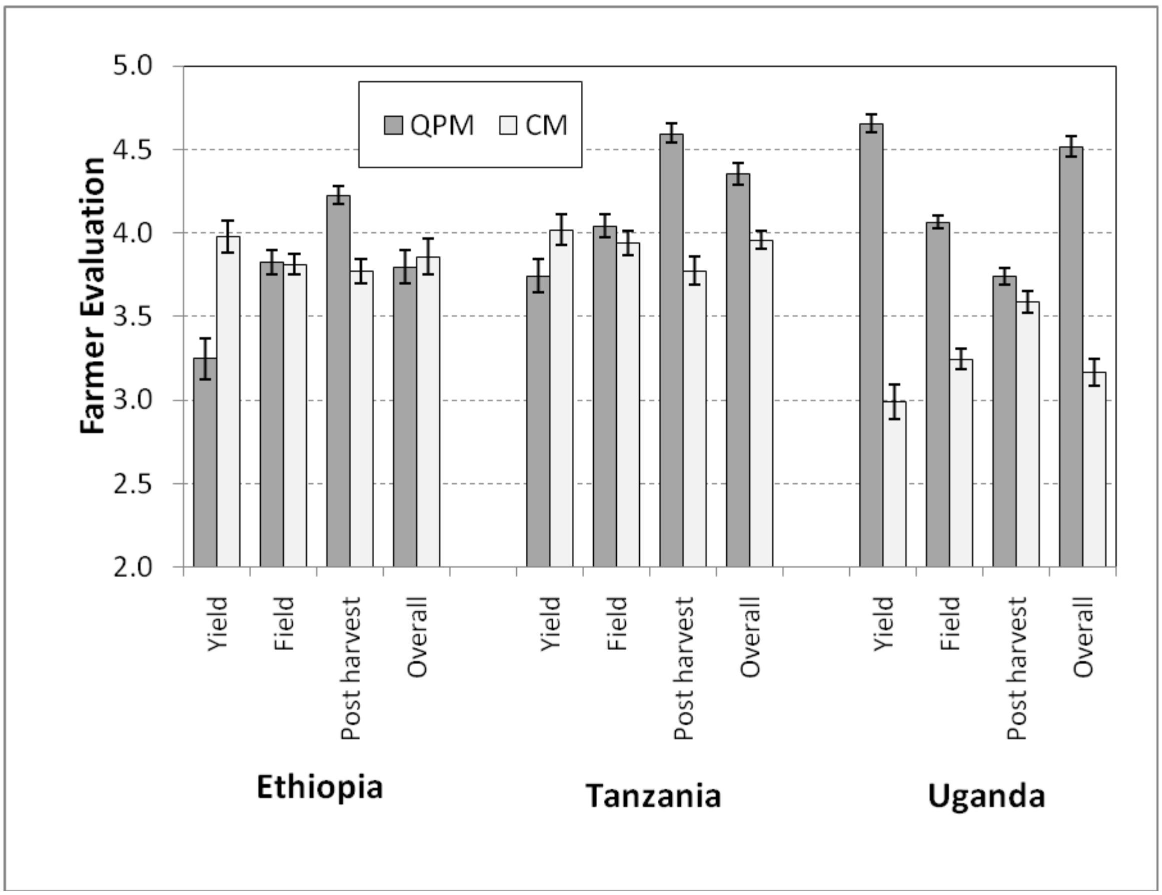

Figure 4. Adoption of QPM in 2003-2007 (with % of farmers adopting in that year)