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Prospects for Development of Genetically Modified Cassava in Sub-Saharan Africa

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The prospect for the development of genetically modified (GM) orphan crops is reviewed from various perspectives. The article specifically assesses the potential constraints for developing GM cassava based on typical patterns of past genetic modification technology application on crops, the low level of basic research that has been done on cassava, African stakeholders' perceptions on GM crops in general, and regulation issues for cassava. The article also assesses potential factors that might mitigate such constraints, such as the potential benefits of genetic modification technology in overcoming particular problems for cassava over conventional non-genetic modification technologies, the level of interest among African countries on such benefits, and the preferential treatment given to crops like cassava (such as humanitarian use licenses). The article concludes with a discussion of prospects for GM cassava and some knowledge gaps that need to be filled to speed up the commercialization of GM cassava in Sub-Saharan Africa.

Key words: genetic modification, cassava, orphan crops, perceptions to GM crops, humanitarian use licenses, Sub-Saharan Africa.

Introduction and Objectives

Cassava is an important staple crop, particularly in many Sub-Saharan Africa (SSA) countries with low per-capita caloric intake (Table 1). The recent progress in the biotechnology of genetic modification,[1] the reported successes of many genetically modified (GM) varieties around the world, and the continuing importance of cassava in the welfare of impoverished people in Africa make GM orphan crops[2] such as cassava promising tools to significantly reduce poverty and improve food security in the least developed countries (LDCs) in SSA. Transgenic[3] cassava resistant to cassava mosaic disease (CMD) is of particular interest to many African countries due to CMD's prevalence in the continent and the relatively advanced knowledge of the disease in American and European research institutions.

Despite the potential benefits of GM cassava, however, careful analyses are required to assess how quickly the impoverished people in SSA will benefit from GM CMD-resistant cassava. Answers to that question depend on what investment and research capacity is needed for applying GM technology to cassava and its advantages over non-transgenic crops, the perception of biotechnology in SSA and the regulation of GM varieties, the ability of LDCs to develop and disseminate new varieties of cassava, and the cassava market conditions (including the degree of market orientation or price responsiveness in cassava producers and consumers).

This article summarizes the implications of the factors affecting the development and dissemination of GM cassava in SSA countries. This article describes issues associated with developing GM orphan crops, as cassava's status as an orphan crop seems to determine the type of constraints faced by the GM cassava development effort. The article also considers several issues relevant to GM cassava, including the nature of genetic modification technology, and the effect of regulatory frameworks, patent issues, and research capacities in SSA countries on how quickly GM cassava could reach farmers in those countries.

Genetic Modification Technology for Orphan Crops—Pattern and Implications on the Development of GM Orphan Crops

Here, we review the progress in GM research on orphan crops in SSA and the potential benefits for and constraints against faster development and dissemination of

1. *See the Appendix for further distinctions between genetic modification, transgenic, and other plant-breeding methodologies.*
2. *Orphan crops are crops that have received little research attention of varietal development because of the nature of their markets.*
3. *Transgenic is a term used for a particular genetic modification method; genetic modification is a more general term.*

Table 1. Countries with large calorie intake from cassava in SSA.

	Calories per capita, per day		% of calories from cassava	Population (2007)
	Cassava	Total		
DR Congo	893	1,606	56	65,751
Mozambique	742	2,082	36	20,905
Republic of Congo	687	2,182	31	3,800
Angola	655	2,089	31	12,263
Ghana	654	2,680	24	22,931
Benin	461	2,574	18	8,078
Central Africa	334	1,932	17	4,369
Madagascar	323	2,057	16	19,449
Uganda	300	2,360	13	30,263
Tanzania	298	1,959	15	39,384
Nigeria	249	2,714	9	135,031
SSA	252	2,256	11	671,579
World	43	2,808	2	

Source: FAO (2008).

GM orphan crops. The World Bank's *World Development Report* (2008, section "Focus E") provides a similar review of these issues; however, this article focuses on issues associated with orphan crops in SSA countries and uses some empirical evidence which is not included in the World Bank's publication (2008).

Development of GM Crops in SSA

A number of GM varieties have been brought into several SSA countries in the experimental phase, although SSA still lags behind other parts of the world in both the development and commercial release of GM crops. The experience of GM crop adoption in the Republic of South Africa (RSA) provides an example of how small-scale farmers in Africa may benefit from GM varieties, including GM food crops.

While no GM variety has been approved in SSA for commercial purposes outside of the RSA, several GM varieties are in field trial or experimental stages (Tables 2 and 3). Transgenic varieties of some major crops in Africa, including barley, cassava, cowpea, sorghum, sugarcane, and sweet potato, have been developed and brought to the field-trial stage. The current trend of investment in research indicates that GM crops are moving forward in several countries, although the application of genetic modification technology appears limited relative to non-transgenic biotechnology methods in SSA countries.[4]

Table 2. Commodities currently at the field trial stage for GM varieties in SSA.

Commodity	Country
Canola	RSA
Cotton	Ghana, Malawi, RSA, Zimbabwe
Maize	RSA
Soybean	RSA
Cowpea	Zimbabwe
Eucalyptus	RSA
Potato	RSA
Strawberry	RSA
Sugar cane	RSA
Sweet potato	Kenya
Wheat	RSA

Source: FAO (2009).

Note: Although Egypt is excluded from SSA countries, a variety of GM crops are at the field trial stage in Egypt.

Potential Economic Benefits of GM Orphan Crops

In contrast to major commercial crops, orphan crops are rarely traded in the international market, and GM productivity will lead to lower prices, which may shift much of the benefit from producers to consumers. Producers of orphan crops are often impoverished, more so than consumers. Whether producers can capture a portion of benefits from particular GM orphan crop is, therefore, an important indicator of its benefits. In fact, many studies suggest that GM orphan crops will bring substantial share of the benefits (economic and nutritional) to producers of the crops and support pro-poor growth.

Transgenic varietals have been developed for orphan crops such as eggplant or sweet potato only recently, and none of them have been commercialized on a large scale. Currently, only ex-ante studies have been conducted for GM orphan crops. Some studies suggest large potential gains (Demont, Rodenburg, Diagne, & Diallo, 2009; Krishna & Qaim, 2008; Qaim, 1999, 2001). Small-scale producers may be significant beneficiaries of transgenic potato in Mexico (Qaim, 1999) and transgenic sweet potato in Kenya (Qaim, 2001) because

4. The application of other modern biotechnology to cassava has progressed further (Figure 1). In Gabon and Nigeria, cassava developed through micropropagation is already commercialized, and experiments are ongoing in 16 African countries, including Benin. Cassava is also currently being developed in the laboratory through marker-assisted selection in Uganda (FAO, 2004).

Table 3. Commodities currently at the experimental stage[a] for GM varieties in SSA.

Commodity	Country
Cotton	Burkina Faso, Kenya, Tanzania
Maize	Kenya, Nigeria, RSA
Barley	Kenya, Uganda
Cassava	Kenya, Uganda
Coconut	Nigeria
Cowpea	Burkina Faso, Cameroon
Potato	RSA
Rice	Nigeria
Sesame	Kenya
Sorghum	Kenya, Uganda
Sweet potato	Nigeria
Yam	Nigeria

Sources: FAO (2009); Kimenju and De Groote (2008).
[a] The term experimental stage is used by the FAO Bio-Dec (FAO, 2009), although its strict definition is not provided. The FAO Bio-Dec classifies stages of GM variety development into experimental stage, field trial, and commercialization, and thus experimental stage is assumed to include all stages preliminary to the field trial, including the on-station trials.

small-scale producers benefit from either a higher sales income or increased subsistence consumption of these crops. Krishna and Qaim (2008) also suggest that Bt eggplant in India benefits resource-poor farmers and supports pro-poor growth. Demont et al. (2009) estimate that producers will gain the most benefits from herbicide-resistant rice in the Sahel region of Africa.[5]

GM orphan crops have the ability to benefit their producers and have the potential to support pro-poor growth, which will contribute to poverty reduction. Poverty reduction, however, is not emphasized in ex-ante impact assessment research. Future efforts by the public sector, including the international research community, should place more emphasis on the impact of GM orphan crops on poverty reduction. This will aid in encouraging more public investment in the development of GM orphan crops.

Adopting Patterns of GM Crops in LDCs and Their Implications

Recent trends in the adoption of GM commercial crops and commodities in developing countries in the world indicate that the development and dissemination of GM orphan crops may face great constraints. Only a few developing countries, such as China and India, have the capacity to develop their own GM varieties suitable for their domestic production environment. The adoption of GM crops and commodities in most developing countries relies upon spillover from developed countries, such as the United States; however, these crops are often for cultivation in temperate climates, and are not suitable for the tropical or sub-tropical climate zones of SSA. Most GM crops and commodities adopted in LDCs were obtained by backcrossing varieties initially developed for use in the United States or other early-adopting countries. Three primary GM crops or commodities are cotton, soybean, and maize, and at least one of them has been adopted in Brazil, China, India, Paraguay, Argentina, Mexico, and the RSA (James, 2006). For Mexico and the RSA, private companies were able to enter the market with very low research and development costs, as varieties performing well in temperate zones in the United States could be directly introduced into both countries, which are also in temperate zones (Pingali & Traxler, 2002). However, the introduction of GM crops to tropical areas has been limited (Eicher, Maredia, & Sithole-Niang, 2006). The commercial adoption of GM commodities in the African continent has been limited to the RSA partly due to the climatic constraints and has been very slow in tropical areas (Eicher et al., 2006).

The development of GM varieties of tropical crops, such as cassava, for African countries has thus been lagging behind developed countries. Although the adoption speed of GM crops is also affected by other factors such as seed cost (Pray, Huang, Hu, & Rozelle, 2002), suitability of the varieties to the local production environment (Gouse, Pray, Kirsten, & Schimmelpfennig, 2005), or an existence of external support in the form of credit or information by seed-supplying companies (Gouse et al., 2005; Wolson, 2007), the availability of technologies in early-adopting countries seem to determine the overall speed of the development and dissemination of GM orphan crops.

Potential Barriers for GM Orphan Crops Including Cassava

The development and dissemination of GM orphan crops, such as cassava, in SSA countries is also affected by factors including the research capacity to apply GM methods to plant breeding, the perceptions of GM crops in major markets for SSA, and the capacity to regulate

5. *While rice is a commercial crop, herbicide-resistant rice for the Sahel region in Africa is considered an orphan crop, as the market size is small and private companies have little incentive to develop the variety (Demont et al., 2009).*

the cultivation and dissemination of GM crops. The lack of research capacity has already been experienced in non-GM research on orphan crops, whereas perception and regulatory issues are new.

Research Capacity Regarding the Development of GM Orphan Crops. There are two issues regarding research capacity relevant to the development of GM orphan crops. One issue is the shortage of knowledge regarding the biological characteristics of orphan crops, and the other is the institutional capacity for GM research.

Less is known about the biological characteristics of orphan crops than of other commercial crops. Falck-Zepeda and Cohen (2006) emphasize the importance of increasing the knowledge base of the biological characteristics of orphan crops such as cassava—including how genetic modification technologies applied to orphan crops alter their characteristics—in order to speed up biotechnology research on orphan crops. Genetic modification can only be applied if there is some base level of knowledge about the biological characteristics of the crop in question.

Notably, many African countries still rely heavily on foreign institutions for much of the research required to develop GM crops. Only a handful of African countries, such as the RSA and Egypt, currently have significant capacities for genetic modification research. The low research capacity in national agricultural research systems could slow down the adoption of GM varieties in LDCs. The domestic public research institutions in LDCs may still, however, be the primary developers of GM varieties for orphan crops, as foreign private companies such as Monsanto have little incentive to develop GM orphan crops (Tollens, Demont, & Swennen, 2004).

Arends-Kuenning and Makundi (2000) suggest that effective partnerships between the public and private sectors may be important to speed up the development of GM orphan crops in the foreseeable future. Graff, Roland-Holst, and Zilberman (2006) suggest that significant investment in higher education, or the buildup of the educational-industrial complex, could help build the basic capacity for research of biotechnology and commercial application. Efforts by the public sector (including providing private firms easier access to germplasm that is owned by the public sector) are crucial for smaller developing countries who wish to offer an incentive to private firms developing GM varieties, as the small size of the market in these countries naturally discourages private firms from developing particular GM varieties for these small countries (Hareau, Bradford, & Norton, 2006).

Certain preferential licensing agreements may aid in faster development and dissemination of GM orphan crops in the near future, but research capacity remains a heavy constraint to speeding up the development of GM orphan crops.

Perceptions of GM Crops in Major Markets for SSA. Whether the new GM orphan crops are introduced into SSA countries hinges on how GM crops are perceived by SSA farmers, consumers, and stakeholders, as well as by countries importing agricultural commodities from SSA. According to recent studies, negative perceptions by European countries toward GM crops seem to partially influence perceptions in SSA countries. However, these perceptions may change if African stakeholders see how certain GM varieties can help mitigate problems in their own agricultural sectors.

The perceptions of GM crops vary greatly across SSA countries. While Kenya and Uganda promote genetic modification research and support the introduction of GM crops, several other SSA countries have placed a moratorium on imports of GM crops or have rejected GM grain as food aid. The perceptions of GM crops in SSA countries can be explained by the influence of international opinions of GM crops, as well as the uncertain economic consequences of adopting GM crops.

Some African governments are skeptical about GM crops. This skepticism arises in part from a distrust of multinational seed companies and from food safety concerns. There is also concern about environmental effects and the practical difficulty of implementing strict biosafety regulations, as is the case in the RSA (Aerni & Bernauer, 2006).

Many governments in SSA are hesitant to go ahead with GM crops because of the mixed perceptions of genetically modified organisms (GMOs) observed in the domestic market and the negative reactions in some of their largest export markets, particularly the European Union (EU) market.

The anti-genetic modification stance in EU nations influences policy among African governments in several ways. Some countries with relatively large exports of agricultural commodities to Europe are discouraged from investment because it means no gain or even a loss of export revenue. The EU is the largest export market for agricultural commodities for several African countries. However, the risk of potential export losses due to the introduction of GM crops may be overemphasized, as the majority of African countries have a relatively small export share to the EU (Paarlberg, 2006). Numerous examples are found in developing countries in which decision-makers adopt anti-genetic modification policies based on the unsubstantiated fear of potential loss of markets in Europe or Japan, or other commercial risks such as the high costs incurred to segregate non-GM products when GM products are commercialized (Gruère & Sengupta, 2009).

In the RSA, perceptions of GM crops seem to fall into one of three categories: natural scientists and business groups are generally enthusiastic about GM crops, NGOs are moderately or radically opposed, and consumer groups and producer organizations are moderately positive (Aerni & Bernauer, 2006). Aerni and Bernauer (2006) also suggest that the public in the RSA trusts academic sources more than it does NGOs or other interest groups, which puts into question the view that the EU stakeholder strongly influences the perceptions of GM crops in the RSA. However, many urban consumers and environmental interest groups in the RSA have recently become skeptical of GM crops, reflecting attitudes in the United Kingdom (Wolson, 2007).

Although the stance in the EU on GM crops is likely affecting the perceptions of GM crops in African countries, policies differ among each African country. In the case of food aid from the United States to SSA containing GM maize, since 2002 some countries—such as Zimbabwe and Malawi—have accepted milled GM maize, while others—such as Zambia—rejected even milled GM maize (Bodulovic, 2005), even though immediate food aid needs for all three countries were comparable. These differences indicate that socioeconomic factors other than the EU's perception of GM crops are affecting SSA perceptions.

Many African stakeholders may start to support genetic modification technology if they see it being used to address the urgent agricultural problems in their own countries, as some stakeholders—especially nationalist politicians—turn away from genetic modification technology because it is imported from the United States and Europe (Aerni & Bernauer, 2006).

Perceptions of GM crops by African consumers remain under-observed. However, a few studies assess how SSA consumers perceive GM crops or commodities.

Consumers in some SSA countries may be in favor of GM crops if they have a good understanding of the added benefits of such crops. Nigeria generally supports Bt maize, Bt cotton, and Golden Rice (Adeoti & Adekunle, 2007), and Kenya supports Bt maize (Kimenju & De Groote, 2008). In Kenya, Kimenju and De Groote (2008) found that in 2003, there was a 13.8% higher willingness to pay for GM maize meal over non-GM maize meal, with this willingness associated with higher income, higher education levels, and ethical views. Findings by Vermeulen, Kirsten, Doler, and Schonfeldt (2005) suggest that about two-thirds of urban consumers in the Pretoria/Johannesburg area in the RSA were somewhat positive to Bt white maize. Vermeulen et al. (2005), however, also suggest that perceptions of GM crops in the Pretoria/Johannesburg area are clustered and polarized, and that a cluster of consumers with anti-genetic modification views who make up a third of the urban consumers in the area are unlikely to switch their views on GM crops.

Overall, there is great variability among consumer perceptions of GM crops; some consumers' perceptions are based on ethical perspectives, which will not likely change based on their understanding of the benefits of GM crops. General perceptions among consumers in SSA countries, however, seem to be positive, and can be located somewhere between those of American and EU consumers.

Relatively favorable views toward GM crops among SSA consumers suggest that GM orphan crops, when commercialized, have the potential to gain significant market share with fair prices or even with premiums in SSA countries. The perceptions of domestic consumers will thus be less of a hurdle to clear for the commercialization of GM orphan crops than those of the EU or Japan.

The difference between European consumers and some of the SSA consumers is also noteworthy. Combined with the findings by Paarlberg (2006) and Gruère and Sengputa (2009), relatively favorable views and potentially higher willingness-to-pay expressed for GM crops by SSA consumers indicate that many SSA countries need to re-evaluate the benefits of commercializing GM crops in their domestic market. More specifically, the consumers' perceptions toward GM crops suggest that many SSA countries may benefit from increased efforts in GM orphan crop development.

Biosafety Regulatory Capacity. Crops bred using the transgenic or recombinant DNA method are subject to biosafety regulation (see the Appendix for detailed descriptions of transgenic, recombinant DNA method, and other plant-breeding methods). In the absence of a biosafety regulatory system, the development of GM varieties could slow down due to constraints. Companies licensing particular genes or methods to research institutions that develop particular varieties of GM crops are reluctant to do so if the varieties under development are to be introduced in countries that have no biosafety regulatory framework in place. This is because from the perspective of companies developing GM varieties it is more costly to obtain approvals for their varieties from the countries with no biosafety regulatory framework, and the companies are more likely to get caught in liability issues as the recipient countries have less capacity to handle the GM varieties properly (Kent, 2004).

Some companies are concerned not only about the biosafety regulatory system in adopting countries, but also that of neighboring countries. Syngenta, for example, was reluctant to give a license to Michigan State University to develop the Bt potato in the RSA because of their fear of trans-boundary movement of Bt potato into neighboring countries with no biosafety regulatory system (Eicher et al., 2006). Similarly, a transgenic disease-resistant banana developed in Belgium for Rwanda and Burundi was blocked due to the absence of biosafety protocols (Remy, Francois, Cammue, Swennen, & Sagi, 1998). Multinational seed companies, such as Monsanto, Pioneer, Syngenta, or Bayer, may also hesitate to sell their products in countries with no regulatory system simply because they consider it a bad business practice or are afraid of any liability issues that may arise (Kent, 2004). Graff et al. (2006) emphasize that similar bottlenecks apply to patents held by universities. However, the establishment of intellectual property clearing houses should greatly facilitate the transfer of patented technologies to research institutions in developing countries.

Another constraint that may be encountered if there is an absence of a biosafety regulatory system is that GM varieties that have already been developed and brought into confined field tests in potential adopting countries might be found unacceptable during the process of setting up a biosafety regulatory framework (Cohen & Paarlberg, 2004). Transgenic maize under development in Kenya was destroyed in 2005 when a biosafety bill was passed because that particular variety fell into a category that violated the restrictions of the bill (Kameri-Mbote, 2007).

Development and dissemination of GM crops are usually costly and require significant time lags for approval (Eicher et al., 2006). The lack of a sophisticated biosafety regulatory system limits the introduction of transgenic crops (Tollens et al., 2004). Even China or India, which have relatively developed research capacities and have already introduced insect-resistant cotton, have not succeeded in introducing major transgenic food crops because more biosafety regulations are usually applied to GM food crops.

The lack of sophisticated regulatory capacities among SSA countries can add significant costs to the development and dissemination of GM orphan crops. The cost of biosafety regulation for a single event can be US$1 million, as was the case for GM maize in Kenya and GM potato in South Africa (Falck-Zepeda & Cohen, 2006). Further, biosafety assessment and regulation of GM orphan crops may be even more costly and require even more time because the effects of genetic modification in orphan crops have been studied less than those in major commercial crops (Falck-Zepeda & Cohen, 2006). In addition, the Cartagena Protocol of Biosafety allows countries to voluntarily include socio-economic considerations into the biosafety regulation system, and this can delay or block the release of products (Falck-Zepeda, 2009). The inclusion of socio-economic considerations will delay or block the release not because GM orphan crops will have negative socio-economic effects, but because of the capacity required to assess socio-economic effects. However, the cost of regulations may lower over time if capacities are built and experiences are accumulated through the introduction of new GM varieties.

Examples of GM Orphan Crops and the Development of GM Cassava

Transgenic methods can be an improvement on non-transgenic conventional breeding of virus-resistant cassava. Some insights can be obtained from past cassava research and by looking at detailed descriptions of how transgenic methods have been applied to cassava, how the research is carried out, and potential barriers related to the development of transgenic cassava.

Cassava is a typical orphan crop. Only a small quantity of cassava is consumed in developed countries, but there is a relatively large market, particularly in developing countries, where cassava is an important source of nutrition and income.[6] As cassava is rarely grown or consumed in developed countries, much less research has been conducted on cassava than on crops familiar to developed countries, such as wheat or maize. Public research institutions have less accumulated knowledge about cassava and thus less capability for effective applied research. Furthermore, cassava's low monetary

6. *Cassava, which has a relatively large market size in developing countries, is different from other minor crops, which have been neglected simply due to market size.*

Table 4. Major problems of cassava subsistence agriculture.

	Description	Best approach
Root quality	Cyanogenic glycosides [HCN]; low starch content; low storage life; low protein content	GM
Diseases	Cassava Mosaic Virus Disease; Cassava Bacterial Blight; Cassava Brown Streak Virus; fungi & nematode diseases	IPM, genomics, GM
Pests	Lepidoptera; mites; mealybugs; whiteflies	Biocontrol, IPM
Yield	Low yield [gap between potential and real yield]; late bulking; leaf senescence	Conventional breeding, GM
Abiotic stresses	Soil nutrient uptake; drought; flood	IPM
Soil erosion		IPM
Clean planting material		Tissue culture

Source: Aerni (2006).
Note: "Best approach" is inferred by author from Figure 5 in Aerni (2006).

value and role as a subsistence crop means there has been little political incentive to invest in cassava research.

Relative Advantage of the Transgenic Method and Focus of Recent Research on Cassava

Because cassava is an orphan crop, the role of transgenic methods in cassava plant breeding is somewhat different from the role of such methods in major commercial crops. Many problems in cassava have been left untouched not only because the transgenic method has not been available until recently, but also because resources have not been enough even for conventional and non-transgenic plant-breeding methods. In other words, the transgenic method is used to mitigate very specific problems for cassava, while many other problems are mitigated more effectively by non-transgenic methods if there are enough resources.

Aerni (2006) summarizes how different problems associated with cassava in subsistence agriculture are ranked by cassava experts around the world. Table 4 lists the current major problems of cassava in subsistence agriculture as identified in Aerni (2006), and how each of those problems can be mitigated. Among techniques of biocontrol, including integrated pest management (IPM), conventional breeding, marker-assisted selection, tissue culture, genetic modification (transgenics), and genomics, experts generally agree that genetic modification is best suited to improve the root quality of cassava and is better in improving yield and resistance to abiotic stress and diseases (Aerni, 2006). Although Aerni (2006) does not specify whether this suitability is due to the effectiveness of the research tools or whether the effectiveness is relative to the cost, the suggestion is that the transgenic method is important in achieving specific goals such as improving both the yield and root quality of cassava that have been difficult to improve through non-transgenic methods.

Another benefit of the transgenic method is its ability to transform some attributes of cassava, such as disease resistance, without changing other desired attributes (such as taste) that are already favored by the producers. Although some non-transgenic methods have been successfully employed in developing disease-resistant cassava in Uganda, its attributes were often altered so much that producers did not fully benefit from the new varieties.[7]

The major problems cassava faces are disease, pests, low yield, root quality (cyanogenic glycosides, low starch, and low protein contents), abiotic stresses, soil erosion, and lack of clean planting material (Aerni, 2006). Among these, both diseases and pests also cause low yield, which indicates the importance of developing varieties that are resistant to major diseases and pests. Recent progress in the application of transgenic methods to cassava seem consistent with the findings by Aerni (2006), as most genetic modification research on cassava is currently targeted toward the development of disease-resistance cassava and biofortification to improve root quality (Stupak, Vanderschuren, Gruissem, & Zhang, 2006).

Application of Genetic Modification to Cassava

Several economic issues emerge with regard to the development of GM cassava. This section briefly discusses some of the important issues, such as the difference between the transgenic method and other methods

7. *Based on personal communication with Dr.Omongo at the Namulongue Research Institute in Uganda.*

in their scientific nature, as well as cost factors (including patent issues), which are unique to transgenic methods and other general cost-benefit structures.

Patent and Licensing Issues. Patent issues associated with the development of transgenic cassava have been partially resolved. Much genetic material used in the development of transgenic cassava has been obtained through research-only licenses, such as material transfer agreements and nonassertion agreements.[8] Patent issues have been further resolved by a royalty-free commercial license (humanitarian use license) given by major seed companies to the inventors of transgenic cassava as part of nonassertion agreements.

Humanitarian use licenses have been used for several crops, including the Vitamin-A-enriched rice, Golden Rice. Table 5 lists the conditions under which a technology is considered eligible for humanitarian use. In the case of Golden Rice, Syngenta retains the patent on Golden Rice technology and rights to commercialize Golden Rice, and gives humanitarian licenses to the inventors of Golden Rice with the rights to sub-license public research institutions and low-income farmers in developing countries (Krattiger & Potrykus, 2007). However, a country must have a biosafety regulation system in place before adopting Golden Rice. As long as the use of the technology satisfies the conditions in Table 5, the sub-licensee can introduce the Golden trait (the trait related to Vitamin A) into any locally adopted varieties.

Humanitarian use licenses provide the inventors of transgenic crops with inexpensive means to develop varieties that have significant humanitarian impacts. Humanitarian use licenses also provide companies such as Monsanto and Syngenta with a potential market to which these companies can apply their technologies because they retain the right to commercialize the developed varieties in different regions of the world where the conditions in Table 5 do not apply.

The conditions in Table 5 also apply to the execution of humanitarian use licenses for transgenic cassava. The experience of Golden Rice has been followed by the humanitarian use licensing of many other GM orphan crops. For the development of virus-resistant cassava, a similar royalty-free license was given by Monsanto to the Danforth Center in 2002 (Donald Danforth Plant Sciences Center, 2002).

Table 5. Conditions for humanitarian use of a technology and research leading to the technology.

Condition
1) Used in developing countries (low-income, food-deficit countries as defined by FAO)
2) Used by resource-poor farmers earning less than $10,000 per year from farming
3) Introduced into public germplasm (seed) only
4) Free from any surcharge (seed should cost only as much as a seed without the inserted trait)
5) Can be sold by farmers defined in #2 above to domestic consumers (no export is allowed)
6) Harvested seed can be reused in the following planting seasons

Source: Krattiger and Potrykus (2007).

When the humanitarian use licensing does not apply, developing countries can obtain a license from the patent holders with the right to distribute GM seeds domestically (Basu & Qaim, 2007). Basu and Qaim (2007) show that there exists the possibility for foreign patent holders to be compensated for foregone profits while allowing for a high level of domestic welfare when the government practices marginal-cost pricing for GM seeds. This indicates that with appropriate resource uses by developing countries and efforts by international donor communities, the application of patented technologies to orphan crops can be significantly accelerated and made accessible to farmers at affordable prices.

Procedures GM Cassava Must Go Through Before Approval. Any varieties developed through transgenic methods must pass a confined field-trial test. It is possible to start a confined field-trial test in the absence of an approved biosafety regulatory framework, and this would be done because field-trial tests are often time consuming. However, field-trial tests in the absence of a biosafety regulatory framework can be risky, as in the case of Bt maize in Kenya in 2005 when a biosafety bill restricted the variety being tested.

One example of the field-trial procedures for transgenic cassava resistant to cassava mosaic disease (CMD) is provided by the Danforth Center in Kenya (Donald Danforth Plant Sciences Center, 2006). The Danforth Center plans to put the potential varieties

8. *Material transfer agreements are used to exempt the patent enforcement on tangible materials when the recipients intend to use them for research purposes. Nonassertion agreements (nonasserts) "grant permission to third parties to practice a patent they would otherwise infringe. Legally, nonasserts are patent-infringement settlement agreements that are designed and drafted with the purpose of preemptively resolving future infringement disputes" (Krattiger, 2007, pp. 739). Nonassertion agreements often reduce transactions costs.*

through four selection stages. The first of these is the greenhouse selection and the other three are selections in the field through three production seasons. The varieties that exhibit a sufficiently low CMD score will be considered for commercial release. The application for a field trial is submitted to the Kenyan National Biosafety Committee (NBC) after the greenhouse selection (first stage). Each round of selection is expected to take a year, although two rounds can be done in a year in equatorial countries such as Kenya and Uganda. A similar process is ongoing in Uganda, and if the approval from the NBC is obtained, the field trials may start in Uganda in 2009.

The Danforth Center plans to add another year to the field-trial test by adding a mock field trial, which is equivalent to the actual field trial except that unregulated non-transgenic cassava will be used in place of transgenic cassava. The purpose of the mock field trial is to demonstrate to the NBC the Danforth Center's ability to conduct field tests and to obtain information about the differences between the greenhouse and the natural environment.

Other Special Concerns about the Development of Transgenic Cassava in Africa. Other cost-increasing factors in developing GM cassava include a lack of knowledge about the behavior of transgenic cassava under certain environmental conditions. Transgenic methods have been applied sparsely to vegetatively propagated tropical crops in the world, and thus empirical data are limited regarding how transgene expressions are affected when transgenic cassava is grown in the field in the tropics. It is thus difficult to judge whether a transgenic cassava variety is expressing desired traits, such as virus resistance, in the predicted manner (Taylor, Kent, & Fauquet, 2004).

Another cost-increasing factor is the diversity of cassava cultivars in Africa. While desired transgenic traits for seed-propagated crops can be backcrossed into the desired local cultivars to obtain transgenic varieties that maintain the attributes desired by local producers, the more realistic approach for vegetatively propagated crops (such as cassava) is to identify the important local cultivars first and then develop transgenic traits that work well with those particular cultivars. Unlike in parts of Asia or Latin America where a relatively small number of cultivars are grown on a large scale, cassava in Africa is diverse in terms of landraces and varieties. Such diversity may add to the cost of developing GM cassava in Africa as the identification of economically important cultivars is crucial to successfully bring economic benefits to African countries through GM cassava (Taylor et al., 2004).

The cost of investing in transgenic cassava can be high. Under-investment in conventional breeding for orphan crops means that the marginal returns for conventional breeding are expected to be high. The return for non-transgenic plant breeding in general is around 20-30% (Evenson & Gollin, 2003). Thus the return for non-transgenic plant breeding may be even higher for orphan crops like cassava, which have had relatively little investment compared to other agricultural crops.

Summary of the Benefits and Costs of Transgenic Cassava

Transgenic methods, if used optimally, can improve cassava varieties in ways that have been difficult to do with non-transgenic methods. However, development costs for transgenic cassava will determine the feasibility of using this technology in SSA countries. Some cost factors are unique to transgenic methods, while others are unique to cassava in SSA. This latter cost factor will remain as constraints unless there is a significant increase in research resources.

Some cost factors unique to transgenic methods may be partially eliminated through humanitarian use licensing agreements, the establishment of a biosafety regulatory framework in SSA countries, and a shift to a more favorable view toward GM crops among SSA consumers. As cost factors unique to transgenic methods are eliminated, the development of transgenic cassava will become more cost-efficient and the use of GM cassava is expected to accelerate in the foreseeable future.

Future Prospects for GM Cassava and the Knowledge Gap to be Filled

This article has reviewed aspects of the development of GM cassava in SSA countries. The prospects for the introduction of GM cassava into SSA countries are unclear. The application of humanitarian use licensing may reduce the cost and time required for the development of disease-resistant transgenic cassava. In addition, several economic studies suggest that the introduction of GM orphan crops can bring sizable benefits to farmers and consumers, and this may attract more resources from funding organizations such as the Gates Foundation. The governments in African countries such as Kenya and Uganda have started to show greater interest and invest more fully in the development of virus-resistant transgenic cassava in cooperation with foreign institutions. The public in SSA countries is generally in favor of GM crops, and this provides a favorable environment for the development of GM cassava.

Unfortunately, recent GM crop adoption patterns in developing countries indicate that fewer resources, such as research capacity and knowledge, are currently available than are needed for the development of virus-resistant transgenic cassava. Some of those obstacles arise from the very nature of orphan crops, such as a low research capacity due to little commercial interest. It is also unclear how the biosafety regulatory framework will be formed in the near future. The general concern about GM crops in the international community must also be taken into account. This concern has led to more extensive regulation of GM orphan crops, and some argue that it may still take 10 to 15 years before most GM crops reach the small farmers in SSA countries (Eicher et al., 2006). Overall, the introduction of transgenic cassava into African countries still seems to face greater constraints than major commercial crops, and more serious efforts are necessary to speed up the introduction of GM cassava in SSA countries on a substantial scale.

The environment surrounding the development of GM cassava indicates that increased efforts by the public sector in developing countries and the research communities in developed countries are essential in significantly speeding up the development and commercialization of GM cassava. SSA countries need to re-evaluate potential benefits from GM orphan crops—including cassava—for their domestic markets, as they are likely to be much bigger than the potential losses through anti-GM exports in Europe and Japan. The unique benefits of GM cassava, such as their support of pro-poor growth and contribution to poverty-reduction, should be emphasized in evaluation studies.

There also needs to be coordinated efforts among the international research community and developing countries' governments to understand the cost of delaying the building capacity for biosafety regulation and development of GM cassava. Such evaluations are complicated, as they need to consider the fact that the commercialization of GM cassava in SSA countries is handicapped by both technical constraints (research capacity) and institutional constraints (perceptions by various stakeholders and regulatory capacity in SSA countries). However, more ex-ante impact assessment research may be beneficial in estimating how the commercialization of GM cassava can be accelerated by the relaxation of various types of constraints. Issues to be considered include how the application of humanitarian use licensing reduces the time and costs of obtaining the rights for the application of patented technologies and how this translates into increased benefits from GM cassava through faster commercialization in SSA countries. Knowledge of benefits can lead to the strengthening of research capacity in SSA and the setting up of more favorable procedures such as humanitarian use licensing, but little research has been actually done on such benefits. This is an area that requires significant and immediate attentions from both the public sector in SSA countries and the international research community.

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Appendix

Distinction of Transgenic Methods from Other Biotech Methods and Conventional Breeding Methods

Figure 1 (see next page) illustrates the simplified version of the plant-breeding process and how transgenic and non-transgenic biotechnology methods are applied at different stages of producing new varieties. At the first stage of creation and release of variation, gene sequences that express desired traits such as virus resistance are produced in the target variety. This can be done by either searching for mutant varieties that contain desired genes (induced mutation) or through recombination. Recombination can be done by either sexually crossing two compatible genotypes (conventional) or by using other approaches such as protoplast fusion or directly inserting genes into the target varieties (recombinant DNA method). Strictly speaking, the term *transgenic* is used to refer to plants produced with the recombinant DNA method. The two terms, however, often are used interchangeably.

The methodology subject to biosafety regulation is the recombinant DNA method, which inserts genes with desired traits into the target plant variety. Other biotechnology methods are not subject to biosafety regulations. Some of those modern methods using biotechnology are applied during the second stage. For example, marker-assisted selection (MAS) is used at the selection stage. In MAS, marker genes are inserted into the target varieties to track varieties that contain the genes with the desired traits when they are grown in the field.

A plant variety is subject to biosafety regulation if it is developed using the recombinant DNA method, regardless of what methods are applied at the selection stage. Conversely, a variety is not subject to biosafety regulation if it is developed without using the recombinant DNA method, even when some other biotechnology methods such as MAS are applied along the process.

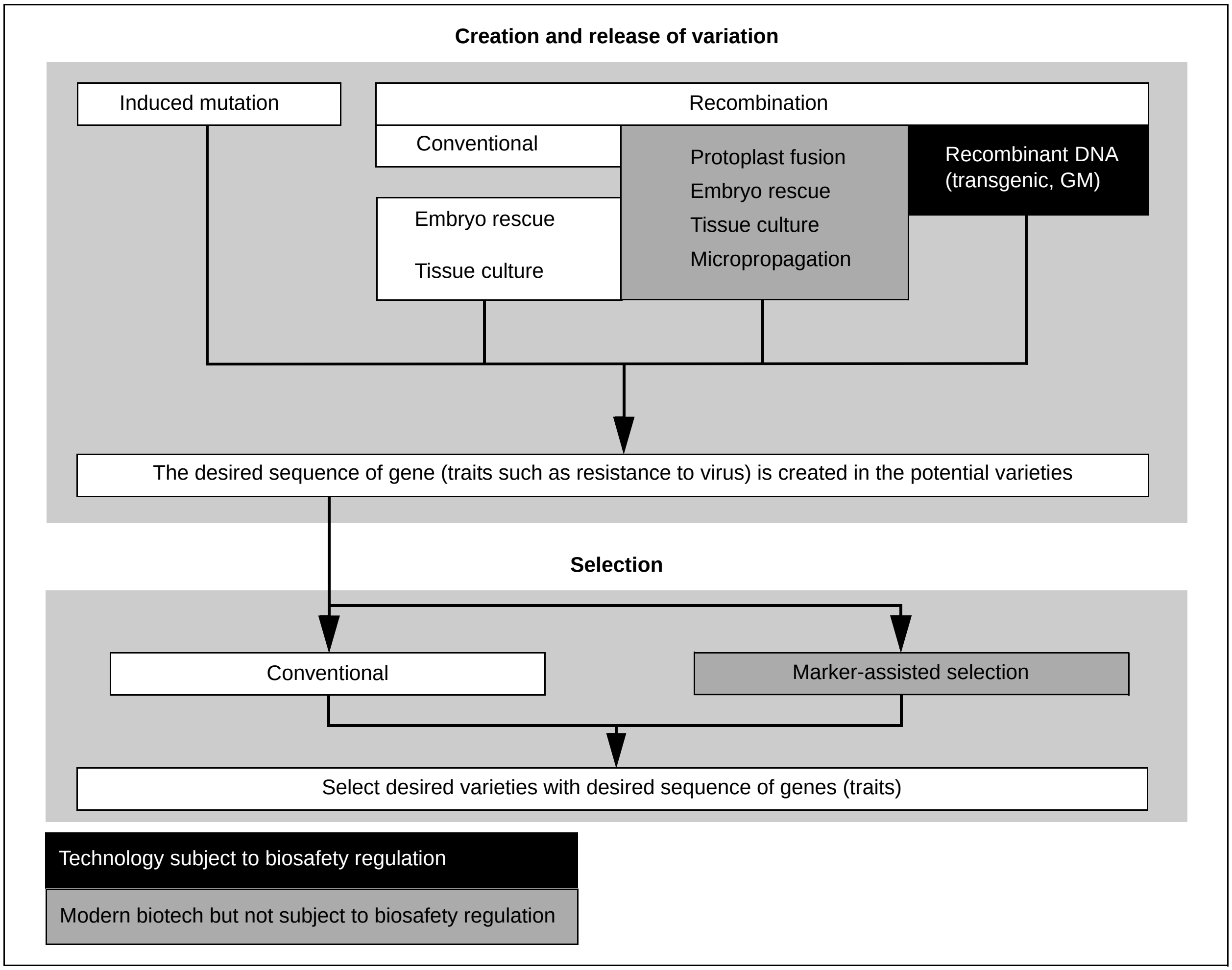

Figure 1. Breeding technologies subject to biosafety regulation.
Source: Author.