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An Ex-Ante Economic Impact Assessment for Adoption of Transgenic Cassava Varieties in East Africa

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Abstract

Cassava has been a major staple in Sub-Sahara Africa for generations, securing several households against food poverty and hunger. However like other tropical crops, cassava has been susceptible to various pests and diseases, thus threatening millions of persons with food insecurity and severe hunger. Most notable diseases have been cassava brown streak virus (CBSD) and cassava mosaic disease (CMD) that in some instances cause up to 100% harvest losses. Fortunately, recent research efforts have used genetic modifications, and engineered Transgenic Cassava Varieties (TCVs) that are resistant to CBSD and CMD. But because these are recent technologies, their economic value has not yet been estimated to inform policy and other stakeholders (breeders, traders, farmers etc.). Using data from Kenya and Uganda, we estimate the ex-ante economic impact of TCVs. Adoption of CBSD –resistant TCVs, would bear a net financial benefit of US$ 436 million in Kenya and US$ 790 million in Uganda over a period of 35 years. This would substantially contribute towards households' incomes and food security.

Key words: Transgenic cassava varieties, ex-ante economic assessment, adoption, Africa

1. Introduction

Since inventing genetically modified (GM) crops in early 1990s, there has been wide spread debates on appropriateness for use of these foods. Various consumption regions given their needs have had varying perceptions towards GM foods. According to Bett et al. (2010) consumers in Europe and North America have extreme negative perceptions and attitudes towards GM foods consumption. The governments of these regions have also developed strict regulations and policies governing availability of GM foods in their food markets; whereas in Japan, food consumption from import markets is restricted to organic produce (De Groote et al., 2011). However, the liberty of Europe, America, and Japan to choose either organic or GM foods is widely due to an existing food surplus but not that GM foods pose proven human health, environmental or ethical hazards (Bett et al., 2010; Qaim, 2009; Qaim, 2015; Klümper and Qaim, 2014).Unfortunately in large parts of Sub-Saharan Africa (SSA), there has always existed a food deficit, severe hunger, rapid population growth, crop destroying natural hazards like; disease, pests, floods, and droughts, all of which create a serious human problem of hunger (Clover, 2003; Haile, 2005; Barrios et al., 2006; Baro and Deubel, 2006; Liu et al., 2008).

Africa has been continuously exposed to critical food aid needs, a factor that has seriously crippled her labor productivity, and consequently vibrant economic growth due to persistent hunger (Barrett and Maxwell, 2005; Baro and Deubel, 2006). Persistent hunger can only be solved through continuous ample food production, a goal that would be easily achieved through using GM foods (Edmeades et al., 2008; Qaim, 2015; Taylor et al., 2015). Smallholder farmers demand GM crops to better their food security and incomes, (Klümper and Qaim, 2014; Taylor et al., 2015). For instance smallholders in East African highlands demand bananas and other important GM crops (Edmeades and Smale, 2006).

High birthrates, thus high population growth rates in SSA, have availed the region with a population than it can ably feed. SSA’s tropical nature that bears higher temperatures favoring growth and development of crop pests and diseases, further ensures heavy crop losses; rendering food shortage situations worse. Pests and diseases for particular crops have at several instances led to total crop loss (Taylor et al., 2015), thus subjecting the region to continuous food aid needs which is sometimes unavailable; thus prolonged hunger and deaths of millions. Therefore GM crops resistant to notorious diseases are a solution to averting crop losses, ensuring food security, and human welfare (Klümper and Qaim, 2014; Qaim, 2009; Qaim, 2015; Taylor et al., 2015).

In the spirit of combating food security in East Africa, the VIRCA (Virus Resistance for Cassava in Africa) project established in 2006 funded by the John Templeton foundation through the Donald Danforth Plant center, has engineered two Transgenic Cassava Varieties (TCVs) the (TME204 and EBW), that are resistant to CMD and CBSD; aimed for future deployment in East Africa. CMD deforms leaves and reduces storage root harvests, whereas CBSD causes severe necrosis of the eatable roots, making these roots non-worthy for sale or consumption, (Taylor et al., 2015). However, there needs to be an empirical ex-ante economic impact assessment of these TCVs to fill knowledge gaps on expected costs and benefits of such a deployment. This assessment is yet unavailable to inform policy, and other stakeholders.

Although a number of GM crop technologies have been studied in Western or Asian countries; these countries’ policy environments are different from those in Africa. According to Bett et al. (2010) the major consumption problems in Europe revolve around foods’ nutritional qualities but not quantities, which is the major consumption problem in Africa. De Groote et al. (2011) assert that consumers in Europe have a clear negative attitude towards GM foods whereas in Africa GM foods have been accepted widely by certain governments to combat rampant food shortages.

Although GM crops like biotechnology (Bt)-maize, Bt-cotton, Bt-sorghum, and tissue culture bananas have been studied in the African context, there has been no such research conducted on TCVs, at least at policy formulation level. Africa is also widely divided ethnically and certain ethnicities grow particular food crops, thus reasonable to widen studies of GM-crops to all African staples. Africa is also ecologically diverse, that particular crops only grow in particular ecological zones yet all these zones inhabited by humans, who must feed. Cassava is among the top five most grown food crops in Africa (FAO, 2012) like maize, plantains and potatoes, hence it's an important staple with; wide acceptability, heavy commercial contributions, and wide ecological adaptability. Therefore since there is an expected release of TCVs in Uganda and Kenya, yet no clear ex-ante analysis has yet been done, to guide policy on prospects and economic impact of TCVs, a wide knowledge gap on "transgenic trait" in cassava exists. We contribute to closing the gap by assessing; farmers' awareness and knowledge of CBSD and CMD, and the potential economic impact of TCVs in East Africa. We also draw policy implications on TCVs. Next we present data and methods used, after which are results, and then conclusions.

2. Materials, Data and Methods

2.1 Study Area

Research was done in Kenya and Uganda's cassava growing and trading areas identified by Kenya Agriculture Research Organization (KARI) for Kenya, and National Agriculture Research Organization (NARO) in Uganda. Research was done in conjunction with VIRCA to benefit from free distributions of new TCVs, covering Eastern Uganda (Kamuli and Busia districts), Northern Uganda (Lira and Apac districts), and Western Kenya (Busia and Teso). Cassava wholesale traders interviewed in Uganda were from Kampala and Wakiso districts, whereas in Kenya they were from Busia, Kakamega and Kisumu towns.

2.2 Sampling and Data

The multi-stage proportionate random sampling technique was used. KARI and NARO identified districts where they were dealing with cassava farmers against CMD and CBSD. Cassava farmers were then grouped into villages from which the sample was randomly selected. A total of 200 farmers from each country; already growing traditional cassava varieties but also targeted for TCVs were interviewed in Kenya and Uganda. These included 100 farmers from Northern Uganda and 100 from Eastern Uganda. For its importance as a prime producing cassava region in Kenya, all 200 farmers were from Western Kenya. Farmers were interviewed on their knowledge of TCVs, as well as other opinion on TCVs using structured questions.

Cassava traders were from major cassava trading towns in Kenya and Uganda, as guided by KARO/NARO and literature, dealing in both traditional and available TCVs but also prospectively with knowledge on CMD and CBSD resistant varieties. Traders were dealing either in cassava cuttings, fresh roots or flour. In Kenya the study considered Busia, Kakamega and Kisumu whereas in Uganda it was Kampala and Wakiso towns. Random sampling was also used to sample traders within trading centers, since it was difficult to compose them into strata, as each trader independently chose his varieties for trade. Questions concerning both TCVs and traders' perceptions and attitudes towards the same, their opinion on labeling GM cassava, and its products were asked. A sample of 56 traders; 30 from Kenya and 24 from Uganda were interviewed. A similar methodology has been used by Bett et al. (2010) to study Bt Maize in Kenya. Secondary data from KARI, NARO and UBOS were also used in the study. Primary data was collected in 2014.

2.3 Methods

2.3.1 Theoretical Framework

In their assessment of methods for assessing agricultural technologies, Alston et al. (1995; 1998) focused on the classical economic surplus model (ESM) for ex-ante evaluation. In a small closed economy as Kenya or Uganda may be in relation to cassava production, a release of TCVs is expected to increase supply on the local market since there is no international trade. However, Alston et al. (1998) add that even though there was international trade involved, the ESM would be in position to estimate the effect of international price and distribution effects on local supply; a reality that would not be revealed by econometric or cost-benefit analyses. Kristjanson et al., (1999); Kostandini et al., (2009); Krishna and Qaim (2008); Napasintuwong and Traxler (2009); De Groote et al., (2011), have used the ESM to predict the potential economic impact of agricultural technologies. Therefore we use the ESM, particularly the partial equilibrium model in this study. An increase in cassava productivity due to disease resistant TCVs, causes a parallel shift of cassava supply curve downwards from S_0 to S_1, increasing quantity produced from Q_0 to Q_1 consequently lowering cost of cassava to consumers; thus price paid to producers from P_0 to P_1. This brings about a new equilibrium at E_1 from the initial E_0 and hence a change in both producer and consumer surplus. The sum of the change in the two surpluses is the potential economic surplus impact caused by the release of TCVs as illustrated in Figure 1.

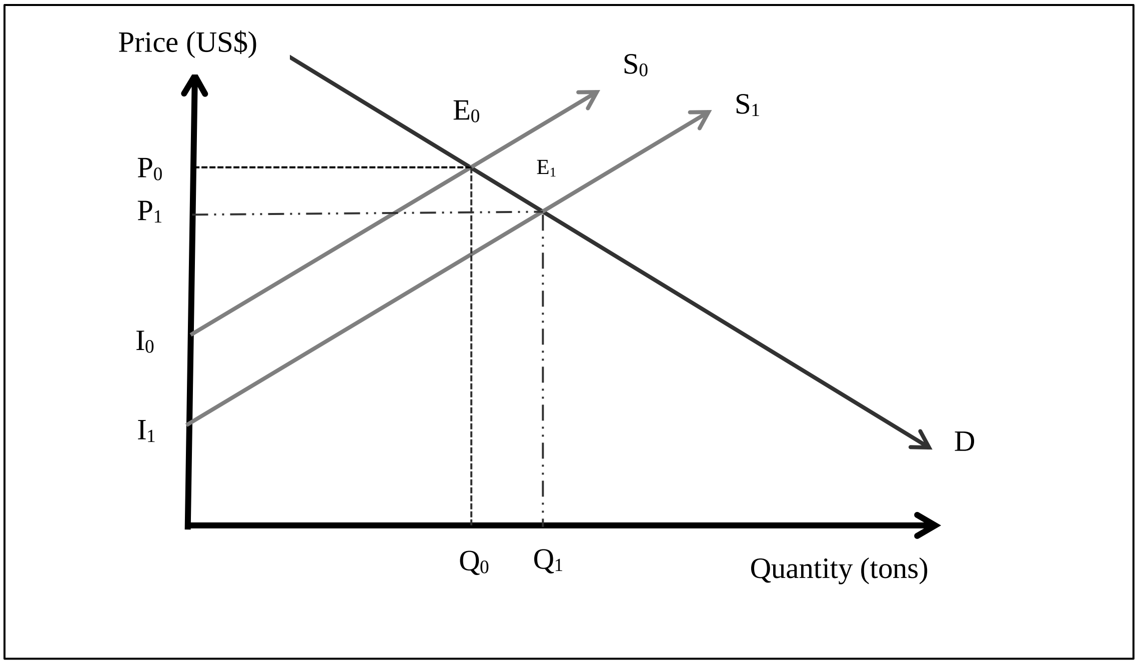

Figure 1: Illustrations of the Economic Surplus Model

Whereas the demand curve D, does not change given the nature of the domestic market that is supplied solely, dropping of the price, increases consumer surplus by area $P_0E_0E_1P_1$ creating a change in producer surplus equaling to area $P_1E_1I_1 - P_0E_0I_0$ causing an aggregate change in total economic surplus of $E_0I_0E_1I_1$. At farm level, all Cassava in western Kenya and Uganda is sold as fresh roots due to farmers' lack of processing technologies. Therefore at farm level, we focus at aggregate supply of cassava but reflect the impact of transport costs to principle markets. We employ a closed market model as exports of cassava roots to Southern Sudan are negligible. However at market level, cassava in Uganda exists in two forms including; fresh roots and flour based on regional needs. However due to insufficient quantities of data at market level from market agents like; cassava wholesalers and processors, the study focuses on cassava market supply for fresh (including slices) roots mostly supplied for home consumption, and cassava flour supply that is usually targeted to institutions like; schools, hospitals, security agencies and aid to devastated regions. We specifying initial demand and supply functions of TCVs as follows;

$$Q_D = \theta - \eta P \quad (1)$$

$$Q_S = \alpha + \beta P \quad (2)$$

Equations (1) and (2) are used respectively to estimate demand and supply curves for TCVs, assuming that price will be the only cause for variability in consumers' expenditure on TCVs. η is price elasticity of demand and β is price elasticity of supply, Q_D and Q_S are quantity demanded and supplied respectively that are estimated with a known market price . θ is a constant and α is normally distributed, thus demand is stable, and supply is expected to vary due to ecological zones, technological suitability, weather and other factors that influence supply. Hence, initial equilibrium price P_0 and quantity Q_0 are mathematically estimated as;

$$P_0 = \frac{\theta - \alpha}{\eta + \beta} \text{ and } Q_0 = \frac{\theta\beta + \eta\alpha}{\eta + \beta} \quad (3)$$

Further mathematical manipulations are used to generate total potential economic surplus of TCVs (TES) in Kenya and Uganda, as the sum of potential change in consumer ΔCS and producer surplus ΔPS added to Gross technology revenue (GTR) that will potentially accrue to institutions producing TCVs' cuttings for sell to farmers. The procedure was described in detail primarily by Alston et al. (1995), and modified by Moschini et al. (2000), and used by; Krishna and Qaim (2007) in assessing potential economic impacts of Bt-eggplant in India, and Napasintuwong and Traxler (2009) in an Ex-ante assessment of GM-papaya adoption in Thailand. The procedure is expressed in equation 4;

$$TES_t = \Delta CS_t + \Delta PS_t + GTR_t \tag{4}$$

Where t refers to the specific time period or year relative to base period

Change in Consumer and Producer surplus was computed as in 5 and 6;

$$\Delta CS_t = P_0 Q_0 Z_t (1 + 0.5 Z_t \eta) \tag{5}$$

$$\Delta PS_t = P_0 Q_0 (K_t - Z_t)(1 + 0.5 Z_t \eta) \tag{6}$$

Where K_t is expected unit cost reduction at period t or the vertical shift in supply curve, whereas Z_t is the reduction in price due to supply shift. K was estimated as in 7;

$$K_t = \left[\frac{E(Y)}{\beta} - \frac{E(C)}{1 + E(Y)} \right] A_t \tag{7}$$

$E(Y)$ is the expected yield increase due to TCVs per hectare, $E(C)$ the proportionate change in variable costs per hectare due to TCVs, A_t is the expected adoption rate for TCVs, estimated from a logistic binary model using data from stated preferences.

GTR is calculated following equation 8. GTR is included on assumption that private/public sector will be responsible for production of TCVs for selling to farmers but on a commercial or cost-recovery basis.

$$GTR = Co(S^{TCVs} - S^{Non-TCVs}) \tag{8}$$

Where Co is the potential land coverage of TCVs in hectares and S^{TCV} is potential price charged for TCVs cuttings per hectare. Thus, Net Present Value (NPV) of TCVs is estimated following 9.

$$NPV = \sum_{t=0}^{T} \Delta TES_t / (1+r)^t \qquad (9)$$

Where r is the discount factor, and T is total number of years, impacts due to TCVs are expected to last after initial adoption.

To mathematically estimate yield-effects of TCVs (Δy) for farmers; Qaim and De Janvry (2005); Qaim et al., (2006); De Groote et al. (2011) followed equation 10 that we too follow.

$$\Delta y = y_{TCVs} - y_{Conv} \qquad (10)$$

Where Δ_y is difference in effective yields between expected TCVs' yield (Δy_{TCVs}) and realized conventional cassava varieties' yield (Δy_{Conv}). We assume that conventional varieties are those currently grown with either CMD or CBSD, and TCVs are those grown without any of the two diseases. Primary data from farmers based on their farming experience was collected on yield potentials of conventional cassava varieties grown in farmers' conditions without either CMD or CBSD. Furthermore, secondary data were collected from national libraries of KARI and NARO on yield potentials of these conventional varieties. Then considering the two data, an average score was estimated for yield potential of conventional cassava varieties grown in farmers' conditions without CMD or CBSD, and this result was used in the study as the y_{TCVs}. The current yield of conventional varieties grown in farmers conditions but with CMD or CBSD were collected directly as primary data from using farmers' survey tool, and generated y_{Conv}. The difference is used to generate expected yield potential of TCVs required for use in estimation, along other data including bio-physical, social, market factors and expected changes in production costs to finally estimate the total potential economic impact of TCVs in Kenya and Uganda from TCVs' adoption. Such considerations are necessary because relative importance of consumption and production attributes fluctuate by distance to and from market sites (Edmeades et al., 2008). Therefore market characteristics were considered, to properly estimate total potential economic impact of TCVs.

We also include important characteristics of cassava markets; (1) a quite high subsistence component and where there is uncertainty as to how home consumption responds to declining market prices, (2) very high marketing margins so that changes in price at farm level are only partially reflected in changes in price at consumer level, and (3) high transport costs, and root perishability which limits size of supply to principal urban markets, and limits price transmission between spatially separated markets.

2.3.2 Empirical Framework and Data used

Empirically, we use STATA software to evaluate the potential economic impact of TCVs. We briefly describe the empirics below for key variables as well as assumptions, and data used in final computations. We have documented details of other information for instance cassava attributes preferred by farmers as well as consumers in Sibiko *et al*., (forthcoming).

2.3.2.1 Ex-Ante Economic Impact Assessment of TCVs

We determine the ex – ante economic impact of release of virus resistant cassava varieties through summation of; direct benefits to farmers from lower costs of production, indirect change in farmer benefits due to changes in price as overall cassava supply adjusts, and indirect benefits to consumers from the prospective fall in cassava price. We derive the methodology used for such calculations from consumer surplus theory, and is assessed through a shift in the cassava supply function due to the new technology. Benefits arise principally through changes in price in cassava markets, and the economic welfare effect on both farmers and consumers. We develop a realistic modelling of cassava markets and an adequate understanding of the shift in cassava supply, production, and markets.

The supply shift is projected over a period sufficient to capture the discounted benefit stream. The shift captures changes in cost of production, and farmer adoption. The change in cost of production is essentially due to changes in cassava yield, and these are a function of presence and severity of two virus diseases, and the next most limiting constraint on cassava yield. The latter is generally due to soil and crop management constraints. The change in yield is calculated by country on basis of these two factors. The adoption rate, particularly early in deployment of TCVs, is a function of biological multiplication rate in producing cassava stakes, deployment strategy across sub-regions — targeted initially to where the disease is severest, and farmer adoption as defined by percentage of area planted to virus resistant varieties. Over time cassava multiplication and deployment shifts from reliance on public sector capacity to reliance on farmer informal seed systems.

Finally, costs of developing transgenic varieties are calculated based on; existing costs to date, past programs deploying CMD resistant varieties, and projections of costs in release of TCVs. The more basic research in developing constructs and protocols are not included. Rather the intent is to establish costs for a routine varietal transformation protocol employing different numbers of resistance traits. The costs of multiplying and deploying improved varieties are based on experience during CMD pandemic in Western Kenya and Uganda. The cost stream is then discounted over time and compared to discounted benefit stream to produce a cost benefit estimate for the impact of the resistant varieties.

2.3.2.2 Modelling Impact during the CBSD Pandemic

Modelling the potential impact of virus resistant TCVs is complicated by particular phase of spread of the two diseases. The pandemic associated with the recombinant CMD was first reported in the late 1980's and the response was the distribution of resistant varieties produced by the International Institute of Tropical Agriculture (IITA), and working with national partners. By 2005 the pandemic was effectively under control in Western Kenya and Uganda, and this is reflected in the importance of these introduced varieties in the portfolio of varieties grown by farmers in the 2014 survey. However, the CBSD pandemic began in about 2004 and spread quickly in Uganda and then into Western Kenya. The CBSD pandemic is still proceeding and benefits will be dependent on how the deployment of resistant varieties affects the epidemiology of disease – in essence the yield with the resistant varieties compared to what would have been the case without the transgenic varieties. Timing of the introduction of the varieties is thus a key issue, as the earlier the introduction; the greater the potential to prevent future losses.

The economic benefits from the introduction of TCVs are measured through changes in yield, as costs of production are essentially constant under both pre- and post-deployment conditions, as costs essentially depend on labor and land inputs. There should be no significant costs associated with planting materials, as these will be distributed through government multiplication programs. Unfortunately, there is no epidemiological model for CBSD and there is only limited data on CBSD's current distribution and severity. Therefore, estimating impact on average national or regional yields is done by assembling data on best estimates from both; surveys, and other sources.

2.3.2.3 Estimating Yield Change

Based on photos of leaf and root symptoms, most farmers in both Kenya (95%; 91 %) and Uganda (93%; 74%) were able to confirm that they had CBSD and CMD respectively in their cassava plots. However, only 79% of Kenyan farmers and 45% Ugandans rightly identified CBSD, while 77% in Kenya and 51% in Uganda rightly identified CMD, (Table 1). In Kenya, 29% of farmers recorded high prevalence of CBSD, while in Uganda, 31% recorded such prevalence. In Kenya, 27% and 31%of farmers had low prevalence of CBSD and CMD respectively while in Uganda it was 16% and 23%. In Kenya, 19% of farmers reported a 50% crop loss due to both CBSD and CMD whereas in Uganda, 31% reported crop loss of 50% due to CBSD and 22% due to CMD. In the case of a 75% loss, 12% of Kenyan farmers reported such a magnitude of loss to CBSD and 5% due to CMD. In Uganda, figures stood at 24% and 11% respectively. As was expected, data indicate that CBSD is more prevalent and threatening of the two virus diseases.

Table 1: Farmers' knowledge of CBSD and CMD in Kenya and Uganda

Variable	**Categorization**	**Kenya %**		**Uganda %**	
		Diseased roots & leaves: CBSD	Diseased leaves; CMD	Diseased roots & leaves: CBSD	Diseased leaves; CMD
Show disease	Yes	95.04	91.32	92.67	74.35
Which disease	CMD	15.70	76.86	47.8	50.68
	CBSD	79.34	14.46	44.9	45.21
Prevalence	High	28.93	22.73	31.28	13.38
	Moderate	28.51	26.03	36.87	35.92
	Low	26.86	30.99	16.2	22.54
Estimated loss	25% loss	45.45	44.63	26.11	49.58
	50% loss	19.01	19.01	30.57	21.85
	75% loss	11.98	4.55	24.2	10.92

Source: Survey data 2013-14

For CBSD; based on farmers' evaluation, it is associated to an average yield loss of 39% in Western Kenya, and 40% in Uganda. This compares to a similar study in Malawi, where farmers estimated yield losses at 23% (Gondwe, 2003), but this was at a much earlier stage in the spread of the disease. There appears to be sufficient consistency across these studies to suggest an average yield loss of 40% from CBSD and therefore a potential yield gain of 40% from the release of resistant varieties. But this assumes that the pandemic has reached its full distribution and impact. In using this figure in benefits estimation, yield change is discounted by expected percentage of the area that resistant varieties will assume in an average farmer's portfolio of varieties.

Given the progress to date in the development of CBSD resistant varieties and projected stages for biosafety certification, national varietal trials, and first stage multiplication, a best estimate is that the varieties will be first available to farmers in 2025. Given current distribution of the disease and its past rate of spread, it is assumed that CBSD will essentially be an endemic disease, much as CMD, by that time. After the initial confirmation of the disease in 2005; by 2009 its rate of spread suggested its epidemic potential. The VIRCA program was a relatively quick response, with the Danforth Plant Science Center starting work on the Ugandan strain of CBSD around 2005, and the VIRCA program starting in 2011. Because the disease is spread by whitefly vectors, there are no practical cultural control measures, although there may be some gain from distributions of disease-free planting materials. However, this requires a functional seed system. Moreover, breeding has yet to produce a resistant variety. In most respects TCVs will be the quickest means to produce a resistant variety, and possible only between 2020 and 2025 (see next section) until a variety gets to farmers. Sometime in that period, the expectation is that the disease will have reached its maximum distribution and prevalence.

But what would expected yields be with the release of the resistant varieties? In 2004-05 a farm survey and on-farm trials were done evaluating the yield gap for cassava (Fermont, et al, 2009). At this time the CMD pandemic was under control with resistant varieties and the CBSD pandemic was only just beginning. In fact, virtually no pest or disease problems were found at this time and researchers were able to focus on edaphic factors, particularly soil fertility, and management factors influencing cassava yield. At that time average farm yields in western Kenya were 6.1 t/ha and 11.7 t/ha Uganda. It is assumed that other constraints on cassava yields as identified in this study will not have been ameliorated and that these yields represent average yield potential on the release of resistant varieties.

2.3.2.4 Costing the Development and Deployment of TCVs

Research, development and deployment costs of producing virus resistant TCVs, covers a range of activities associated with TCVs' production. The costing suggests; some activities where there are economies of scale in working with a number of varieties, cost implications of working with different numbers of traits, and costs associated in working across different countries and regulatory regimes. However, for simplicity, the costing is based on the development of routine protocols for transformation, testing and deployment of a single variety. It does not include research costs associated with understanding the virus, developing genetic constructs, and optimizing development of cell cultures, transformation protocols, and molecular characterization. Nevertheless, for cassava developing, cell cultures necessary for efficient transformation are varietal dependent and not yet routine. This is not factored into costings.

Costs are broken out into six stages in the development of these TCVs. These include; laboratory phase (including cell culture, construct insertion, screening and molecular characterization), confined field testing under biosafety requirements, biosafety testing and formal release, national performance trials and formal varietal release, first stage multiplication, and finally second stage multiplication and deployment. Regulatory protocols for formal release of a transgenic variety have not yet been tested in either Kenya or Uganda. Moreover, the Ugandan Parliament has just passed the Biosafety Bill in October 2017, which would allow such releases. There is thus some uncertainty as to whether confined regional trials for testing final lines of TCVs will be sufficient for varietal release or whether varieties will also have to go through formal national varietal testing and release procedures for all improved varieties. The VIRCA program is arguing for an aggressive schedule for release, given the severity of CBSD pandemic, along the following lines:

2017 – 2018: grow 0.5 ha of final transformation event and back up event (confined field trial)

2018-2019: 5 ha final event only (confined field trial)

2019: projected regulatory approval, assuming 1 year review

2019 – 2020: 50 ha multiplication plus open field trial (final step in variety release testing), with release of first wave of 500,000 stakes to farmers (25 stakes each to 20,000 farmers)

A more extensive set of regional varietal performance trials would extend this time frame. This analysis has adopted more conservative time frame and additional costings for varietal performance trials. The VIRCA time frame would be expected to significantly increase benefits from release of CBSD resistant TCVs.

Although not integrated into the benefit analysis, it is also useful to distinguish across activities where costs are incurred in working with more varieties or more traits per variety. The additional costs of working with more traits, as for example in the case of Ebwanateraka (EBW), only come principally at the laboratory phase. There are no scale economies of working with a number of varieties at this stage, but there are at the confined field testing, biosafety, and national performance trials. At the stages of doing confined field tests, and biosafety trials, there is need to work in individual countries, and this obviously increases costs due to the need to work within national regulatory policies. This is where large countries, such as Brazil and India, have a significant advantage, compared to the small country context that exists within sub Saharan Africa. For the biosafety trails, costs decline with numbers of varieties, assuming each variety has the same trait or traits. Finally, costs of multiplication and deployment, usually within a two or three stage multiplication system, may have slight scale economies when working with a number of varieties but these are probably minimal. The advantage at this stage is that it gives farmers increased choice, particularly given the heterogeneity of farmer preferences, and thus increases the probability of adoption, as well as augmenting genetic diversity in cassava populations.

The cost of developing a transgenic cassava variety (TCV) is presented in Table 2. The minimal time required to produce and distribute such a variety is 20 to 25 years. There is some expected cost efficiencies associated with developing a pipe line of varieties with these traits. Biosafety costs are a particularly high cost activity, and to the extent that these decline with experience with the virus resistance trait or traits, these costs and time taken to release a TCV could be substantially reduced. With a varietal pipeline for these traits, a new set of transformed varieties could be produced and released in as little as five years.

These development and deployment costs will be compared to the estimated, discounted benefit stream from the adoption of these varieties. It should be noted that such benefits do not start until year 16, and then only at relatively low levels, given the slow multiplication rate for cassava of about 1 to 5. Rapid multiplication techniques could speed this up somewhat, but also at additional costs. Given that these varieties are being developed during a pandemic, time taken for deployment of these varieties has a significant effect on projected losses.

Table 2: Development and Deployment costs for a CBSD-resistant TCV

Activity	Year	Costs ('000 US $)	
		Kenya	**Uganda**
Varietal Transformation	2011	85	85
Confined Field Testing	2012	173	173
	2013	163	163
	2014	163	163
Biosafety Tests	2015	178	178
	2016	523	523
	2017	531	531
	2018	145	145
National Varietal Trials	2019	15	20
	2020	15	20
	2021	15	20
1st Stage Multiplication	2022	5	5
	2023	10	10
	2024	20	30
	2025	20	35
	2026	20	40
2nd Stage Multiplication	2024	5	10
	2025	12	20
	2026	25	60
	2027	25	65
	2028	25	80
	2029	25	80
	2030	25	80
Total		**2,223**	**2,536**

Source: VIRCA program estimates

2.3.2.5 Ex-Ante Benefits Estimates from the Release of TCVs

The ex-ante economic benefits from the release of CBSD and CMD virus resistant TCVs are estimated using the economic surplus methodology. The estimation is done using STATA and Excel. The technique empirically calculates net benefits to farmers from; the decline in costs of production from the new technology, the decline in price of cassava, and the benefits to consumers from the fall in root prices. The total benefit stream is discounted at 5% and compared to discounted cost stream, to calculate the internal rate of return (IRR) to investment in development of transgenic varieties. The key to benefit estimates is the calculation of an annual vertical shift in the cassava supply function due to the decrease in cost of production — in this case due to increase in yield — with the new technology, and the rate of adoption of resistant varieties. The data parameters that form the basis of these estimations are presented in Table 3.

Table 3: Data and Assumptions used in the TCVs Economic Surplus Analysis

Variable	Western Kenya	Uganda
Production (Mt)	622,189	2,350,544
Farm Gate Price ($US/Mt)	199	135
Retail Price ($US/Mt)	485	217
Price elasticity of demand	-0.70	-0.66
Price elasticity of supply	0.33	0.23
Proportionate yield change for CMD/CBSD resistance	29%	28%
Maximum adoption	70%	60%
Years to maximum adoption after variety release	11	11
Probability of success	100%	100%
Discount rate	5%	5%
Number of years over which cost/benefit analyzed	35	35
Number of years till initial adoption	14	14

Source: FAO, 2012, and Survey data 2013-14

3. Results and Discussions

3.1 *Descriptive Statistics*

A large body of descriptive statistics on household and farmers' characteristics, producer and consumer preferred attributes and traits for cassava, determinants of such preferences, awareness on biotechnology etc. for both Kenya and Uganda have been extensively documented in Sibiko et al., (forthcoming) who investigate trait preferences for TCVs in East Africa. We skip this section.

3.2 *Economic Surplus Model Results*

3.2.1 *Ex-ante Economic Impact Assessment of TCVs*

Table 4 shows the base data used in estimating the Net present values (NPVs) of TCVs in Uganda and Kenya. Cassava production data for Uganda shows that the country produced 2.34 million metric tons (Mt) from an area of 868,974.7 ha with a 101kg/capita consumption in 2012 (UBOS, 2013). Kenya on the other hand produced less; at 0.89 million Mt from an area of 97,000 ha

(Faostat, 2012). Cassava demand in Uganda was markedly higher than in Kenya by 1.65 million Mt. Industrial cassava use in Uganda was at 0.18 million Mt annually while in Kenya it was lower (0.12 million Mt), (Kleih *et al*., 2012; Karuri *et al*., 2001). This could be explained by lower importance of cassava as a staple in Kenya, and also the higher cassava yield losses due to CMD and CBSD. Adams *et al.* (2013) noted that Africa loses 30% - 40% of her cassava yield to these diseases which ranges from US$6 to US$25 billion annually yet East Africa of which Uganda and Kenya are part losses up to $180 million annually.

We predict a higher maximum adoption rate in Kenya at 70% compared to Uganda's of 50%, thus there are higher expected benefits in Kenya from TCVs' adoption as compared to Uganda. Rudi (2008) also finds that the TES in Uganda for CMD resistance was US$280.5 million, and returns on investment in Marker Assisted Breeding (MAB) of resistance to CMD in Uganda was at 48%, while research and breeding costs were at US$120,000 in first year, and US$ 100,000 by the tenth year of the program.

Table 4: Data and Assumptions used in the TCVs Economic Surplus Analysis

Variable	Uganda	Kenya
Production (Mt)	2,350,544	852,522
Quantity demanded (Mt)	2,535,071	882,871
Equilibrium quantity (Q_o)	2,595,648.78	981,511.75
Equilibrium price (US$)	123.41	202.61
Area (ha)	868,974.7	97,000
Price (US$/Mt) of fresh roots (2013 farm gate)	149.73	104.46
$\triangle y$ yield gain due to TCVs (Mt/ha)	0.64	0.68
Price elasticity of demand	-0.21	-0.65
Price elasticity of supply	0.85	0.85
Proportionate yield change for CMD/CBSD resistance	25.6%	61.81%
Proportionate input cost increase	5%	5%
Maximum adoption	50%	70%
Probability of success	60%	65%
Discount rate	5%	5%
Exchange rate 1US$	UGX 2,337.5	83.50
Years over which cost/benefit analyzed	35	35
Gross Technology Revenue in year1 (US$)	6,864,951.58	11,924,082.83
Change in consumer surplus (US$)	144,757,450.39	84,609,431.35
Change in producer surplus (US $)	169,932,659.15	64,701,329.86
Total Economic Surplus (US$)	314,693,046.42	150,541,080.5

Source: FAOSTAT, 2012; UBOS (2013), and Survey data 2013-14

For a crop like cassava where there is a large price differential, and a significant subsistence consumption, benefits could be captured primarily by farmers and middlemen. Results for cost and benefit estimates, and internal rate of return (IRR) are presented in Table 5. Results remain robust even when tested with more conservative parameter estimates. In all cases, benefits far out way costs associated with the development of virus resistant varieties. The Net present value (NPV) is US$ 436 million in Western Kenya and 790 million in Uganda over a 35 year period, and with adoption starting after 11 years. This yields an IRR of about 50% in both countries. This is comparable to rates of return found in other studies of agricultural research. Alston, et al (2000) found an average rate of return of 65% to agricultural research in a meta-analysis across over 1000 studies. In a meta-analysis of GM crops, Klumper and Qaim (2014) found that GM crops on average increased farmer yields by 22%, and farmer profits by 68%, which is also comparable. As expected, farmers are the principal beneficiaries, although consumer benefits are also significant. Such high rates of return are achieved with effective control measures during a pandemic. A meta-analysis of returns to CGIAR investments in sub-Saharan Africa found that about 80% of total benefits were due to biological control of cassava mealybug during a continental wide pandemic (Maredia and Raitzer, 2006). In the case of TCVs, costs are smaller in relation to potential economic benefits. The time taken to develop these varieties was also reasonable as compared to other approaches, and could be substantially reduced. However, costs for a typical national agricultural research institute are still high, even assuming that necessary lab infrastructure was installed. Under these conditions, projected impact areas can be quite small, as is suggested by the economic benefits in Western Kenya. These results provide very strong support for the strategy of transforming preferred local varieties, even when expected target area is quite limited. A guarantee of high adoption, a large yield gain, and relatively low R&D investment costs are key aspects of the strategy that supports such a large economic return. The strategy could also support development of a number of transgenic varieties if the objective was also to maintain or improve genetic diversity within a region's portfolio of varieties – with potential as well of improving targeting of varietal deployment based on variation in farmer preferences. However, this would require transitioning from a research laboratory to a more dedicated production unit.

Table 5: Net Present Value of Economic Benefits for TCVs (Million US$ over 35 year period)

Region	**Economic Benefits**				**R&D Costs**	**IRR**
Category	Producer	Middleman	Consumer	**Total**		
Western Kenya	202	54	180	**436**	1.7	46.0 %
Uganda	525	34	231	**790**	1.8	56.7%

Source: Authors' computations

4. Conclusions

Prospects of biotechnology to solve food insecurity, and severe hunger, especially those of transgenic varieties, are often exaggerated. However, trait deployment through transgenic varieties can play a very strategic role in agricultural research and development (R&D) in sub Saharan Africa. The development of CBSD and CMD resistant cassava varieties through genetic transformation is a perfect example of such strategic use of the technology, but also combined with critical design options that optimize potential adoption of transgenic varieties. We study and validate the approach being pursued by the VIRCA program in terms of both adoption potential of TCVs, and expected economic returns to investments in the program. The disease control efficacy of the approach has already been demonstrated in confined field trials. We further empirically assessed the economic potential for the release of the two varieties as the final stages of the regulatory process are completed in the two countries.

The economic benefits, which averages at US$ 35 million per year across the two countries, are large and are based on number of factors and design decisions particular to the use of transgenic varieties including; (1) the choice of preferred landraces for transformation that will lead to high adoption, (2) successful resistance to CBSD during an evolving pandemic, (3) ability to build on a strong, existing research base that allows rather routine transformation, and (4) R&D costs that are low in comparison to potential benefits, and in relation to other research options based on traditional breeding approaches. The ex-ante impact analysis supports the extension of the approach to other countries and sub-regions being impacted by CBSD, with an argument that such economic benefits, the use of preferred local landraces, and compliance with biosafety regulations in Kenya and Uganda; might support passage of biosafety legislation in those cassava producing countries that do not yet have such regulatory procedures. The study supports the potential of rather fine grained varietal targeting in the deployment of the CBSD and CMD resistance.

Most ex-ante impact studies do not include an ex-ante evaluation of farmer adoption. The approach used in this study is quite novel and evaluates the relative importance of the targeted trait within the array of other traits preferred by farmers (see Sibiko et al., (forthcoming) for details). The study did not produce any unexpected results but rather confirmed the approach being followed by VIRCA. CBSD resistance is in fact the trait that is most important for farmers in Uganda and Western Kenya, and moreover, it is combined in trait backgrounds that conform to farmer preferences for both other production and consumptions traits. Our results suggest a relatively rapid uptake of transgenic varieties, assuming access to these varieties. Multiplication and widespread deployment of planting materials is however slow as compared to seed crops. We suggest that sub-regional deployment be done first, and then more fine grained deployment based on farmer household characteristics, done later.

Finally, initial assessments done on farmer and trader knowledge of biotechnology and transgenic varieties and how this affects preferences for GM traits; suggests at least a relatively widespread familiarity with biotechnology, and GMO's but no widespread GM trait rejection , even by traders, (Sibiko et al., (forthcoming). Therefore, this suggests a relatively positive initial acceptance of transgenic varieties, particularly as there is yet to be a first release of a transgenic crop in Kenya or Uganda. However, deployment would need to be complemented by a finely targeted information and communication strategy, which is being planned for within VIRCA.

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