Adoption of improved maize varieties, varietal turn-over and their effect on yield and food security - evidence from four household surveys over 20 years in Kenya

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Abstract

The liberalization of maize markets in Kenya resulted in the development and release of many new maize varieties since the 1990s. While younger varieties have higher yield potential than old ones, maize yields did not, however, increase. In this paper, we therefore analyze the effect of new maize varieties and varietal turnover on yields, maize production and food security, factors of stagnating maize yields, controlling for fertilizer and other factors, over time, using four household surveys conducted over the span of 20 years. Further, we analyze if the liberalization increased the share of the private sector in the maize seed market. This study analyses data from four representative farm household surveys, each with about 1500 households, conducted in 1992, 2002, 2010 and 2013, using panel regression models. We find that Kenya has made only limited progress in the adoption of improved varieties, and that the public sector, in particular the parastatal Kenya Seed Company, still dominates the seed market. Furthermore, we find that varietal turnover is slow, but does have a positive effect on both yields and food security. Varietal turnover does increase with

access to privately released seed source, education of the household head, access to extension and to credit. Our findings suggest the need to improve the seed market environment to facilitate increased private sector participation and leveraging on extension systems and credit facilities to enhance the uptake of newly released varieties.
Key words: Varietal turnover, adoption, weighted average age, yield, food security.

1. Introduction

Maize is the most important food staple in East and Southern Africa, but yields are not keeping up with population growth (Gitonga and De Groote, 2016). The low yields have mainly been attributed to low use of farm inputs, in particular new improved maize varieties and fertilizer (Smale and Olwande, 2011a; Walker and Alwang, 2015), despite many studies showing the effect of these inputs on maize yields(Gitonga and De Groote, 2016; Mathenge et al., 2014; Naseem et al., 2018). Further, it has been argued that farmers are slow to adopt the latest varieties, leading to a low varietal turnover (Naseem et al., 2018; Spielman and Smale, 2017).

Varietal turnover or replacement is defined to as the rate at which farmers replace old cultivars and is expressed as the weighted average age of the particular variety (Brennan and Byerlee, 1991). The liberalization of the agricultural sector in Kenya was aimed at improving the involvement of the private sector in the input and output markets, and in particular seed and fertilizer, and was expected to increase the uptake of new cultivars and thus varietal turnover (Naseem et al., 2018). However, so far limited empirical information on varietal turnover in Kenya is available, and its effects on yield and food security. Further, the effect of the liberalization on the expansion of the private sectors has not yet been analyzed.

Before the policy reforms in the 1990s, the Kenya Seed Company had the monopoly for maize seed production and dissemination in Kenya. The policy reforms of the agricultural liberalization, together with complementary investments , enabled the private sector to participate in the agricultural input and output markets in Kenya (Ariga et al., 2006). As a result, many seed companies entered the market, and many new maize varieties were released. These new releases led to an increased yield potential, but only to a certain point, after which the increase stagnated (Smale and Jayne, 2003).

One of the reasons for the stagnation was that genetically advanced seed releases by the breeding sector were not accompanied by improved agronomic practices and efficient support systems for smallholders especially in the marginal areas (R. Hassan, 1998). At the farm level, seed supply problems remained, an indication of the incomplete seed market liberalization process (Smale and Jayne, 2003), further curtailing availability of improved hybrid seed (Hugo De Groote et al., 2005). From 2000 onwards, one of the key policies was to create complementary roles for both the public and private sector in ensuring efficient functioning of markets and resource allocation (MAFAP, 2013).

Despite the liberalization efforts to promote the local seed industry, the KSC remains a parastatal with exclusive rights to many popular varieties (Naseem et al., 2018). There is need to better understand the trends in terms of maize area covered by both public and private organizations in order to assess whether liberalization policies were successful or have been partially implemented as confirmed by the dominance of KSC (Swanckaert, 2012).

Varietal turnover has been shown to increase yield productivity, for example in wheat in Pakistan (Hartell et al., 1998) and in China (Jin et al., 2002), and in maize in Kenya (Hartell et al., 1998; Jin et al., 2002; Smale and Olwande, 2011b, 2014). The optimal rate of varietal turnover is generally achieved when the weighted average age of the variety is less than 10 years and the adoption rate is more than 35% (Walker and Alwang, 2015Chp. 5). Such rates have been observed in for maize the USA, South Asia and America (Brennan and Byerlee, 1991; Brooks, 2009; Mason and Ricker-Gilbert, 2013). In Sub Saharan Africa (SSA) the rate of varietal turnover is, however, much lower (Abate et al., 2017). While in Kenya the weighted average age of maize varieties has been declining, it is still above 10 years (Abate et al., 2017; Naseem et al., 2018; Smale and Olwande, 2014). While a number of studies as discussed above have shown that varietal turnover increases yields, the effect on food security has not yet been explored. Furthermore, following the liberalization of agricultural markets, the proportion of maize area under public or privately released varieties has not yet been documented.

The specific objectives of this paper are to analyze i) the trends in the adoption of improved maize varieties over the last decade and the factors that drive the adoption; ii) the effect of the liberalization on the private sector's share in the seed market. iii) the trends in age of maize varieties and varietal turnover and their factors; iv) the effect of varietal age, among other factors, on maize yield and on food security.

This study aims at providing critical information to policy makers on whether continued research and development in relation to varietal releases has sustained impacts on farm productivity and food security. The vibrant seed development industry in Kenya has grown immensely over the years (Abate et al., 2017; Naseem et al., 2018; Smale and Jayne, 2003) and this provides a good case study to explore the issue of varietal development and release in the maize sector.

2. Methodology

2.1. Conceptual framework

Improved maize varieties are developed and bred to enhance yields and overcome various environmental stresses that limit productivity (Evenson and Gollin, 2002; Walker and Alwang, 2015). Farmers who adopt improved maize varieties are likely to have higher yields and a higher production more than non-adopters. We hypothesize that adoption of improved maize varieties is a function of social, institutional, geographic and climatic factors. Social factors include age, education, household size, land area and gender. Institutional factors include access to credit, extension services and farming groups. Geographic and climatic factors include agroecological zone, precipitation, elevation. Households with educated members and have access to institutional factors such as credit and extensions are more likely to adopt improved varieties (Jaleta et al., 2018; Ouma and De Groote, 2011). Households with larger tracts of land are more likely to adopt improved varieties (Wondale et al., 2016). Geographical factors are an important determinant of the adoption of technologies such as improved maize varieties (Kaguongo et al., 2012; Njagi et al., 2017).

The process of varietal turnover an important aspect of keeping food production in line with population growth. The varietal turnover rate provides information to plant breeders on the success of their breeding programs. Farmers replace varieties to obtain the advantages of improved genetics associated with newer varieties (Spielman and Smale, 2017). We posit that the rate of variety replacement/turnover is a function of socioeconomic, institutional, geographical and climatic factors. Farmers with longer experience have been found to continuously grow older varieties (Smale and Olwande, 2011a). Access to extension services has been shown to have a positive association with varietal replacement (Jamison and Lau, 1982). Households owning larger tracts of land have been found to grow younger varieties (Smale et al., 2011).

Varietal turnover is expected to increase yields, as recent varieties tend to be higher yielding (Atlin et al., 2017),and therefore improving household food security. We hypothesize therefore that maize yield and household food security are a function of varietal turnover, expressed as weighted average varietal age of maize grown (Hartell et al., 1998; Jin et al., 2002; Smale et al., 2008).

2.2. Data Collection

CIMMYT (International Maize and Wheat Improvement Center), in collaboration with its partner KARI (Kenya Agricultural Research Institute) now known as KALRO (Kenya Agricultural and Livestock Research Organization) conducted four representative household surveys 1992, 2002, 2010 and 2013, with total of 5730 maize growing households. All surveys had the same two-stage stratified sampling design, with sublocations as primary sampling units, households as secondary sampling unites, and the six maize production or agroecological zones as strata. These zones are, going from East to West : Coastal Lowlands, Dry Mid-Altitude, Dry Transitional, Moist Transitional, High Tropics and Moist-Mid Altitude zones (R. M. Hassan et al., 1998). The 2010 and 2013 are a panel data set consisting of information collected from the same households, with 20% replacement.

The 1992 survey was conducted by CIMMYT and KARI covering 79 clusters totaling 1397 farmers (Hassan et al., 1998). The 2002 survey covered 185 locations based on the 1999 census, a total of 1652 farmers (H. De Groote et al., 2005). The 2010 survey covered 120 sublocations interviewing 1341 farmers while the 2012 survey interviewed the same farmers sampled in 2010 though with a replacement of 20% of randomly sampled households (Wainaina et al., 2016).

Data sets collected across the six defined agroecological zones focused on maize farmers. The data collected consisted of various modules that include: socio-economic characteristics of households, climate change, social capital, improved maize knowledge and adoption, maize production, production of other crops, storage practices, livestock production, access to institutional factors and household food security.

2.3.Empirical framework

The methodological framework in this study is based on the four objectives mentioned under the introduction section. For the first objective examining the determinants of improved maize varieties we employ a random effects probit regression model, with a binary dependent variable indicating adoption of IMV or not. The independent variables include characteristics of the household head (age, gender, number of household members, and education), farm household characteristics (land owned, sale of maize), institutional variables (access to credit, extension, and markets) and geographic factors (elevation, precipitation, and agroecological zone). This is specified by the following regression function:

$$\Pr(S_i = 1) = pr(S_i^* > 0) = 1 - F(-\beta X_i) \tag{1}$$

Where S_i is a binary indicator variable that takes a value of 1 if household adopts an improved maize variety and 0 if otherwise, β is a vector of parameters to be estimated, X is a vector of explanatory variables while ε is the error term. F is the cumulative distribution function for ε_i and is assumed to be a logistic distribution for the logit model or normal distribution for probit model.

The second objective examines the trend in age of maize varieties and varietal turnover. The dependent variable is varietal turnover, measured as weighted average age. This can be expressed as (Brennan and Byerlee, 1991):

$$WA_t = \sum_i p_{it} R_{it} \tag{2}$$

Where WA_t is the weighted average age/variety age, p_{it} is the proportion of area sown to variety *i* in year t, R_{it} is the number of years at time *t* since the release of variety *i*. The independent variables include age, gender, number of households, education, land owned, credit, extension, sale of maize, elevation, precipitation, AEZ. We employ a random effects linear regression function specified as (Schunck, 2013):

$$WA_{it} = \beta_0 + \beta_1 M_{it} + \beta_2 C_{it} + \mu_{it} + \epsilon_{it} \tag{3}$$

Where WA_{it} is the weighted average age at each time period (t), β_0 is the intercept, β_1 and β_2 are regression coefficients, M_{it} is a vector of time varying variables, C_{it} is a vector of time invariant variables, μ_{it} is the error term..

The third objective examines the effect of varietal turnover on yield. We first analyze the correlation between the weighted average age and maize yield, followed by a random effects linear regression model. We further explore crosseffects between weighted average with fertilizer and agroecological zones (AEZ) and how these independent variables affect yields. This can be specified as:

$$Y_{it} = \beta_0 + \beta_1 X + \beta_2 F + \beta_3 XF + \beta_4 XFAEZ + \mu_{it} \quad (4)$$

where Y_{it} is yield (kg/ha) β_0 is the intercept, β_1,β_2 , β_3 and β_4 are regression coefficients, X is weighted average age, F is fertilizer quantity, AEZ is agroecological zone and μ_{it} is the error term.

For the fourth objective we explore the effect of effect of varietal turnover on food security, but taking into account other factors, in particular fertilizer. We further examine the cross effect between weighted average age and fertilizer on food security. The dependent variable is food security measured using the HFIAS (Household Food Insecurity Access Scale) developed by Coates et al. (2007). The HFIAS is measured by asking nine occurrence questions, representing an increasing level of food insecurity, as well as nine frequency questions, inquiring on the frequency of the condition over a 30 day period, leading to a score of 0 (no food insecurity) to a maximum of 27 (Coates et al., 2007). The explanatory variables are weighted average varietal age, fertilizer quantity(kg/ha) , age, gender, number of households, education, land owned, credit, extension, sale of maize, elevation, precipitation and Agroecological zone. We use a random effects linear regression model specified as:

$$FS_{it} = \beta_0 + \beta_1 X + \beta_2 M_{it} + \beta_3 F + \beta_4 XF + \beta_5 C_{it} + \mu_{it} \quad (5)$$

Where FS_{it} is the household food insecurity score, β_1,β_2 , β_3, β_4 and β_5 are regression coefficients, X is weighted average age/variety age, M_{it} is vector of time varying variables, F is fertilizer quantity, XF is the crosseffects between weighted average age and fertilizer, C_{it} is a vector of time invariant variables and μ_{it} is the error term.

3. Results

3.1. Descriptive statistics of participating farmers

Several changes in the characteristics of the households over time can be observed. The average age of the household head reduced from an average of 49 years in 1992 to 33 years in 2013 (Table 2). The average number of household members also reduced, from an average of 7 to 6 in 2013. There has been an increased access to institutional and infrastructural support services across the years, in particular in terms of access to credit and extension services, as well as in better access to markets. Overall the average maize area has reduced corresponding to decreased yield levels between 1992 and 2013. There has been a marginal increase in the proportion of households engaged in sale of maize produce.

[Table 1]

3.2. Adoption of improved maize varieties

The proportion of farmers who adopted IMVs (improved maize varieties) increased over time, but only slightly, from 72% to 79% over the survey years, from 1992 to 2013 (Figure 2A). However, the adoption rates in the first three surveys were nearly the same, so the small increase was only realized between the last two survey, 2010 to 2013.

The analysis also shows how adoption rates differ substantially between the different agroecological zones (AEZs), with a clear increase of adoption along a gradient from low to high potential zones. The highest adoption rates are found in the high potential areas such as the moist-transitional and high tropics, where almost all farmers (89%) had adopted IMVs by 2013. In the medium-potential areas, the results vary from high in the dry transitional zone (77%) to medium in the moist mid-altitudes (64%). Adoption rates are, understandably, lower in the low-potential areas, but still about two thirds of farmers adopted IMVs at the coastal lowland (64%) and the dry mid-altitudes (71%).

The adoption trends also varied between the zones, although the differences between years are small in comparison to the standard errors. The high potential areas saw a small increase in adoption rates over the study period; the trend was clearly more visible in the high tropics, while in the moist transitional zone a dip was observed in 2010 (Figure 2A). In the medium-potential areas, there was a clear increase in adoption in the dry transitional areas (35% to a high of 77% in 2010), while the moist mid-altitudes experienced a gradual decrease over the first three surveys, to peak up again in 2013 (to 64% from 37% in 2010). While in the dry mid-altitude adoption dropped in the second survey and remained at a similar level in the subsequent surveys.

[Figure 2A]

Next, the factors affecting the adoption of improved maize varieties in Kenya were analyzed using a random effects probit model, using all four surveys (Table 2). Both household and institutional characteristics were found to influence adoption. The household characteristics that increased adoption of improved maize varieties were education level (each year increased the probability by 0.8%), household size (0.6% for each extra member) land owned (2.2% for each ha) and if the household sold maize (4% more). Gender of the household head did not significantly affect adoption. Among institutional factors, access to extension services increased the adoption rate by 5%, but access to credit and distance to the market had no effect. There were also substantial differences between AEZs, with farmers located in the zones with higher potential more likely to adopt improved maize varieties as compared to those in areas with lower potential.

[Table 2]

3.3.Trends in percentage of area under improved maize varieties

Next, we analyze the trends in percentage of area under IMVs for the four surveys in the same way, with descriptive statistics first, followed by regression. When graphing the trend shows, overall, a small decline in the average area under improved varieties between 1992 and 2013, from 81% to 78% (Figure 2B). However, over the same period of time there is first a substantial drop in adoption area under IMVs in 2002 (58%), which then increases in 2010 (to 64%) to only reach the 1992 levels in 2013. The area under IMVs also differs across the agroecological zones. As with adoption rates, adoption intensity is higher in the high potential areas, where almost all maize area is under improved varieties as seen in the last survey (90% in the moist traditional and 89% in the high tropics). While in the dry transitional there is a general increase in the area under improved varieties, this is more evident in the dry transitional zone with an increase from 36% in 1992 to 75% in 2013. In the low potential zones, adoption rates in the last survey were slightly higher in the coastal lowland (61%) compared to the dry mid altitude (58%).

[Figure 2B]

3.4.Sources of improved maize varieties

We analyze the trends in percentage area under varieties in function of their origin (Figure 3). In 1992, the old varieties from the KARI/KSC were still dominating, taking half of the market (50%), while local varieties had already been pushed back to only 30%. By now, KSC had started developing their own varieties, which had a market share of 22%. The results from 2002 showed that the liberalization disturbed the markets, as new players had come in but could not immediately replace the old production and distribution channels (Figure 3). The proportion in old varieties remained the same, but the proportion in local varieties increased. As a result, the share of old KARI/KSC varieties remained the same, the share of the new KSC varieties actually decreased (to 12%), but the proportion in local varieties increased, private companies just barely participated. Private sector varieties picked up in 2010, but the share remained relatively small (7%) and consisted mostly of multinational companies.

The share of old KARI/KSC varieties was now reduced to 30%, while the share of new KSC varieties increased to 25%. In 2013, finally, the share of old KARI/KSC remained at 31%, but KSC managed to increase the share of its new varieties to 29%, while the private sector increased its share to 15% (still mostly international). The share of local varieties was substantially reduced, to 24%. Note that the old KARI/KSC were still distributed by KSC, as KARI was legally not allowed to license them to other seed companies, so KSC actually still covered a whopping 60% of the market (Figure 3). KARI, on the other hand, started developing its own varieties, which they either released themselves, or passed them on to local private seed companies to be released under their name. However, the share of both types of varieties remained very, very small.

[Figure 3]

Conducting the same analysis for the different agroecological zones shows clear differences in transition from private to public maize varieties over time (Figure 4). Sorting the zones by their agricultural potential shows a striking resemblance between the lowest potential zone (the coast) and the highest potential zone, the highlands: neither have any meaningful contribution of the private sector in the seed business. At the coast, the share of local varieties has been reduced but still covers half of all seed. Further, the old improved OPV (coastal composite mostly) have been replaced by KSC hybrids specifically developed for this region, as the old improved OPVs are no longer on the market. The private sector, on the other hand, has not really entered this market, as it does not have hybrids adapted for this zone, leaving KSC with a de facto monopoly in IMVs.

In the highlands, similarly, the private sector is not to be seen, and for the same reason: they do not have appropriate varieties, in this case late-maturing varieties adapted to this zone. The highlands have the highest adoption rate in IMVs, as expected in this high-potential zone, it also has the highest share in old KARI/KSC varieties, in particular H614 (from 1986) that covers a remarkable 40% variety share (see SM2 for individual varieties). KSC also made inroads with its new varieties in this zone, but their eight new varieties together still only cover 38%, less than H614.

The other high potential zone, the moist mid-altitudes, shows a similar pattern, with old KSC/KARI varieties (35%) and new KSC varieties (34%) dominating. Here, the private sector did somewhat better (with 19% market share), because they offer many medium-maturing maize varieties suitable for this zone. Moreover, in this zone national seed companies reached their highest market share, albeit still only 8% while there are hardly any the dry mid-altitudes, suffered from the liberalization and a large increase in local varieties' share. But KSC came back with dryland hybrids and so did the private sectors (Figure 4).

The private sector made most progress in the drylands, especially in the dry transitional zone (with an impressive 58%) but also in the low-potential dry mid-altitudes (30%). The share is uniquely by multinationals, who seem to have well-adapted and popular varieties. KSC also has replaced most of the old KARI/KSC varieties, which were mostly OPVs, with new drought tolerant hybrids (with only the old workhorse Katumani Composite remaining, with 8% in the dry mid-altitudes), The moist-midaltitude, finally, the private sector has made good progress, with a market share of 26%, but almost all from multinational companies.

[Figure 4]

3.5.Trends in varietal age

In this section we calculated the weighted average age for all varieties (both improved and local) and for improved varieties only (Figure 5). The weighted average age of a crop variety is an inverse indicator of the speed of variety change/replacement. The average age of all maize varieties increased between 1992 and 2010, from 20 to 35 years, and only dropped by 2013, to 30 years. The main causes are a limited increase in improved varieties, and a limited turnover in improved varieties, causing the average age of improved varieties to increase. Only between the last two surveys did the average age of improved varieties not increase, but stayed stagnant at 20 years.

[Figure 5]

The weighted average age of maize varieties also differed across the agroecological zones (Figure 6). Sorting the zones by their agricultural potential, there is a drop in the average age of all varieties except for the coastal area where it remains stagnant in both 2010 and 2013. We see a slight increase in the age of IMVs in the high tropics between 2010 and 2013. Conversely in the medium potential areas, there is a noticeable drop in the age of IMVs in the dry transitional between 2010 and 2013. The drop is observed in the dry mid-altitudes as well but not that much. Additionally, there is a remarkable increase in the age of IMVs grown in the coastal lowland and high tropics between 2002 and 2013, while the change is similar in the moist transitional zone, it is not that large over the same period (Figure 6).

[Figure 6]

3.6.Relationship between varietal age and maize yields

Correlation analysis showed a significant negative but weak correlation between average varietal age and yield over all study years (Table 3). The correlation is stronger with age of all varieties (0.20 for the pooled data), compared to that of only improved varieties (0.072).Similar results are found for all individual years, except for IMVs in 2013. The results indicate younger varieties are associated with higher yields.

[Table 3]

Regression analysis of maize yield over average varietal age shows that younger varieties have higher yields (Table 4). In the basic model, yield increases by 7 kg/ha for each reduction of varietal age by one year. Of course, other factors also matter, in particular fertilizer, and these are correlated ($r = -0.18$, $p < 0.001$), and there could be a general trend. In the long model, incorporating these factors, the effect of varietal age is slightly less, at -4 kg/ha for each year. Moreover, as expected, fertilizer also increases yields, by 5 kg/ha for each kg of fertilizer, while the cross effect is significant and negative implying that fertilizer use has more effect on younger varieties.

[Table 4]

To analyze the differences between agroecological zones, we add zones as main effects, as well as with cross-effects with varietal age and fertilizer (Table 5). We find that, as expected, yields differ strongly between AEZs, with higher potential zones having higher yields. However, the interactions of varietal age with zones are not significant, indicating the effect of varietal age does not differ between zones. The effect of fertilizer, on the other hand, significantly differs between zones, with higher potential areas having higher yields compared to the coastal zone, which is the base category.

[Table 5]

3.7.Determinants of weighted average age

We analyzed the factors affecting weighted average age of the maize varieties at the household level (Table 6). The demographic characteristics of the head of the household clearly matter: male heads and older heads tend to grow older varieties, while heads with more education tend to grow younger varieties. The maize varieties in male headed households are on average 2.4 years older than in female headed households. The farm household also matters: larger households tend to grow younger varieties, but those with large farms grow older varieties.

Market orientation is a major determinant: households selling maize grow varieties that are more than 3 years younger. Note that market participation increased from 20% in 1992 to 49% in 2013, but this is still low. Institutional factors also make a difference: varieties of household with access to credit are, on average 2 years younger; but the most important factor is access to extension, which reduces varietal age by a remarkable 12 years.

The seed source is also an important factor, varieties from privately owned organizations reduce the varietal age by 22 years. Distance to the market, on the other hand, did not affect varietal age. Agroecological zone, finally, also matters, with high potential areas growing younger varieties (and more improved) while low potential areas growing older varieties in comparison to coastal lowland.

3.8.Determinants of household food security

Finally, we analyze the effect of varietal age and other factors on household food security (Table 7). Both the use of younger varieties and of fertilizer decrease household food insecurity, however, the effects are significant but small. In the short model, a reduction of varietal age of 10 years would only decrease the index by 0.2. Similarly, adding 100 kg/ha of fertilizer only reduces the index by 0.7.

We therefore explore which other factors can be identified. Demographics of the household head are important: households with male heads, as well as those with younger and more educated household heads, tend to have less food insecurity. Larger households tend to be more food insecure, but those with more land less. Market orientation is also important: households that sell maize are less food insecure, as do those with access to credit. Other institutional factors did not seem to have a significant effect.

The agroecological zone also affects food security. In comparison to households located in the coastal zone, households in the dry mid-altitudes are more food insecure, while those in the high tropics are food secure.

[Table 7]

4. Discussion

The results from the analysis of trends of four household surveys show that the adoption of improved maize varieties has increased, but only slightly. While the rates differ across AEZs, the adoption rates are consistently high in both the high potential areas (moist transitional and high tropics) with the other zones also showing increased adoption of improved varieties. This increase could possibly be due to the development of the seed distribution system (Sheahan and Barrett, 2017).

The factors we found affecting the adoption of improved varieties are also found in other studies, in particular, education and access to extension services, previously observed in Kenya (Ouma and De Groote (2011) and Jaleta et al. (2018) also found in Ethiopia, have been found to positively influence adoption of improved varieties. Farm size was found to be an important factor influencing adoption of improved varieties by Wondale et al. (2016) in Ethiopia. Mabe et al. (2018) found that commercially oriented farmers are more likely to adopt improved rice varieties in Ghana. Larger, commercially oriented farmers understand the benefits of new varieties, for example high-yielding characteristic thus increasing the adoption probability (Feder et al., 1985). In contrast to the percentage of farmers adopting improved varieties, the area percentage under improved maize varieties has declined slightly, with the highest percentage being in the moist transitional and high tropics.

Within the medium and low potential areas, there is a noticeable increase in area under improved varieties though local varieties still account for a significant area under maize. Two possible hypotheses could possibly explain why farmers combine both improved and local varieties. The safety first model postulates that farmers constrained with meeting their subsistence needs may choose crop combinations that diverge from those linked to profit maximization (Smale et al., 1994). Secondly, in the portfolio selection theory, risk averse farmers can choose to maximize their returns or reduce the variance on overall returns by selection a combination of varieties (Barkley et al., 2010). We also find that there has been a minimal adoption of varieties from private organizations as those from public sector still dominate.

Our results with higher adoption rates in high potential areas of Kenya are also found by Gitonga and De Groote (2016) and Smale and Olwande (2014). Our finding that improved varieties occupy much of the area under maize in Kenya agree with other results, from two surveys (Abate et al., 2017; Smale et al., 2011). While our findings show that the adoption of improved maize varieties has increased though marginally, studies on fertilizer usage in Kenya (Jena et al., 2020; Smale et al., 2011) come to a similar conclusion that application rates have not increased significantly.

Our findings show that generally, the old KARI/KSC varieties still dominate much of the maize area with newer KSC varieties also increasingly covering the area especially in the last three surveys. Considering that KSC has license rights to varieties released in collaboration with KARI, it is quite evident that KSC is the main key player in the seed market. The finding of KSC domination agrees with Nagarajan et al. (2019) and Smale and Olwande (2014). The popularity of KSC varieties can further be attributed to their low costs despite of packaging, sales location and development of varieties targeted for high potential areas (Nambiro et al., 2001). On the other hand, our results show that multinational private released varieties occupy much area in the dry transitional and dry mid-altitude compared to the high potential areas. the KSC (Kenya Seed Company) still dominates as shown by area under maize varieties especially in the high potential areas. The area under local private organizations has not much increased over the years. This could be attributed to the investment costs in continuously developing and releasing new varieties (Naseem et al., 2018).

We found that the weighted average age of all varieties increased over the survey period, except for 2013 where it dropped. While for improved varieties it remained stagnant in the last two surveys. This could imply that there was some level of varietal replacement in relation to all varieties and that the same varieties were grown during the last two surveys, both suggesting slow varietal turnover rates. A number of hypotheses could possibly explain the slow variety turnover rate. First, there is limited degree of crop commercialization as the system is characterized by limited market linkages and production is mainly for subsistence needs (Spielman and Smale, 2017) . Secondly, is that newer released varieties are having a hard time competing with older released varieties (Walker and Alwang, 2015, p. Chp 3 p.34).

Our finding relating to the age of all maize varieties in Kenya (30 years) is similar to that in East and Southern Africa (31 years) reported in Walker and Alwang (2015, p. 66). Conversely, the result on the average age of improved varieties is higher (20 years) than found in previous studies, Abate et al. (2017) at 13 years, Smale and Olwande (2011a) at 16 years and Walker and Alwang (2015, p. 66) at 15 years. However findings by Abate et al. (2017) and Smale and Olwande (2011a) were based on the main cropping season while Walker and Alwang (2015, p. 66) estimates the varietal age of 10 countries.

In contrast, Brooks (2009) as cited in Atlin et al. (2017) notes that the average age of maize varieties is 3 to 4 years in the United States. The authors attribute this to the rapid replacement model characterized by the existence of a competitive seed market sector coupled with highly commercialized farmers. The varietal turnover for maize in various parts of Brazil, Argentina and Mexico ranges from 3-4 years in the tropics and 5-7 years in the subtropics (Mason and Ricker-Gilbert, 2013).

Our finding on the negative correlation between varietal age and yield agrees with Smale and Olwande (2014) who found out that yields are negatively correlated with maize yields in Kenya. Smale and Olwande (2014) linked the negative correlation between varietal age and yield to the yield advantage of older varieties which are late maturing and thus high yielding and this is in line with Naseem et al. (2018). The finding of Naseem et al. (2018) was based on regressing the effect of number of varieties released on yield rather than average age. Smale and Olwande (2014), on the other hand, used the year in which a variety was released to examine the relationship with yield.

We showed that reducing varietal age increases yields while crosseffects with fertilizer had an effect on younger varieties. Furthermore, we found out that the interaction between varietal age and AEZ had no effect on yield, but the interaction between fertilizer and AEZ had a significant effect on yields. Our finding that the reduction of varietal age is positively associated with yields agree with other surveys. The first study conducted in 1998 in Pakistan using a productivity model found negative effects of increased varietal age on wheat yield (Hartell et al., 1998).

In the second study, data conducted in 2002 and covering the period 1982 to 1995 in China found significant effects of varietal turnover on total factor productivity for wheat (Jin et al., 2002). In a third study in Punjab in India, Smale et al. (2008) established that slow variety change in farmer fields was associated with partial yield losses.

We established that age, gender and land size are associated with growing older varieties. Older farmers are more likely to continue growing older varieties and this could be attributed to their long farming experience in terms of cultivating the same varieties over a long period of time (Jamison and Lau, 1982). Our finding that households with large tracts of land are positively associated with older varieties contradicts with Smale and Olwande (2011a). Their study evaluating maize hybrid change in Kenya found that larger commercially oriented farmers are able to keep up with the latest releases.

Households with higher education levels are more likely to understand the benefits of newer varieties while those with access to credit and extension services are at a higher likelihood of replacing older varieties. Extension services offer a critical platform on informing farmers about recently released varieties while credit in terms of capital needed to purchase newly released varietal seed positively increases varietal replacement (Naseem et al., 2018; Walker and Alwang, 2015). Households engaged in sale of maize are likely to grow younger varieties. This could possibly be due to the yield advantage of newly released varieties (Atlin et al., 2017; Spielman and Smale, 2017) that would allow households to increase their sales volume.

We established that households who grow privately released varieties tend to grow younger varieties compared to growing public released varieties. This could possibly be due to the production of medium maturing varieties and that these private companies produce varieties that are ten years or younger (Rutsaert and Donovan, 2020).

Our findings show that varietal age and fertilizer reduce food insecurity. With increased yields, households are able to improve their food security situation. Through continuous varietal replacement, farmers are able to grow improved cultivars that are tolerant and have higher yield capacity compared to older varieties (Atlin et al., 2017). Food insecurity is found to be a decreasing function of age, education, land, gender, maize sales, access to credit and extension services.

On the other hand, food insecurity is associated with large family sizes and households located in the dry mid-altitude zone. While there is limited empirical evidence to compare our finding on the potential of younger varieties to reduce food insecurity, Atlin et al. (2017) discusses the relationship between climate change and reduced maize yields. Our result can be explained in the perspective that older varieties are more susceptible to stress tolerance and diseases resulting in reduced yields (Atlin et al., 2017; Brennan and Byerlee, 1991).

While our study offers insights into the topic of variety turnover and its effects, a few limitations were encountered during the study. First, we used a panel data set that was collected from different sources, with only the last two rounds in the same households. Second, we only used the last two rounds, with a shorter time period to examine the effect of varietal turnover on food security. The use of a longer panel data from the same sources would help provide better estimates and results of the effect of varietal turnover on welfare outcomes.

5. Conclusion

Findings from the study confirm that Kenya has made some progress in increasing adoption of improved maize varieties and that varietal age has an effect on yield and food security. Despite the link of varietal age with increased yields and food security, varietal turnover remains low. Despite the agricultural liberalization, our finding that KSC released varieties still dominate implies that the seed market still faces various challenges in terms of providing a conducive environment for increased private sector involvement. The need for increased private sector development is based on the finding that households growing privately released varieties tend to grow younger varieties. We establish that education, credit, and extension services are positively associated with varietal turnover. This implies that education and extension services enhance the awareness of information on newly released varieties, while credit access enables households to purchase the varieties as inputs.

From the above discussions, we draw two policy recommendations. First, a policy framework is needed to improve the market environment for increased private sector participation. Thus can be achieved by strengthening the existing distribution networks to enable the private sector penetration across the different agroecological zones. Such a policy would lead to a robust competitive seed industry.

Secondly, there is need for an efficient and effective dissemination system through public-private partnerships. The public sector through the government can offer facilitation through legal and institutional mechanisms such as information on new varieties through extension services while the private sector invests in development of quality seed, marketing and distribution. Furthermore, through public-private involvement of providing credit facilities for the purchase of newly released varieties as inputs in production, the varietal turnover rate would increase.

Our findings confirmed previous studies conducted in SSA countries are characterized by low varietal turnover (Abate et al., 2017; Smale et al., 2011; Walker and Alwang, 2015). Therefore, based on our recommendations there is need for concerted efforts towards strengthening public-private partnerships to help bridge the gap between crop breeding programs and outreach to farmers. This will turn progressively help improve varietal turnover rates in the long run.

Future research could explore the link between the traits of different varieties and their effect on varietal turnover.

Table 1. Descriptive statistics of participating farmers

Variable	Year of survey							
	1992		2002		2010		2013	
	Mean	Std Err	Mean	Std Err.	Mean	Std Err.	Mean	Std. Err
Age of household head (years)	48.74	0.420	47.9	0.387	52.55	0.418	33.07	0.609
Household size(number of members)	7.15	0.117	7.52	0.109	6.12	0.074	6.46	0.070
Distance to the nearest market(km)	8.69	0.367	7.53	0.345	2.04	0.175	1.81	0.161
Household head education(years)	4.81	0.113	4.77	0.108	7.09	0.118	7.72	0.122
Access to credit (1=yes:0=no)	0.18	0.010	0.18	0.010	0.47	0.014	0.54	0.014
Access to extension services (1=yes:0=no)	0.41	0.013	0.35	0.012	0.19	0.011	0.85	0.010
Adopts improved maize variety(1=yes;0=no)	0.67	0.013	0.72	0.011	0.68	0.013	0.75	0.012
Maize area(ha)	3.62	0.547	1.67	0.062	1.2	0.042	1.54	0.062
Maize yield (kg/ha)	1498.22	39.537	1191.8	29.682	1092.93	27.006	1287.66	39.112
Uses commercial fertilizer(1=yes;0=no)	0.52	0.013	0.53	0.012	0.52	0.014	0.6	0.013
Fertilizer use intensity(kg/ha)	64.26	3.060	73.04	2.677	62.33	2.981	89.08	3.488
Sale of maize(1=yes;0=no)	0.2	0.011	0.19	0.012	0.25	0.012	0.49	0.014
N	1397		1652		1341		1340	

Table 2. Determinants of Adoption of Improved Maize Varieties (dependent variable=binary, using panel probit regression)

	Variable Description	RE Probit Model Average Marginal Effects			
		Coefficient	St. Err.	p-value	Sig.
Socioeconomic characteristics	Age of Household Head	0.000	0.00	0.166	
	Household head is male	0.013	0.013	0.353	
	Formal years of schooling of household head	0.008	0.002	0.000	***
	Number of household members	0.006	0.002	0.004	**
	Total land owned by household head	0.022	0.006	0.000	***
	Sale of maize	0.038	0.015	0.011	**
Institutional characteristics	Access to credit	0.008	0.015	0.619	
	Access to extension services	0.048	0.013	0.000	***
	Distance to the market in km	-0.004	0.005	0.47	
AEZ	Coastal lowland	0.069	0.024	0.004	**
	Dry mid altitude	0.086	0.023	0.000	***
	Dry Transitional	0.133	0.025	0.000	***
	Moist Transitional	0.289	0.019	0.000	***
	High Tropics	0.308	0.02	0.000	***
Climatic characteristics	Elevation (meters above sea level)	-0.014	0.01	0.184	
	Total precipitation (mm/year)	-0.005	0.007	0.433	
Measures of Fit	Number of Observations	4306			
	Number of groups	3370			
	Log likelihood	-2372.897			
	Wald chi2(16)	268.05			
	Prob>chi2	0.000			

***p<0.01, **p<0.05 , *p<0.1

Table 3. Correlation analysis between maize yield (kg/ha) and varietal age, both all varieties and improved varieties, in Kenya in between 1992 and 2013

Year of Survey	All Varieties[a]				Improved Varieties			
	Correlation	p-value	N	Sig.	Correlation	p-value	N	Sig.
1992	-.137**	0.000	1162	***	-.089**	.010	843	**
2002	-.232**	0.000	1360	***	-.123**	.000	1027	***
2010	-.320**	0.000	1058	***	-.114**	.001	866	***
2013	-.146**	0.000	980	***	.070*	.032	940	*
All	-.198**	0.000	4560	***	-.072**	0.000	3676	***

[a]Improved plus local varieties

***p<0.001, **p<0.01 , *p<0.05

Table 4. Effect of weighted average varietal age and fertilizer on maize yield (kg/ha) in four household surveys (1992 to 2013), using random effects model

	Model 1			Model 2		
	Coefficient	Std. Error	p-value	Coefficient	Std. Error	p-value
Variety age (years)	-6.9	0.6	0.000	-3.97	0.62	0.000
Fertilizer (kg/h)				5.05	0.25	0.000
Variety age*fertilizer				-0.02	0.01	0.001
Year of survey				-18.69	2.38	0.000
Constant	1537.9	30.5	0.000	1323.39	43.80	0.000
No. of observations	4,560			4,560		
No. of groups	3,628			3,628		
R-square	0.04			0.20		
Wald chi2(1)	21.52			971.90		
Rho	0.42			0.37		
Prob>chi2	0.000			0.000		

***p<0.01, **p<0.05 , *p<0.1

Table 5. Regression of variety age(years), fertilizer quantity (kg/ha) on maize yield (kg/ha) for the four surveys by zone (using a random effects regression)

		Coef.	St.Err.	p-value	Sig
	Variety age (years)	-1.00	1.818	0.583	
	Fertilizer (kg/h)	1.90	0.909	0.037	**
	Variety age x fertilizer	-0.01	0.006	0.171	
	Year (1992 = 1)	-7.71	2.258	0.001	***
AEZ	Dry mid altitude	72.97	125.738	0.562	
	Dry Transitional	252.48	128.465	0.049	**
	Moist Transitional	621.87	110.049	0	***
	High Tropics	1285.30	112.798	0	***
	Moist mid-altitudes	321.50	116.271	0.006	***
	Dry mid altitude x age	-0.23	2.20	0.918	
AEZ x age	Dry Transitional x age	-0.32	2.39	0.893	
	Moist Transitional x age	-1.45	2.23	0.516	
	High Tropics x age	-1.89	2.30	0.411	
	Moist mid-altitudes x age	-0.936	2.103	0.656	
	Dry mid altitude x fertilizer	-1.15	1.27	0.366	
AEZ x fertilizer	Dry Transitional x fertilizer	1.26	1.06	0.236	
	Moist Transitional x fertilizer	2.21	0.92	0.016	**
	High Tropics x fertilizer	3.14	0.95	0.001	***
	Moist mid-altitudes x fertilizer	0.036	0.975	0.97	
	Constant	625.44	95.39	0.000	***
	No. of observations	4,560			
	No. of groups	3,628			
	Overall r-squared	0.32			
	Chi-square	1960			
	Prob > chi2	0.000			

*** p<.01, ** p<.05, * p<.1

Table 6. Determinants of weighted average age (years) of maize varieties for the four surveys, using random effects regression)

Group	Variable Description	Coef.	St.Err.	p-value	Sig
Head of household	Age of household head	0.14	0.03	0.000	***
	Household head is male	2.64	0.93	0.000	***
	Formal years of schooling of household head	-0.25	0.12	0.04	**
Farm household	Number of household members	-0.43	0.14	0.000	***
	Total land owned (acres)	0.01	0	0.060	*
	Sale of maize (1=yes, 0 = no)	-2.66	1.05	0.010	**
Institutional/market characteristics	Access to credit(1=yes,0=no)	-1.93	1.08	0.070	*
	Access to extension services(1=yes.0=no)	-12.46	0.97	0.000	***
	Distance to the market in km	-0.03	0.05	0.550	
Seed source	If seed source is from private sector(1=yes,0=no)	-22.39	1.59	0.000	***
Climate	Precipitation survey year (mm)	0.001	0	0.028	**
AEZ	Dry mid altitude	20.84	2.02	0.000	***
	Dry Transitional	10.32	2.3	0.000	***
	Moist Transitional	-1.44	1.84	0.430	
	High Tropics	-8.46	1.86	0.000	***
	Moist mid-altitudes	12.62	1.92	0.000	***
	Constant	39.78	2.51	0	***
	Number of Observations	3836			
	Number of groups	2944			
	R^2	0.37			
	Wald chi2(16)	1019.77			
	Rho	0.35			
	Prob>chi2				

***p<0.01, **p<0.05 , *p<0.1

Table 7. Effect of varietal age and other factors on household food insecurity index (HFIAS), for the panel survey data of 2010 and 2013, (using random effects model)

Group	Variable Description	Coefficient	St.Err.	p-value	Sig.	RE Model Coefficient	St.Err.	p-value	Sig.
Technologies	Variety age	0.023	0.005	0	***	0.010	0.005	0.074	*
	Fertilizer (kg/ha)	-0.007	0.002	0	***	-0.003	0.002	0.078	*
	Variety age*fertilizer quantity	0	0	0.23		0.000	0.000	0.622	
Head	Age of Household Head					-0.015	0.007	0.035	**
	Household head is male					-0.806	0.292	0.006	***
	Formal years of schooling of household head					-0.351	0.035	-	***
Household	Number of household members					0.299	0.053	-	***
	Total land owned by household head					-0.171	0.042	-	***
	Sale of maize					-1.119	0.284	-	***
Institutional characteristics	Access to credit					-0.63	0.28	0.025	**
	Access to extension services					-0.22	0.31	0.487	
	Distance to the market in km					0.02	0.03	0.453	
	Total precipitation (mm/year)					0.00	0.00	0.438	
AEZ	Coastal lowland								
	Dry mid altitude					1.34	0.66	0.043	**
	Dry Transitional					-0.37	0.68	0.587	
	Moist Transitional					-0.78	0.64	0.225	
	High Tropics					-2.52	0.67	-	***
	Moist_mid_altitudes					-0.28	0.64	0.668	
	Constant	6.525	0.269	0	***	10.00	0.94	-	***
	Number of Observations	2125				1981			
	Number of groups	1111				1094			
	R^2	0.052				0.175			
	Wald chi2	91.596				365.44			
	Rho	0.25667173				0.171			
	Prob>chi2	0				0.000			

***p<0.01, **p<0.05 , *p<0.1

Figures

Figure 1. Map of the survey sites, with agroecological zones

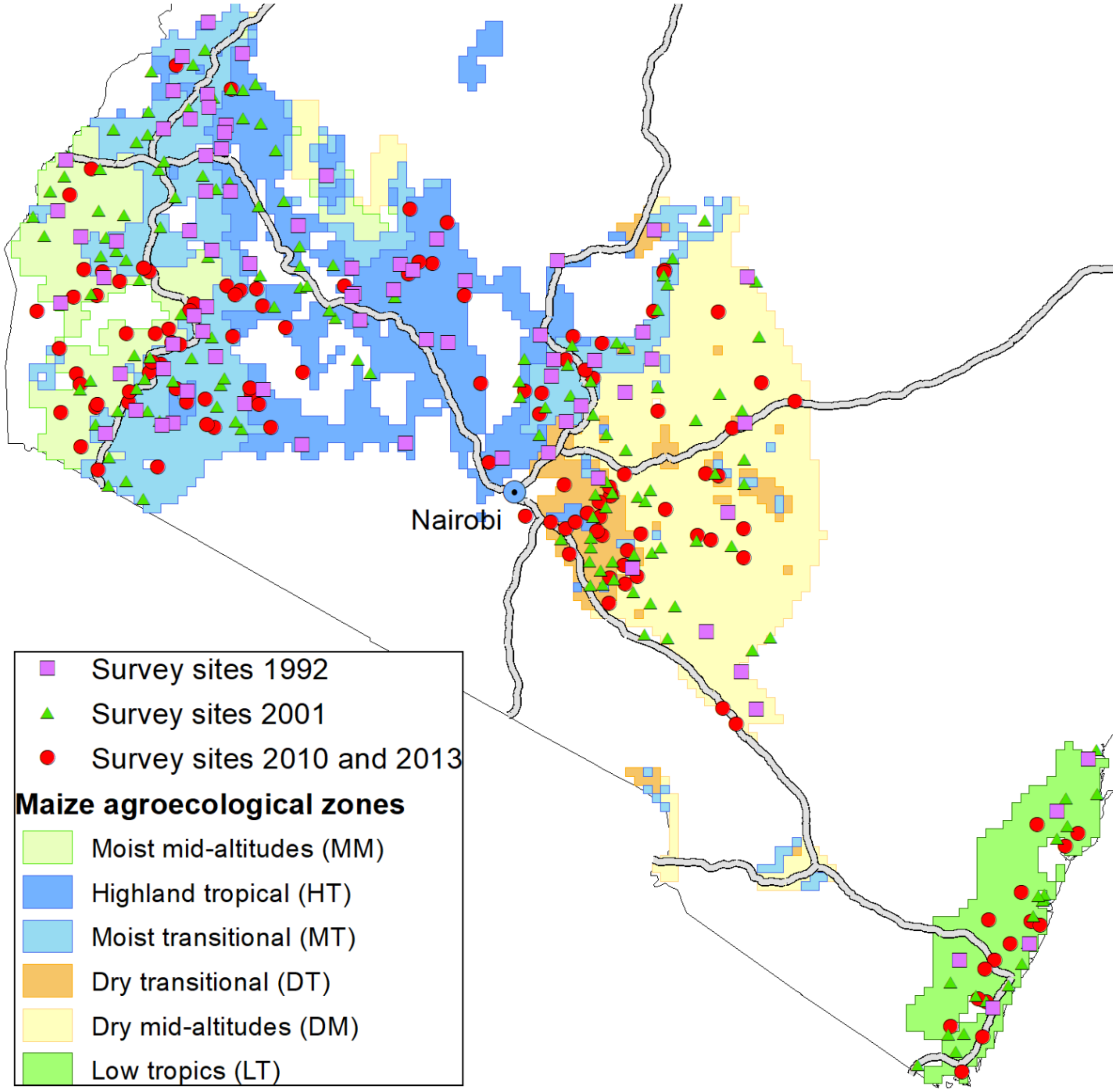


Figure 2A. Trends in the adoption of improved maize varieties in Kenya from 1992 to 2013, in adoption rate (% of farmers adopting) and adoption intensity (%are in IMV)

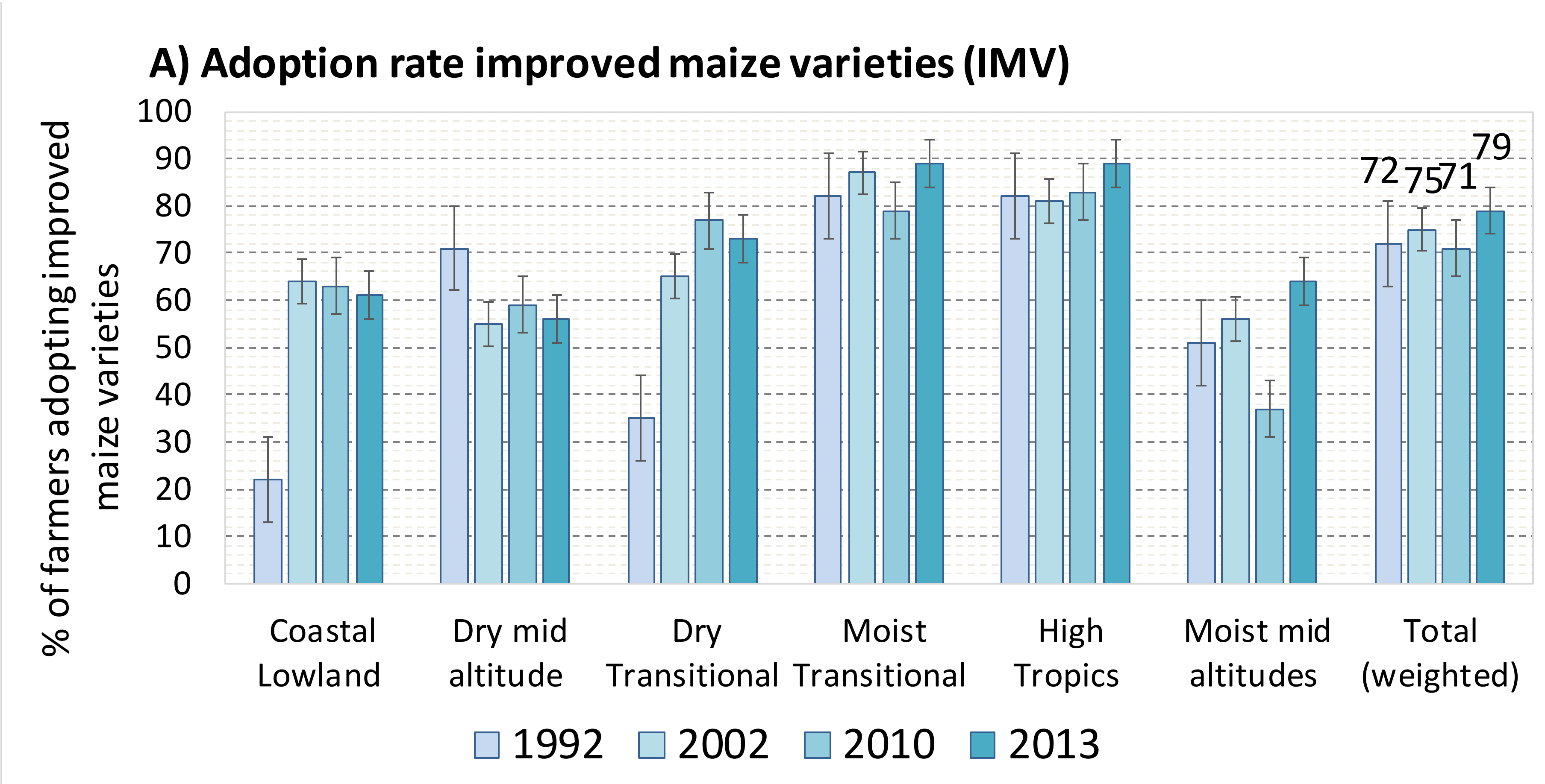


Figure 2B. Percentage of area under improved maize varieties between 1992 and 2013 (errors bars represent standard errors)

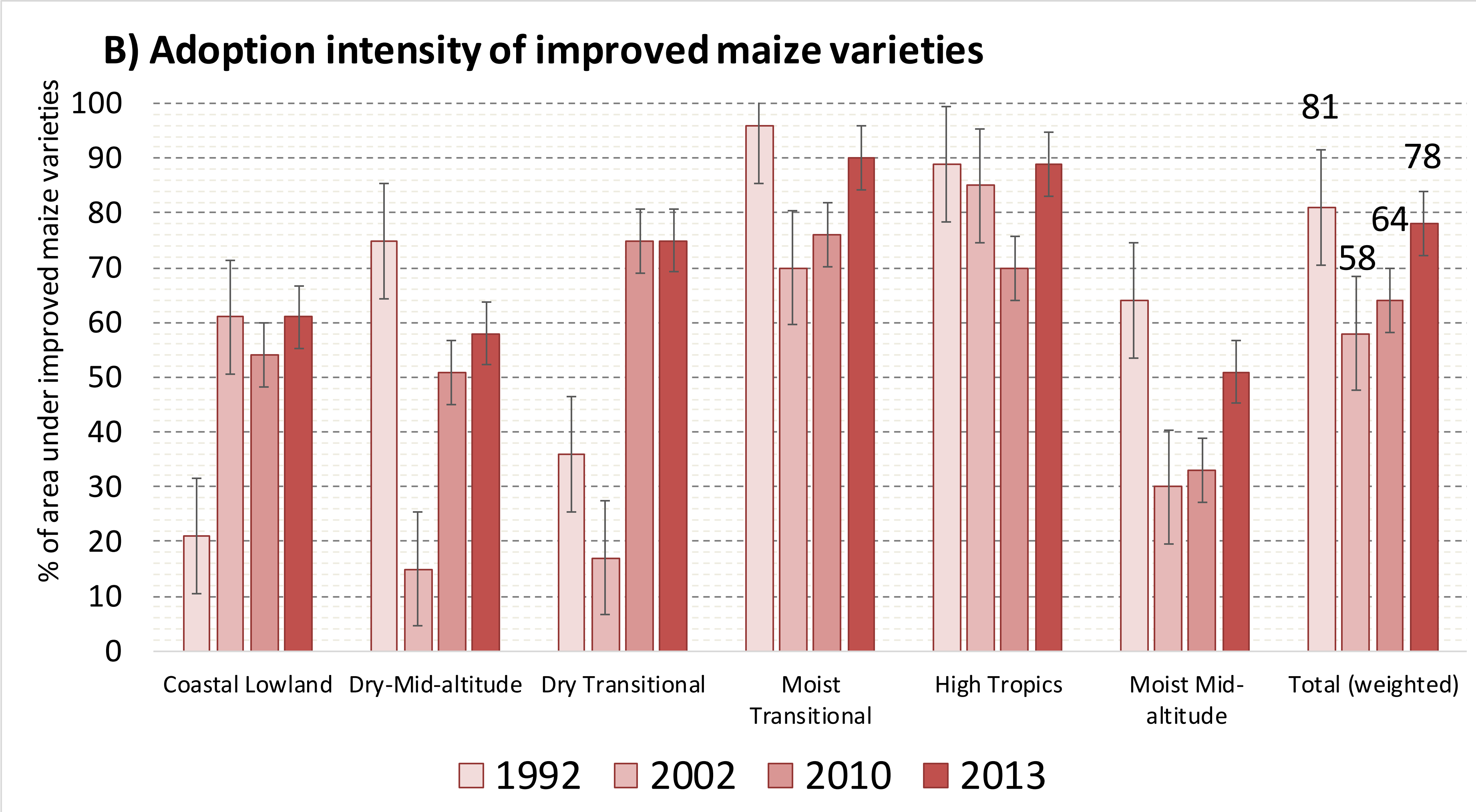


Figure 3. Market share of maize varieties by institutional origin

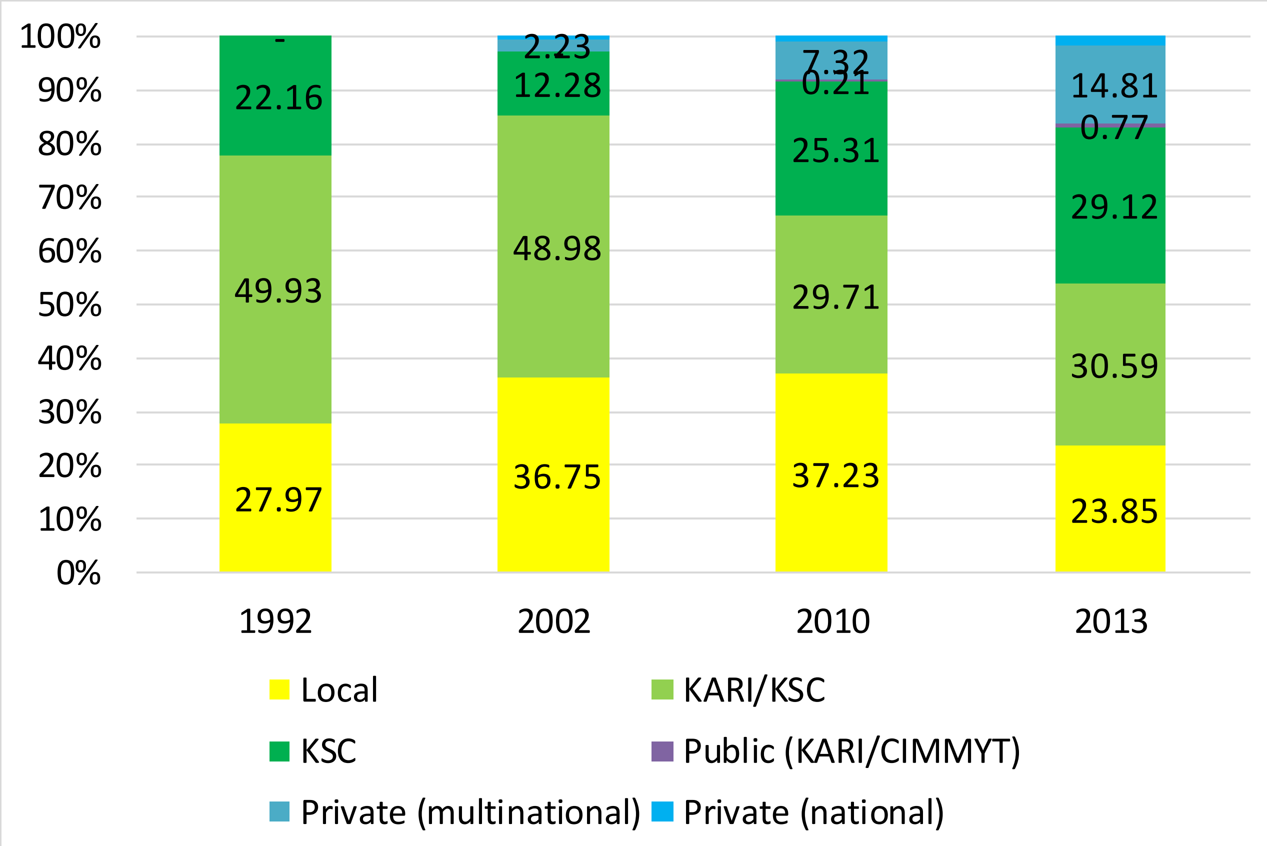


Figure 4. Market share of maize varieties by institutional origin and AEZ

Figure 5. Trends in weighted average age (years) of all maize varieties and improved maize varieties

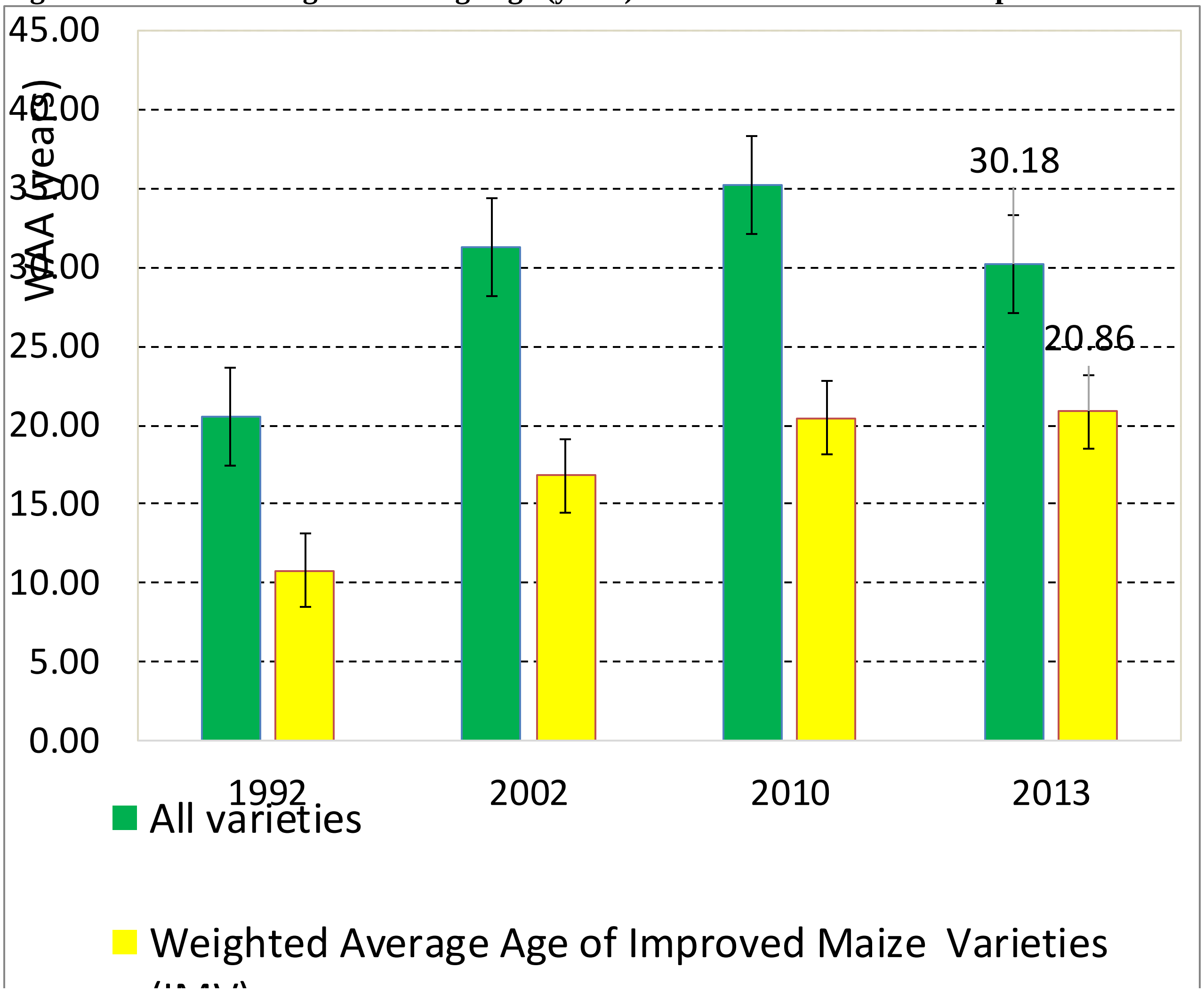
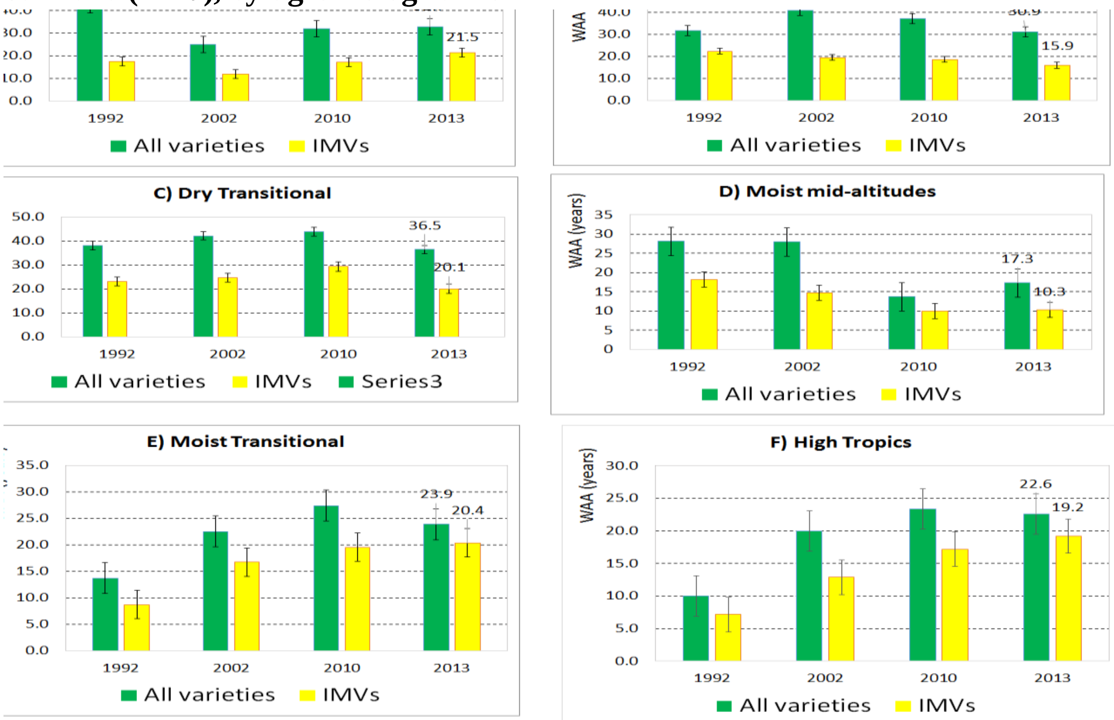


Figure 5. Trends in weighted average age (WAA, in years) of all maize varieties and of improved maize varieties (IMV), by agroecological zone



Appendix 1. List of improved maize varieties, year released, organization of origin and production

Variety Name	Variety Type	Year Released	Origin of Variety	Type of Organization Releasing	Organization Producing Variety	Type of Organization Producing Variety
H631	Hybrid	1964	KARI	Public	Kenya Seed Company	Public
H622	Hybrid	1965	Kenya Seed Company	Public	Kenya Seed Company	Public
H632	Hybrid	1965	KARI	Public	Kenya Seed Company	Public
H512	Hybrid	1967	Kenya Seed Company/ KARI	Public	Kenya Seed Company	Public
Katumani Composit	OPV	1967	KARI	Public	Kenya Seed Company	Public
H513	Hybrid	1970	Kenya Seed Company/ KARI	Public	Kenya Seed Company	Public
Coast Composite	OPV	1974	Kenya Seed Company/ KARI	Public	Kenya Seed Company	Public
H625	Hybrid	1981	KARI/ Kenya Seed Company	Public	Kenya Seed Company	Public
DLC_Makueni	OPV	1986	KARI	Public	Kenya Seed Company	Public
H511	Hybrid	1986	Kenya Seed Company/ KARI	Public	Kenya Seed Company	Public
H613	Hybrid	1986	KARI/ Kenya Seed Company	Public	Kenya Seed Company	Public
H614	Hybrid	1986	KARI/ Kenya Seed Company	Public	Kenya Seed Company	Public
H626	Hybrid	1989	KARI/ Kenya Seed Company	Public	Kenya Seed Company	Public
PH1	Hybrid	1989	Kenya Seed Company	Public	Kenya Seed Company	Public
DHO1	Hybrid	1995	Kenya Seed Company	Public	Kenya Seed Company	Public
DHO2	Hybrid	1995	Kenya Seed Company	Public	Kenya Seed Company	Public
H515	Hybrid	1995	Kenya Seed Company/ KARI	Public	Kenya Seed Company	Public
H627	Hybrid	1995	KARI/ Kenya Seed Company	Public	Kenya Seed Company	Public
Pan5195	Hybrid	1995	Pannar Seed Company	Private	Pannar Seed Company	Private
PH4	Hybrid	1995	Kenya Seed Company	Public	Kenya Seed Company	Public
PH3253	Hybrid	1996	Pioneer Hybrid	Private	Pioneer Hybrid	Private
H623	Hybrid	1999	Kenya Seed Company	Public	Kenya Seed Company	Public
H628	Hybrid	1999	Kenya Seed Company	Public	Kenya Seed Company	Public
CG4141	Hybrid	2000	Cargill	Private	Monsanto	Private
DHO3	Hybrid	2000	Kenya Seed Company	Public	Kenya Seed Company	Public
H516	Hybrid	2000	Kenya Seed Company/ KARI	Public	Kenya Seed Company	Public
H629	Hybrid	2000	Kenya Seed Company	Public	Kenya Seed Company	Public
Pan5355	Hybrid	2000	Pannar Seed Company	Private	Pannar Seed Company	Private
DHO4	Hybrid	2001	Kenya Seed Company	Public	Kenya Seed Company	Public
FaidaSeed650	Hybrid	2001	OCD (Faida Seeds)	Private	OCD (Faida Seeds)	Private
H520	Hybrid	2001	Kenya Seed Company/ KARI	Public	Kenya Seed Company	Public
H6210	Hybrid	2001	Kenya Seed Company	Public	Kenya Seed Company	Public
H6212	Hybrid	2001	Kenya Seed Company	Public	Kenya Seed Company	Public
Kh600 15A	Hybrid	2001	CIMMYT/KARI	Public	East African Seed	Public
Kh600 16A	Hybrid	2001	CIMMYT/KARI	Public	Freshco	Public
Pan67	Hybrid	2001	Pannar Seed Company	Private	Pannar Seed Company	Private
Pan691	Hybrid	2001	Pannar Seed Company	Private	Pannar Seed Company	Private
H6213	Hybrid	2002	Kenya Seed Company	Public	Kenya Seed Company	Public
MasenoDC	OPV	2002	Lagrotech Seed Company	Private	Lagrotech Seed Company	Private
Pioneer	Hybrid	2002	Pioneer Hybrid	Private	Pioneer Hybrid	Private
DK8031	Hybrid	2003	Monsanto	Private	Monsanto	Private
DK8071	Hybrid	2003	Monsanto	Private	Monsanto	Private
H611	Hybrid	2003	KARI/ Kenya Seed Company	Public	Kenya Seed Company	Public
WS403	OPV	2003	CIMMYT	Public	Western Seed Company	Private
WS502	OPV	2003	CIMMYT	Public	Western Seed Company	Private
WS505	OPV	2003	CIMMYT	Public	Western Seed Company	Private
DK8053	Hybrid	2004	Monsanto	Private	Monsanto	Private
H6214	Hybrid	2004	Kenya Seed Company	Public	Kenya Seed Company	Public
H624	Hybrid	2004	Kenya Seed Company	Public	Kenya Seed Company	Public
Kakamega Syntheti	OPV	2004	KARI	Public	Kenya Seed Company	Public
Kh500 21A	Hybrid	2004	CIMMYT/KARI	Public	Dryland Seed Limited	Private
SCDuma41	Hybrid	2004	Agri Seed Company Ltd.	Private	Agri Seed Company Ltd.	Private
SCDUMA43	Hybrid	2004	Agri Seed Company Ltd.	Private	Agri Seed Company Ltd.	Private
Simba	OPV	2005	Agri Seed Company Ltd.	Private	Agri Seed Company Ltd.	Private
Kdv 1	OPV	2006	CIMMYT	Public	Dryland Seed Limited	Private
Kdv 6	OPV	2006	CIMMYT	Public	Dryland Seed Limited	Private
H612	Hybrid	2008	KARI/ Kenya Seed Company	Public	Kenya Seed Company	Public
PAN7M 97	Hybrid	2008	Pannar Seed Company	Private	Pannar Seed Company	Private
Panam 419	Hybrid	2008	Pannar Seed Company	Private	Pannar Seed Company	Private
WS105	OPV	2008	CIMMYT	Public	Western Seed Company	Private

Appendix 2. List of improved maize varieties, by year, by zone and area percentage (%)

Appendix 2. List of improved maize varieties, by year, by zone and area percentage (%)

	1992	Type	Type II	Company	Area(%)	2002	Area(%)	2010	Area(%)	2013	Area(%)	Notes
Coastal lowl	Coast Composite	KARI/KSC		KSC	6.9	Coast Composite	8.1			Coast Composi	4.5	
Coastal lowl	DHO1	KSC		KSC						DHO1	1.1	
Coastal lowl	DHO2	KSC		KSC						DHO2	2.2	
Coastal lowl	DHO4	KSC		KSC				DHO4	1.1	DHO4	1.1	
Coastal lowl	H520	KSC		KSC						H520	1.1	
Coastal lowl	Kakamega Synthetic	KSC/KARI		KSC				Kakamega Synthetic	0.8			
Coastal lowl	Katumani Composite	KARI/KSC		KSC	11.5	Katumani Comp	4.6	Katumani Composite	4.9	Katumani Com	5.6	
Coastal lowl	PAN7M 97	Private (int)		PANNAR				PAN7M 97	2.3			
Coastal lowl	Makueni Composite - DLC1	KSC/KARI		KSC		Makueni Compo	0.1					
Coastal lowl	PH1	KSC		KSC	4.4	PH1	16.3	PH1	13.5	PH1	9	
Coastal lowl	PH4	KSC		KSC		PH4	36.5	PH4	32.5	PH4	33.7	
Coastal lowl	SCDUMA43	Private (int)		SeedCo						SCDUMA43	2.2	
Total Coast	Improved varieties				22.8		65.6		54		60.5	
Total Coast	Local varieties				77.2		34.4		46		39.5	
Dry Mid Alti	CG4141	Private (int)		Cargill		CG4141	0.3	CG4141	0.2			
Dry Mid Alti	Coast Composite	KSC/KARI		KSC				Coast Composite	0.1			
Dry Mid Alti	DHO1	KSC		KSC				DHO1	2.7	DHO1	3.2	
Dry Mid Alti	DHO2	KSC		KSC				DHO2	3.3	DHO2	6.5	
Dry Mid Alti	DHO4	KSC		KSC				DHO4	3.4	DHO4	5.1	
Dry Mid Alti	DK8071	Private (int)		Cargill				DK8071	0.9	DK8031	1.4	
Dry Mid Alti	DK8071	Private (int)		Cargill						DK8071	0.4	
Dry Mid Alti	H511	KSC/KARI		KSC	7.4	H511	2.1	H511	0.2	H511	0.5	
Dry Mid Alti	H520	KSC/KARI		KSC						H520	0.5	
Dry Mid Alti	H512	KSC/KARI		KSC	4.4							
Dry Mid Alti	H613	KSC/KARI		KSC	1.2							
Dry Mid Alti	H614	KSC/KARI		KSC	1.9							
Dry Mid Alti	H625	KARI/KSC		KSC	1.4							
Dry Mid Alti	H626	KSC/KARI		KSC	1.2			Kakamega Synthetic	0.5			
Dry Mid Alti	Katumani Composite	KSC/KARI		KSC	48.8	Katumani Comp	14.9	Katumani Composite	13.4	Katumani Com	8.3	
Dry Mid Alti	Kdv 1	CIMMYT/KARI		Dryland seeds						Kdv 1	0.5	
Dry Mid Alti	Makueni Composite - DLC1	KSC/KARI		KSC	0.3	Makueni Compo	9.7	Makueni Composite	0.6	Makueni Comp	0.5	
Dry Mid Alti	Pan67	Private (int)		PANNAR				Pan67	0.4	Pan67	0.9	
Dry Mid Alti	PH1	KSC		KSC				PH1	0.1	PH1	0.4	
Dry Mid Alti	PH3253	Private (int)		Pioneer		PH3253	3.6			PH3253	3.2	
Dry Mid Alti	PH4	KSC		KSC				PH4	0.1			
Dry Mid Alti	Pioneer	Private (int)		Pioneer				Pioneer	0.1			
Dry Mid Alti	SCDUMA41	Private (int)		SeedCo				SCDUMA41	0.9	SCDuma41	1.4	
Dry Mid Alti	SCDUMA43	Private (int)		SeedCo				SCDUMA43	14.5	SCDUMA43	23.1	
Total MA	Improved varieties				66.6		30.6		41.4		55.9	
Total MA	Improved varieties			Makueni Composite - DLC1	33.4		69.4		58.6		44.1	
Dry Transitic	CG4141	Private (int)		Cargill		CG4141	1.1					
Dry Transitic	DHO1	KSC		KSC				DHO1	2.4	DHO1	0.5	
Dry Transitic	DHO2	KSC		KSC				DHO2	1.1	DHO2	3.4	
Dry Transitic	DHO3	KSC		KSC						DHO3	0.5	
Dry Transitic	DHO4	KSC		KSC				DHO4	3.2	DHO4	1.5	
Dry Transitic	DK8031	Private (int)		Cargill						DK8031	12.8	
Dry Transitic	DK8053	Private (int)		Cargill						DK8053	0.1	
Dry Transitic	DK8071	Private (int)		Cargill				DK8071	1.7	DK8071	0.5	
Dry Transitic	H511	KSC/KARI		KSC	33.1	H511	3.7	H511	1.5			
Dry Transitic	H512	KSC/KARI		KSC	8.7							
Dry Transitic	H513	KSC		KSC		H513	1.6	H513	1	H513	3	
Dry Transitic	H520	KSC		KSC						H520	2	
Dry Transitic	H6210	KSC		KSC				H6210	0.5			
Dry Transitic	H6213	KSC		KSC				H6213	0.3			
Dry Transitic	H614	KSC/KARI		KSC	0.5							
Dry Transitic	H625	KSC/KARI		KSC	1.9	H625	0.3	H625	0.1			
Dry Transitic	H627	KSC/KARI		KSC		H627	0.4					
Dry Transitic	H628	KSC		KSC		H628	0.4					
Dry Transitic	Katumani Composite	KSC/KARI		KSC		Katumani Comp	16	Katumani Composite	12.3	Katumani Com	2	
Dry Transitic	Kdv 1	CIMMYT/KARI		Dryland seeds						Kdv 1	1	
Dry Transitic	Makueni Composite - DLC1	KSC/KARI		?		Makueni Compo	1.2	Makueni Composite	0.3	Makueni Comp	2.5	
Dry Transitic	Pan5195	Private (int)		PANNAR				Pan5195	0.4			
Dry Transitic	Pan67	Private (int)		PANNAR				Pan67	0.8	Pan67	1	
Dry Transitic	Pan691	Private (int)		PANNAR						Pan691	0.5	
Dry Transitic	PAN7M 97	Private (int)		PANNAR				PAN7M 97	0.5	Panam 419	0.5	
Dry Transitic	PH1	KSC		KSC				PH1	1.1			
Dry Transitic	PH3253	Private (int)		Pioneer		PH3253	6			PH3253	11.3	
Dry Transitic	PH4	KSC		KSC				PH4	0.8	PH4	0.5	
Dry Transitic	SCDuma41	Private (int)		SeedCo						SCDuma41	1.5	
Dry Transitic	SCDUMA43	Private (int)		SeedCo				SCDUMA43	24.2	SCDUMA43	30	
Dry Transitic	Simba	Private (int)		SeedCo				Simba	0.1			
Total DT	Improved varieties				44.2		30.7		52.3		75.1	
Total DT	Local varieties				55.8		69.3		47.7		24.9	
Moist Transi	CG4141	Private (int)		Cargill		CG4141	0.9					
Moist Transi	Coast Composite	KARI/KSC		KSC	0.6							
Moist Transi	DHO3	KSC		KSC				DHO3	0.2			
Moist Transi	DHO4	KSC		KSC				DHO4	0.2	DHO4	1.1	
Moist Transi	DK8030	Private (int)		Cargill				DK8030	0.1			
Moist Transi	DK8031	Private (int)		Cargill						DK8031	3.7	
Moist Transi	DK8052	Private (int)		Cargill						DK8053	0.8	
Moist Transi	DK8071	Private (int)		Cargill				DK8071	1.1	DK8071	0.3	
Moist Transi	H511	KSC/KARI		KSC	5.7	H511	6.9	H511	0.6	H511	0.3	
Moist Transi	H512	KSC/KARI		KSC	4.8	H512	2	H512	0.4	H512	0.3	
Moist Transi	H513	KSC		KSC		H513	2.9	H513	8.1	H513	9	
Moist Transi	H515	KSC		KSC						H515	0.6	
Moist Transi	H516	KSC		KSC				H516	1	H516	2	
Moist Transi	H520	KSC		KSC				H520	0.3	H520	1.1	
Moist Transi	H524	KSC		KSC						H524	0.3	
Moist Transi	H611	KARI/KSC		KSC				H611	0.2			
Moist Transi	H612	KARI/KSC		KSC				H612	0.1			
Moist Transi	H613	KARI/KSC		KSC	0.6			H613	1.4	H613	1.1	
Moist Transi	H614	KARI/KSC		KSC	43.3	H614	52.9	H614	31.7	H614	31	
Moist Transi	H615 (not in NVL)	KARI/KSC		KSC				H615	1.1			
Moist Transi	H616 (not in NVL)	KARI/KSC		KSC				H616	0.3			
Moist Transi	H6210 (N)	KSC		KSC				H6210	3.1	H6210	1.7	
Moist Transi	H6212	KSC		KSC						H6212	0.3	
Moist Transi	H6213	KSC		KSC				H6213	2.5	H6213	5.1	
Moist Transi	H6214	KSC		KSC						H6214	0.3	
Moist Transi	H622	KSC/KARI		KSC	1.2	H622	0.2					
Moist Transi	H623	KARI/KSC		KSC				H623	0.1			
Moist Transi	H624	KSC		KSC				H624	3	H624	4.2	
Moist Transi	H625	KSC		KSC	22.4	H625	6.3	H625	4.3	H625	3.7	
Moist Transi	H626	KSC		KSC	9	H626	0.2	H626	1	H626	0.3	
Moist Transi	H627	KSC/KARI		KSC		H627	1.6					
Moist Transi	H628	KSC		KSC		H628	1.8	H628	2.8	H628	2	
Moist Transi	H629	KSC		KSC		H629	0.1	H629	1.6	H629	1.5	
Moist Transi	H632	KARI/KSC		KSC	0.2							
Moist Transi	Katumani Composite	KSC/KARI		KSC		Katumani Comp	0.3	Katumani Composite	0.8	Katumani Com	0.8	
Moist Transi	Kh500 21A	KARI		Freshco seed (?)				Kh500 21A	0.1			
Moist Transi	Kh600 15A	KARI		Freshco seed (?)						Kh600 15A	0.3	
Moist Transi	Kh600 16A	KARI		Freshco seed (?)					0.8	Kh600 16A	0.3	
Moist Transi	Kitale Synthetic (N)	KARI/KSC		KSC	0.1							
Moist Transi	Makueni Composite	KARI/KSC		KSC				Makueni Composite		Makueni Comp	1.4	
Moist Transi	MasenoDC	Lagrotech seed co.		Lagrotech seed co.		MasenoDC	0.2					
Moist Transi	Pan5195	Private (int)		PANNAR				Pan5195	0.4			
Moist Transi	Pan67	Private (int)		PANNAR				Pan67	0.1	Pan67	0.3	
Moist Transi	Pan691	Private (int)		PANNAR				Pan691	0.3	Pan691	0.2	
Moist Transi	Pan419	Private (int)		PANNAR						Pan419	0.3	
Moist Transi	PAN7M 97	Private (int)		PANNAR				PAN7M 97	0.3			
Moist Transi	PH1	KSC		KSC		PH1	0.6					
Moist Transi	PH3253	Private (int)		Pioneer		PH3253	5.7			PH3253	2.8	
Moist Transi	PH4	KSC		KSC				PH4	0.5	PH4	0.6	
Moist Transi	SCDUMA43	Private (int)		Seedco				SCDUMA43	2	SCDUMA43	4	
Moist Transi	Simba	Private (int)		Seedco						Simba	0.3	
Moist Transi	WS403	Private (local)		Western Seed Co				WS403	0.3	WS403	0.8	
Moist Transi	WS502	Private (local)		Western Seed Co				WS502	0.3	WS502	0.3	
Moist Transi	WS505	Private (local)		Western Seed Co				WS505	3	WS505	5.1	
Total MT	Improved varieties				11.1		0.9		68		88.2	
Total MT	Local varieties				88.9		99.1		32		11.8	
High Tropics	Coast Composite	KARI/KSC		KSC	0.1			Coast Composite	0.4			
High Tropics	DHO4	KSC		KSC				DHO4	0.1	DHO4	0.4	
High Tropics	DK8031	Private (int)		Cargill						DK8031	0.8	
High Tropics	FS650	Private (local)		Faida Seeds				FS650	0.3			
High Tropics	H511	KSC/KARI		KSC	4.9	H511	0.6	H511	1			
High Tropics	H512	KSC/KARI		KSC	2.3			H512	0.4			
High Tropics	H513	KSC		KSC				H513	0.9	H513	0.8	
High Tropics	H520	KSC		KSC						H520	1.3	
High Tropics	H611	KSC		KSC	0.3			H611	0.2			
High Tropics	H613	KARI/KSC		KSC	3.3			H613	0.9	H613	1.3	
High Tropics	H614	KARI/KSC		KSC	50.3	H614	57.6	H614	37.7	H614	40.3	
High Tropics	H6210 (N)	KSC		KSC				H6210	5.2	H6210	0.8	
High Tropics	H6213	KSC		KSC				H6213	5.5	H6213	16.4	
High Tropics	H622	KSC/KARI		KSC		H622	0.3	H622	0.3			
High Tropics	H624	KSC		KSC				H624	10.5	H624	6.3	
High Tropics	H625	KSC		KSC	18.8	H625	1.8	H625	0.4	H625	0.4	
High Tropics	H626	KSC		KSC	12.8	H626	3.2	H626	3.6	H626	0.8	
High Tropics	H627	KSC/KARI		KSC		H627	6.9	H627	0.7	H627	1.7	
High Tropics	H628	KSC		KSC		H628	9.9	H628	7.9	H628	4.6	
High Tropics	H629	KSC		KSC				H629	1.4	H629	6.7	37.7
High Tropics	Katumani Composite	KSC/KARI		KSC	0.6	Katumani Comp	0.3	Katumani Composite	1.3	Katumani Com	2.5	
High Tropics	Kh500 21A	KARI		Freshco seed (?)				Kh500 21A	0.1			
High Tropics	Kh600 15A	KARI		Agricultural development corporation						Kh600 15A	1.3	
High Tropics	Pan5195	Private (int)		PANNAR				Pan5195	0.2			
High Tropics	Pan5355	Private (int)		PANNAR				Pan5355	0.2			
High Tropics	Pan67	Private (int)		PANNAR				Pan67	0.1			
High Tropics	Pan691	Private (int)		PANNAR				Pan691	0.7	Pan691	0.8	
High Tropics	PAN7M 97	Private (int)		PANNAR				PAN7M 97	0.5			
High Tropics	PH3253	Private (int)		Pioneer		PH3253	0.3					
High Tropics	PH4	KSC		KSC				PH4	0.1			
High Tropics	SCDUMA43	Private (int)		Seedco				SCDUMA43	0.4	SCDUMA43	1.3	
High Tropics	WS403	Private (local)		Western Seed Co				WS403	0.2	WS403	0.4	
Total HT	Improved varieties				93.4		80.9		81.2		88.9	
Total HT	Local varieties				6.6		19.1		18.8		11.1	
Moist Mid-A	DHO1	KSC		KSC				DHO1	0.4	DHO1	0.8	
Moist Mid-A	DHO4	KSC		KSC				DHO4	3.9	DHO4	2.1	
Moist Mid-A	DK8031	Private (int)		Cargill						DK8031	3.8	
Moist Mid-A	DK8071	Private (int)		Cargill				DK8071	0.1	DK8071	0.8	
Moist Mid-A	H511	H511		KSC	10	H511	4.4	H511	1.8	H511	1.7	
Moist Mid-A	H512	H512		KSC	4.9	H512	0.4	H512	0.8	H512	0.3	
Moist Mid-A	H513	H513		KSC		H513	3.4	H513	4	H513	5	
Moist Mid-A	H516	KSC		KSC				H516	0.3	H516	1.3	
Moist Mid-A	H520	KSC		KSC	0					H520	2.5	
Moist Mid-A	H611	KSC		KSC				H611	0.2			
Moist Mid-A	H613	KARI/KSC		KSC	0.6					H613	0.8	
Moist Mid-A	H614	KARI/KSC		KSC	12.5	H614	14	H614	1.6	H614	4.2	
Moist Mid-A	H6210 (N)	KSC		KSC				H6210	0.4	H6210	0.4	
Moist Mid-A	H6213	KSC		KSC						H6213	0.1	
Moist Mid-A	H624	KSC		KSC		H622	2.6	H624	1.3	H624	0.4	
Moist Mid-A	H625	KSC		KSC	7.6	H625	5.5	H625	1.1	H625	1.3	
Moist Mid-A	H626	KSC		KSC	1.3			H626	0.4	H626	0.5	
Moist Mid-A	H627	KSC/KARI		KSC				H627	0.2			
Moist Mid-A	H628	KSC		KSC						H628	0.4	
Moist Mid-A	H632	KARI/KSC		KSC	1.8							
Moist Mid-A	Katumani Composite	KSC/KARI		KSC	0.2	Katumani Comp	1.5	Katumani Composite	0.4			
Moist Mid-A	Kh500 21A	KARI		PANNAR				Kh500 21A	0.1			
Moist Mid-A	Makueni Composite - DLC1	KSC/KARI		KSC				Makueni	1.9			
Moist Mid-A	MasenoDC	Lagrotech seed co.		Lagrotech seed co.		MasenoDC	1.5	MasenoDC	0.4	MasenoDC	1.5	
Moist Mid-A	PAN	Private (int)		PANNAR		PAN	0.2					
Moist Mid-A	Pan67	Private (int)		PANNAR						Pan67	0.8	
Moist Mid-A	Pan691	Private (int)		PANNAR				Pan691	0.1			
Moist Mid-A	PH1	KSC		KSC		PH1	1.3	PH1	1.9	PH1	2.5	
Moist Mid-A	PH3253	Private (int)		Pioneer		PH3253	1.8			PH3253	0.4	
Moist Mid-A	PH4	KSC		KSC				PH4	0.1	PH4	3.3	
Moist Mid-A	SCDUMA43	Private (int)		SeedCo				SCDUMA43	1.2	SCDUMA43	4.6	
Moist Mid-A	Simba	Private (int)		SeedCo				Simba	1.8	Simba	2.1	
Moist Mid-A	WS105	Private (int)		Western Seed Co				WS105	0.4			
Moist Mid-A	WS403	Private (int)		Western Seed Co				WS403	0.6	WS403	5	
Moist Mid-A	WS505	Private (int)		Western Seed Co				WS505	8	WS505	7.1	
Total MM	Improved varieties				38.9		36.6		33.4		53.7	
Total MM	Local varieties				61.1		63.4		66.6		46.3	

Appendix 2 gives a de

Notes

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H627 was

H628 first

H623 to H6

H632 is fro

Categories

KSC/KARI

KSC

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Private - In

Private - lo

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