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The Cost of Coexistence between Bt Maize and Open-Pollinated Maize Varieties in Lowland Coastal Kenya

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Although the commercial use of agricultural biotechnology in Africa is significantly lower than in most other parts of the world, several African countries have made significant strides towards introducing GM crops. Kenya has been one of the more progressive African countries, particularly in maize, where testing and development of Bt maize has been ongoing since 1999. As part of the introduction process, biosafety protocols are being developed. The protocols require adequate measures to ensure the coexistence between GM and conventional maize varieties, minimize risks of cross contamination, and preserve the biodiversity of traditional maize varieties. Establishing coexistence between GM and conventional maize imposes additional costs on potential adopters of GM maize, especially in Kenya, where adoption will take place within highly populated smallholder farming communities. This article estimates the costs of establishing coexistence between GM and conventional maize in Kenya's coastal lowlands. Using a transect survey, data was collected on the size and distribution of maize fields at 100 locations in lowland coastal Kenya. Monte Carlo simulation was used to estimate the costs of coexistence, achieved through spatial isolation, and its effect on the potential adoption of GM maize. The results indicate that the cost of coexistence could be prohibitively high if Kenya were to adopt stringent requirements on spatial isolation, such as the measures adopted by Denmark. For meaningful adoption to occur, isolation distances would need to be less than 50 meters.

Key words: agro-ecological zone, Bt maize, coexistence, regulatory, spatial.

Introduction

The use of biotechnology in Africa remains substantially lower than in most parts of the world (Paarlberg, 2008). Maize, a principal crop throughout much of Africa, is particularly noteworthy. Although 24% of the world's 157 million acres of maize were planted using transgenic varieties in 2008—including 65.4 million hectares (41.6%) in Africa—less than 1% of the world's total Bt maize acreage was grown in Africa (James, 2008). South Africa accounted for virtually all of Africa's use of Bt maize, with 1.62 million planted hectares in 2008 (James, 2008). Africa's reluctance to adopt bioengineered crops includes well-voiced concerns by environmental groups (Greenpeace, OXFAM, GRAIN, Global Justice Ecology Project) and lobbyists over the potential risks to human health and the environment, which in many ways mirrors those of the EU (Byrne, 2006; Graff, Hochman, & Zilberman, 2009; Lieberman & Gray, 2008; Paarlberg, 2008). Such concerns culminated over the past few years with highly publicized bans on the importation of US food aid containing genetically modified (GM) maize, even under conditions of food scarcity (Clapp, 2005; Mulvany, 2004).

Many African countries have, however, begun to lay the foundation for an eventual commercial introduction of bioengineered crops (Cloete, Nel, & Theron, 2006; Eicher, Maredia, & Sithole-Niang, 2006; Sithole-Niang et al., 2004; Thomson, 2009). A majority of African countries have ratified the Cartagena Biosafety protocol, and 19 countries have begun field trials on Bt crops, including cotton, maize, and cowpea (Balile, 2005; Kikulwe et al., 2007). Kenya's stance on biotechnology has been one of the most progressive throughout Africa. Since 1999, the Insect Resistance Maize project for Africa (IRMA)—a joint collaboration between Kenya Agricultural Research Institute (KARI) and International Maize and Wheat Improvement Center (CIMMYT)—has been developing transgenic (Bt) varieties of maize (Hoisington & Ngichabe, 2004). Although Bt maize has not been commercially released, controlled field trials have been conducted in Kenya since May 2005 (Mugo et al., 2005).

Biosafety is one of the most sensitive issues surrounding the introduction of biotechnology in Africa, with African governments and their citizens placing a high priority on protecting the environment and maintaining biodiversity (Conner, Glare, & Nap, 2003; Kimenju & De Groote, 2008). Opponents of biotechnology typically voice concerns over gene flow—the inadvertent transfer of genetic material from one species to another— including the possible contamination of conventional plants by bioengineered ones. Gene-flow events for Bt crops (spontaneous hybridization) have been documented between both host plant and wild relatives (Ellstrand, 2003), as well as crop-to-crop transgene flow events (Hall, Topinka, Huffman, Davis, & Good, 2000). Segregation issues have sparked numerous controversies with the use of biotech crops, with many countries banning their use and importation (Demont & Devos, 2008; Tolstrup et al., 2003).

Most countries legislate the isolation of Bt crops at prescribed minimum distances from conventional maize fields in order to manage risks of contamination (Devos et al., 2008; Perry, 2002; Sanvido et al., 2008). This regulatory regime is based on the assumption that separation distances are sufficient to reduce cross-pollination levels to an acceptable minimum (Devos, Reheul, & de Schrijver, 2005; Perry, 2002). Across countries, however, there is wide variation in what constitutes such a minimum distance; examples include the United States, where no separation distance is required, and Bulgaria and Luxemburg, where 800 m separation distances are enforced (Table 1). Many countries have taken a highly precautionary approach to isolation, requiring threshold levels of cross contamination to be quite low (e.g., the European Union requires levels less than 0.9% and Australia and New Zealand require levels of 1%), while other countries have accepted more modest levels of risk (e.g., Japan requires threshold levels of 5%; Graham & Brookes, 2004). Climate and land-use patterns also play important roles in determining prescribed distances (Devos et al., 2005; Hoyle & Cresswell, 2007).

A socially optimal isolation distance balances the risks of contamination with the economic benefits generated by biotechnology (Beckmann, Soregaroli, & Wesseler, 2010; Demont & Devos, 2008). Large isolation distances help to minimize the risk of contamination, but also reduce uptake and potential benefits. Smallholder farming communities are especially sensitive to isolation distance, as landholdings tend to be fragmented and concentrated around village centers. Such is the case in Kenya, and throughout much of East Africa, where population pressure and land fragmentation have dwindled land holdings to under a hectare in many locations. According to the 2007 World Bank land-use statistics, arable land area per capita in Kenya has decreased by 39% between 1980 and 2005 from 0.23 to 0.14 ha.

Table 1. Isolation distances (m) proposed by EU states to ensure coexistence for GM and conventional maize.

EU member state	Isolation perimeter (m)
Sweden (forage)	15
Netherlands	25
Spain, Ireland, France	50
Czech Republic	70
UK (forage)	80
UK (grain)	110
Germany	150
Slovakia, Portugal, Belgium	200
Hungary	400
Luxembourg, Bulgaria	800
Philippines	500

Source: Adapted from the European Commission's report on the implementation of national measures on coexistence of GM crops with conventional crops.

Kenya's biosafety protocols will need to balance not only risks and benefits of contamination, but also enable coexistence—the ability of producers to choose between GM and conventional crops—without prejudice towards either adopters or non-adopters. Demont and Devos (2008) argue that coexistence is only an issue if there are sufficient incentives for both GM and conventional varieties to be produced, suggesting some minimum amount of heterogeneity within the farming population. In Kenya and throughout much of East Africa, such a duality is expected to exist. While a majority of Kenya's maize is produced for home consumption by smallholder farmers (who prefer traditional, local varieties to modern hybrids for taste and cultural reasons), the farming population also includes more commercially oriented producers, likely to be the early adopters of Bt maize (Wekesa, Mwangi, Verkuijl, Danda, & De Groote, 2003). To ensure that the introduction of GM maize cropping can proceed without inflicting harm on conventional maize producers, Kenyan policymakers and stakeholders are in the process of developing ex-ante coexistence[1] regulations (Andow & Hilbeck, 2004).

Previous studies have found that coexistence between Bt and conventional maize is affected by the spatial distribution of existing crops (Belcher, Norlan, & Philips, 2005), the size of maize fields, and the minimum regulatory distances between Bt and conventional fields (Beckmann et al., 2006; Demont et al., 2008; Messean, Angevin, Omez-Barbero, Menrad, & Rodríguez-Cerezo, 2006). Studies have also estimated the feasibility and costs associated with establishing coexistence (Belcher et al., 2005; Devos et al., 2008; Messean et al., 2006; Perry, 2002). However, the interactions of these factors and their influence on adoption potential have not been studied in Kenya.

This article estimates the economic cost of establishing coexistence between Bt and conventional maize in Kenya's coastal lowlands. This is a representative farming region of not only Kenya, but also throughout much of East Africa. An alternative range of isolation distances are considered, encompassing an expected range of contamination risk using experiences from other countries. Using a transect survey, data was collected on the size and distribution of maize fields at 100 locations within Kenya's coastal lowland. Monte Carlo simulation was used to estimate the costs of coexistence, achieved through spatial isolation, and its effect on the potential adoption of Bt maize. The findings are useful input to Kenya's on-going biosafety protocol design by providing decision makers with trade-offs between reducing risk of contamination and the benefits of Bt maize.

The rest of the article is structured as follows: after this introduction, the importance of maize in Kenya and constraints to its production are briefly described along with the study area. The methodology is then presented, including a description of how the transect survey was conducted. This is followed by the main results and findings of the study. The article ends with conclusions and recommendations.

Background

Maize is the primary staple food in Kenya (De Groote et al., 2005). In a typical year, maize provides 42% of the dietary energy intake for Kenyan consumers, including both rural and urban areas (Muhammad & Underwood, 2004). Maize is also an important source of income for producers, although most producers (65%) maintain a subsistence orientation. Over the past decades, population pressure and urbanization have shifted Kenya from a net exporter of maize to a net importer (DeGroote et al., 2005). Kenyan maize production averages 81 kg per capita, significantly lower than the average demand of 103 kg per capita (Pingali, 2001).

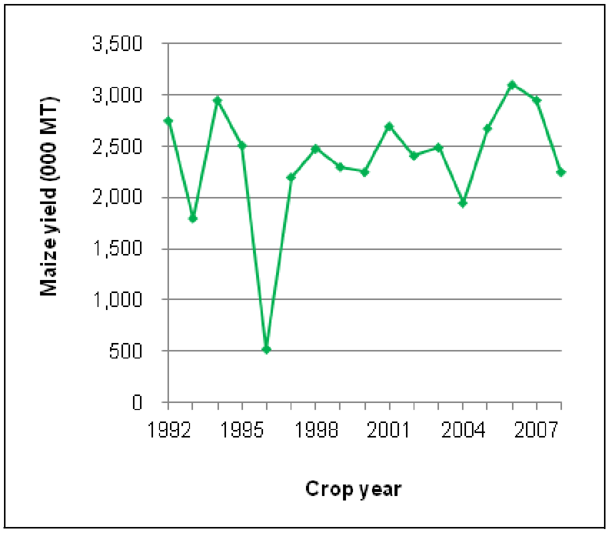

Figure 1. Trend of maize yields in Kenya: 1992-2008.

While the population has continued to grow at a steady pace, Kenya's maize yields have stagnated (Figure 1). Insect pests constitute a principal constraint to maize production (De Groote et al., 2004). Studies have found that maize producers perceive stem borers (mainly *Chilo partellus* and *Buseola fusca*) as the major threat to increasing yields (De Groote et al., 2004; Eicher et al., 2006; Wekesa, De Groote, Ndungu, & Civatsi, 2002). Stem borers are most destructive in the larval stage when, after hatching, they tunnel inside maize stalks where they become difficult to control. Stem borers cause significant structural damage to maize stems, weakening the plant and increasing the likelihood of lodging. Pests can also attack maize ears, leaving the cob vulnerable to disease and rot. Conventional chemical spraying, although modestly effective, is expensive, labor intensive, and difficult to adequately time applications (Mwangi & Ely, 2001).

Genetic engineering offers Kenyan maize producers a promising alternative to conventional pest-control methods (De Groote et al., 2004). With genetic engineering, a gene that produces Bacilius Thuringiensis (Bt, an effective pest-control agent), is inserted into a maize plant's DNA (Eugene, Thomashow, Mathew, & Milton, 2003). Stem borer larvae that penetrate the plant tissues are killed after they ingest Bt toxins. In particular, the Bt provides protection from stem borers (including *Chilo partellus* and *Buseola fusca*, the primary pests in the region), which in a typical year cause maize losses of 13.5% throughout Kenya (De Groote et al., 2004).

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1. *Coexistence is the ability of farmers to make practical choices between growing conventional, organic, or genetically modified crops and is mainly concerned with the potential economic impact of the admixture of GM and non-GM crops (Demont et al., 2008).*

Biotechnology is a sensitive issue in Kenya, as well as throughout most of Africa (Paarlberg, 2008). In Kenya, the IRMA project has been charged to study the environmental and regulatory systems, including how transgenic maize varieties would conform to smallholder farming systems (Mugo et al., 2005). Maintaining biodiversity is a clear mandate to biosafety regulators, which stems not only from environmentalists, but also from producers. In Kenya, a substantial number of smallholder producers prefer traditional maize varieties, which have long standing taste, food preparation qualities, and cultural significance (Muhammad & Underwood, 2004; Wekesa et al., 2002). The early adopters of Bt maize are expected to be primarily producers currently using improved hybrids, particularly since the early releases of Bt maize will be based on hybrid varieties, not local varieties (Andow & Hilbeck, 2004).

Hence, biosafety regulations will need to consider the needs of both adopters and non-adopters. To safeguard the genetic integrity of conventional maize varieties, Bt maize will need to be adequately segregated from conventional maize (Andow & Hilbeck, 2004). This will require isolating Bt maize at a prescribed minimum distance from conventional maize to prevent inadvertent cross pollination and gene outflow between Bt and conventional maize. If those distances are set too high, though, the costs of adopting Bt maize may be prohibitively high, and potential gains will not be achieved. The next section presents a framework to measure these tradeoffs in a key maize production region in Kenya, the coastal lowlands.

Conceptual Framework

Landscape structures are essential when assessing the coexistence of GM crops with conventional crops (Demont et al., 2008). Recent studies have used land-use patterns and field geometry to assess feasibility of coexistence of GM and conventional maize in the European context (Demont et al., 2008, 2009). In Kenya's coastal lowland, the agricultural landscape is fragmented, typically consisting of a mix of several crops and grasses, as well as strong preference for local varieties among smallholder farmers—who are expected to be late adopters (Muhammad & Underwood, 2004). To analyze the economics of coexistence, including the adoption of Bt maize, a profit function is defined for the Bt maize farmer. The profit, Π_B, from planting Bt maize is defined as the expected revenue, R, from Bt maize, less its expected production costs, C.

$$\Pi_{Bt} = E(R - C) \tag{1}$$

The farmer is assumed to adopt Bt maize if Π is equal to or greater than the profit generated by conventional cotton, Π_C. In other words, $\Pi_{Bt} - \Pi_C > 0$ implies adoption.

The expected costs related to coexistence are the implicit costs of respecting *ex-ante* regulations, which are realized through a loss in potential revenue. Following Demont and Devos (2008), potential Bt maize producers are responsible for complying with isolation requirements, leaving the economic welfare of conventional maize producers intact. Presuming the use of a minimum separation distance between Bt and conventional maize, potential revenue is reduced by the amount θ, which represents the loss in production from maintaining a required separation distance. Profit under regulation is given by the following equation.

$$\Pi_{Bt} = E(R - C - \theta) \tag{2}$$

The cost of coexistence (loss in potential revenue), θ, occurs when a nearby producer of conventional maize falls within the prescribed separation distance, D. When this occurs, the Bt maize producer must either forgo adoption or reduce Bt maize acreage to fall within the spatial boundaries dictated by D. Area falling within the isolation zone can be used as a buffer zone, where conventional maize can be grown to offset some of the potential loss, but the potential impacts from Bt maize cannot be fully realized. When an isolation distance is required, adoption faces a higher economic hurdle, with adoption occurring only if $\Pi_{Bt} - \Pi_C > \theta$.

Given maize field geometry, the cost of isolation, θ, can be measured. For square fields of length a, the area of isolation, A, is

$$A = a^2 - (a - 2d)^2, \tag{3}$$

where d is the buffer distance self-imposed by the Bt maize producer to maintain their field within the boundaries of the prescribed isolation distance, D. This is a conservative (upper bound) estimate of θ since it accounts for the possibility of conventional maize fields on all four sides (Figure 2). The resulting cost of isolation, θ, through a loss in revenue, is given by partial budgeting,

$$\theta = (P\Delta Y - \Delta C)A, \tag{4}$$

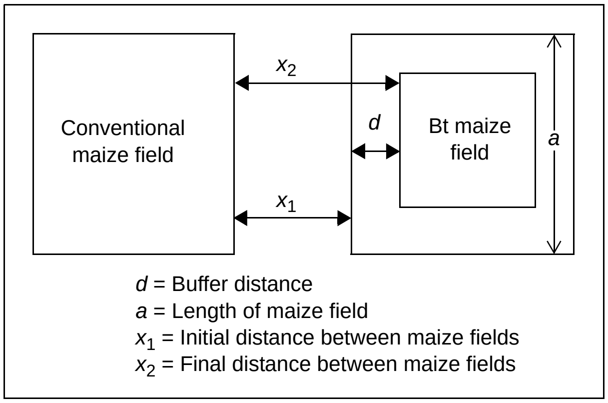


Figure 2. Spatial layout of maize fields illustrating the construction of a buffer zone by the representative farm to comply with biosafety regulations.

where P is the price of maize, ΔY is the yield difference between Bt and conventional maize, and ΔC is the difference in costs between Bt and conventional maize.

This study considered an isolation scenario (Figure 2) where any two maize fields are separated by an initial distance, x_1. In this scenario, x_1 is the expected distance between a representative Bt maize field and its closest neighboring field of conventional maize. There are three cases to consider. If x_1 is less than the prescribed minimum isolation distance, D, then the Bt maize producer will be required to employ a buffer zone (or decide not to adopt). In this case, the buffer distance, d, will be given by

$$d = D - x_1, \tag{5}$$

where the buffer distance, d, must be sufficiently small such that $d < a/2$, or else the required buffer area will be larger than the size of the maize field. Otherwise, the second case occurs, where $d \geq D$. The Bt maize producer is not required to impose any buffer zone in this case since Bt maize is sufficiently far from the nearest conventional maize field. It thus follows that $\theta = 0$ in this second case.

Monte Carlo Simulation

The adoption decision is estimated empirically by valuing the profit function under expected production and economic conditions. Monte Carlo simulation (MCS) was used to generate the results since arriving at a closed form solution was impractical given the complex nature of land-use patterns in the region (Demont et al., 2009; Demont & Tollens, 2004; Dillen, Demont, & Tollens, 2009; Hyde et al., 2003; Law & Kelton, 1991; Winston, 2000). The MCS is based on the probability distribution function (pdf), $\eta(x)$, of the minimum distance, x, between a potential adopter of Bt maize and his/her nearest maize-producing neighbor. The minimum distance is a truncated pdf since there is a non-zero probability that the neighboring field is directly adjacent to the representative farm ($x_1 = 0$). For a representative Bt maize producer, the probability that the minimum distance to a neighboring maize field at point x_1 falls within the prescribed separation distance, D, is given by

$$Pr(x_1 < D) = Pr(x_1 = 0) + \int \eta(x), \tag{6}$$

where $\Pr(x = 0)$ is the lumped probability that the minimum separation distance is 0, and $\int \eta(x)$ is the cumulative density function (cdf) at point x_1 stating the probability that the neighboring field falls within the prescribed isolation distance, D, thus requiring a buffer zone.

One reason for using MCS was that $\eta(x)$ was found to be non-normal, making it difficult to arrive at a closed-form solution. By using a large number of random draws taken from the empirical distribution of land use, it was possible to arrive at the quantitative implications of Equation 6 without specifying a distribution for $\eta(x)$. MCS also made it possible to consider two other practical aspects to the problem. One was the effect of adoption rate on the cost of isolation. When considering the nearest neighbor, it is necessary to know their adoption profile. Neighboring adopters of Bt maize need not configure buffer zones. A second was to include an alternative, rectangular geometry of land-use pattern. Nearest neighbors were significantly closer in the North-South direction rather than in the East-West direction. Hence, the MCS included empirical distributions of separation distances for both N-S and E-W directions.

The MCS algorithm makes random draws from Equation 6, considering nearest neighbor fields in N-S and E-W directions, conforming to the geometry used in the transect surveys. The outcome of each draw is the minimum distance, x_1, from an edge of the representative farm to the nearest maize field. If $x_1 < D$, then the MCS computes the required buffer zone, including the loss in revenue. The buffer zone is only required if the nearest field is a conventional maize producer, which is determined by making another random draw based on the adoption profile. Results for each draw are stored before moving to the next one. Probability distributions of the economic benefits for the representative farm

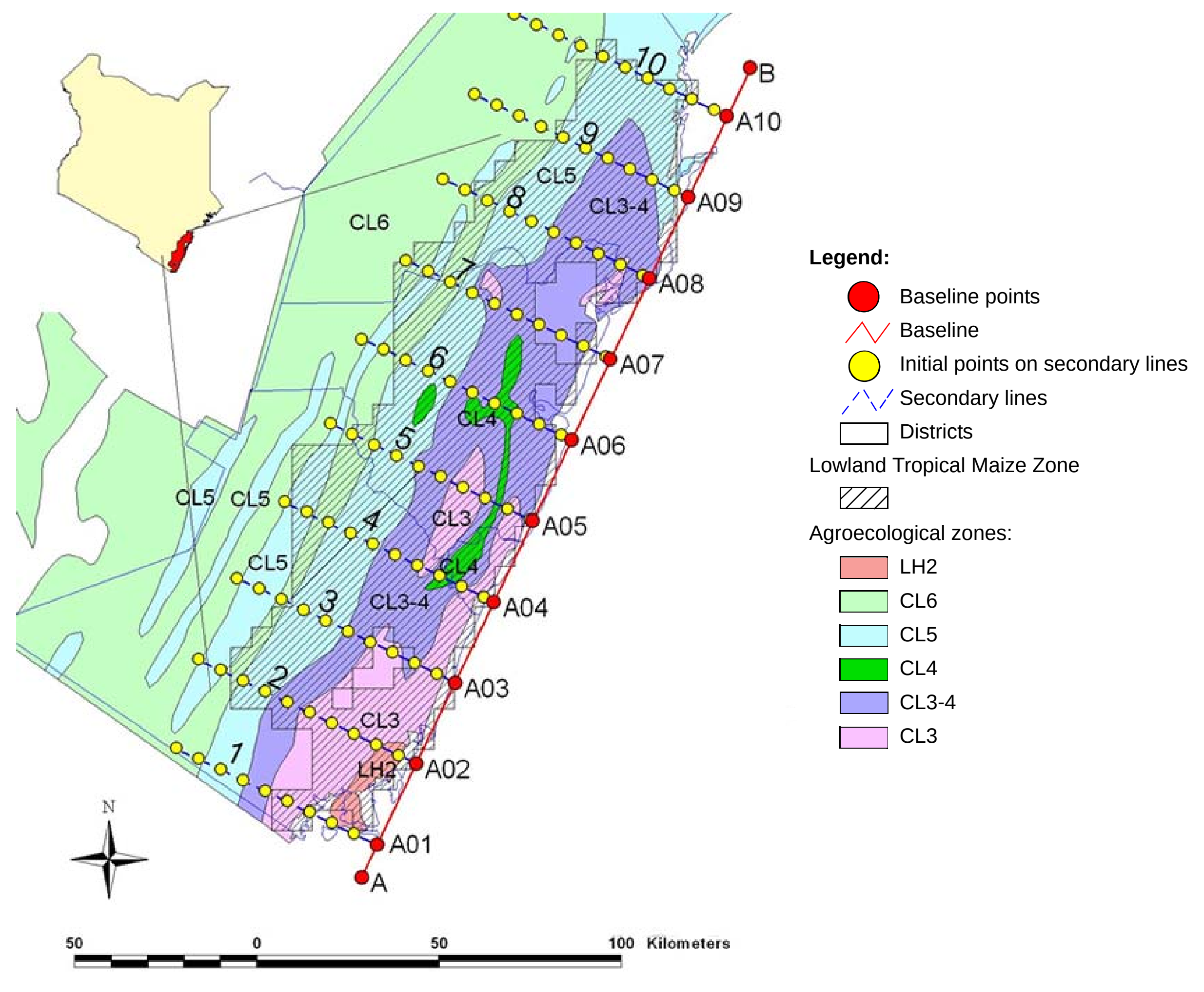


Figure 3. Agro ecological zones at the coast, with the sampling design.

were derived from the MCS. The MCS was repeated to account for the range of parameter values in the sensitivity analysis. Experience in running the MCS found that the probability distributions converged when 5,000 draws were used in the MCS.

Study Area and Data

The study area is the coastal low tropics maize production region of Kenya (see Figure 3), covering the administrative districts of Kwale, Mombasa, Kilifi, and Malindi. Kenya's coastal lowland has five diverse zones, distinguished by climatic, topographic, and edaphic features that shape a gradient of agricultural productivity running inland from the coast (Jaetzold & Schimidt, 1983). Compared with Kenya's Rift Valley, the coastal lowland is a lower potential area, characterized by maize yields that average 1.5 metric tons per ha. Together with the mid-altitude and dry transitional zones, the coastal lowlands cover about 29% of maize area in Kenya, and produce 11% of the country's maize (Hassan, 1998).

Data

A transect survey was conducted to estimate maize field geometry and land-use patterns. Within the study region, 100 locations were randomly selected for survey (Figure 3). A baseline was established, beginning at the coast line, consisting of 10 lines perpendicular to the coast and spaced 30 km apart. Within each of the ten baseline perpendiculars, transect surveys were conducted at ten locations.

The transect design consisted of two line segments. In the initial segment, a 1 km line was walked in the direction of the perpendicular. Land use was recorded along the transect using a handheld GPS receiver to record the location. Once the line was completed, a second transect was performed. This segment consisted of a 0.5 km line walked perpendicular to the original transect, intersecting it at the midpoint (forming the letter T). Land use was also recorded on this transect. Transforming GPS readings to actual ground distance was obtained on a degree-to-km equivalence using ArcView software by triangulation. The average length of maize field sections and in-between plots were calculated from the segments and transition points. This information was then used to approximate the mean distance between maize fields, the mean plot size for a given spatial orientation, and the concentration and distribution of maize plots across the region.

Representative Farm

Representative farm conditions were constructed using the transect survey results and data from other sources. According to the transect survey, the average (representative) farm grows 1.73 ha of maize. Field size had a large variation, with a standard deviation of 3.57 ha of planted maize. Sensitivity analysis was used to account for field size variation (see next section). Across the study area, maize yields average only 1.36 metric tons per ha since input use—including fertilizer, pesticide, and herbicides—is low. The simulation reflects, however, higher input use among more progressive producers growing hybrid maize varieties; these producers account for roughly 20% of the total producers in Kenya and are expected to be the initial adopters of Bt maize (Muhammad & Underwood, 2004). As adoption progresses, it is expected that input use would increase commensurate with the increased levels of productivity from Bt maize. Hence, the simulation bases the representative farm on hybrid maize producers. Input use and maize yields are higher among the hybrid producers than among producers growing local varieties, with typical yields of 2,000 kg. The yield performance of Bt maize is projected by applying a 15% increase to the representative farmer's yield of 2,000 kg per ha, a corresponding yield advantage of 300 kg per ha. This is a nominal yield increase based on observed stem-borer losses in the region that range from 13-20% and a Bt maize control efficacy between 90-95%. Sensitivity analysis is used to account for higher and lower levels of Bt maize performance. A three-year average maize price (2006-2008) of $0.20 per kg ($5.26 per bu) was used to project expected revenue.

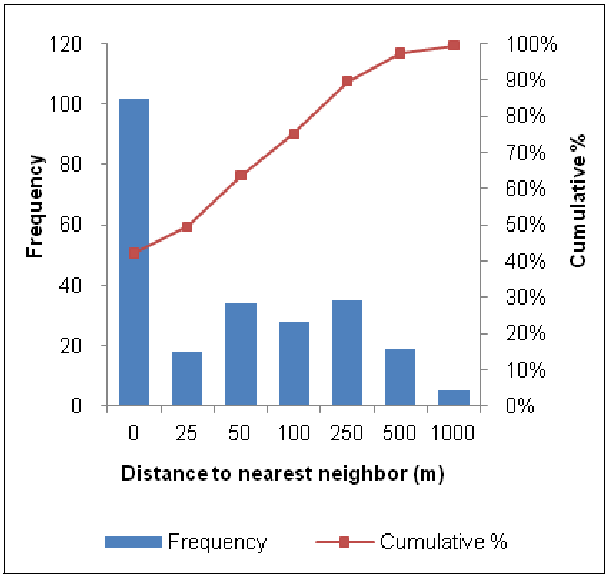


Figure 4. Distribution of separation distance between neighboring maize fields in coastal lowlands of Kenya.

Sensitivity

Sensitivity analysis was conducted to assess various policy instruments. A likely range of isolation distances was considered based on distances used in other countries (Table 1), providing decision makers with a tradeoff comparison among alternative risk levels. Since adoption rates and farm size affect isolation costs, these parameters were also included in the sensitivity analysis. Three different adoption profiles were considered, corresponding to 20, 50, and 80% adoption rates. Field size was varied by including the average field size, as well as maize producers with smaller land holdings of 0.5 ha and larger land holdings of 5 and 10 ha. Sensitivity analysis was also used to vary Bt maize performance; the analysis considered two alternative Bt maize yield advantages of 10% and 20%.

Transect Survey Findings

The transect survey found that maize fields were highly concentrated in the study area. The average distance between neighboring maize fields was 91.9m, with a median distance of 25.4 m (Figure 4). In 42.1% of the cases, the distance between maize fields was 0, with the nearest maize field adjacent to the field of origin. Slightly more than two-thirds of the observations (71%) had distances of 100 m or less. Of the remaining observations, 14% had distances between 100 and 250 m, 8% had distances between 250 and 500 m, and 2% had distances between 500 and 1,000 m.

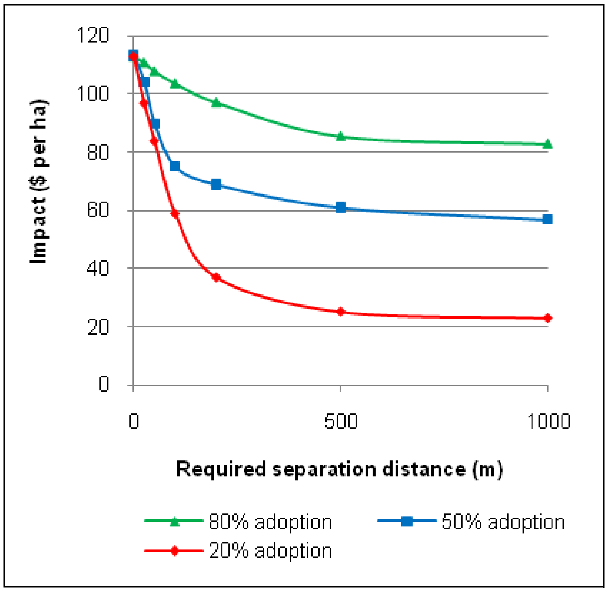


Figure 5. Economic impacts of Bt maize across a likely range of isolation distances at varying adoption rates for a representative producer with a farm size of 1.73 ha.

The distribution of observed separation distances is not normally distributed, neither was it found to conform to other distributions such as exponential, log-normal, etc. The distribution has a wide variability, with a standard deviation of 193.4 m^2, and is right-skewed, with a large number of zeros and a kurtosis of 34.5m. The distribution does support, however, the general characterization of the region that farm size is bi-model, with a majority of producers having small maize landholdings (less than 1 ha), as well as a significant number of producers having larger landholdings greater than 5 ha.

Results

The potential benefits from Bt maize are highly sensitive to the prescribed minimum separation distance (Figure 5). For a representative producer, the maximum expected benefit from Bt maize is $113 per hectare under 20% adoption, which is quickly eroded once isolation distances are imposed on Bt maize producers, even at modest separation distances of 100 m or less (Figure 5). Nearly one-half (49.8%) of the potential benefits would be lost to coexistence with moving the required separation distance from 0 to 100 m. Between 0 and 50 m, benefits would fall by 32.5% (or from $113 to $84 per ha), and increasing the separation distance between 50 and 100 m would reduce potential benefits by an additional 23.8% (or from $84 to $59 per ha; Figure 5). Expected Bt maize benefits would continue to fall at an approximate rate of $0.38 per meter until a separation distance of 500 m is reached, at which point the loss in potential benefits would begin to level off. This leveling off is explained by the occurrences when the representative producer's nearest neighbor is a potential adopter of Bt maize, precluding the need for coexistence, even if the two are adjacent to one another. Hence, with a low level of adoption, expected benefits asymptotically approach 20% of the maximum benefit, which in this case corresponds to potential benefits of $22.60 per ha as separation distance grows larger (Figure 5).

The negative effect of maintaining coexistence is greatest under the 20% adoption profile, but weakens as the adoption rate is increased to 50 and 80% (Figure 5). With greater likelihood of nearby producers adopting Bt maize, the need for creating buffer zones is significantly reduced at the higher adoption rates. As a result, potential impacts are better maintained as isolation distance is increased in the 50 and 80% adoption scenarios (Figure 5). Under an 80% adoption rate, for instance, potential impacts would only fall by 12.3% in moving the isolation distance from 0 to 100 m, compared to 34.5% and 49.7% declines with lower adoption rates of 50% and 20%, respectively. This trend would continue at the more conservative separation distances as well. With an 80% adoption rate, expected impacts would fall by only 26% if the required isolation distance was set at 1,000 m, compared to 45% and 76% declines with 50% and 20% adoption rates, respectively. At large separation distances, potential impacts would approach a limit of $90.40 per ha, corresponding to a 40% increase in potential impacts compared to 20% adoption.

At less stringent requirements—isolation distances between 25 and 100 m—adoption has less effect on potential impacts since it is more likely that producers have either enough distance between themselves and the nearest neighbor, and/or the required buffer zone is modestly sized. As illustrated in Figure 5, the three curves are much closer to one another initially, but grow further apart as separation distance is increased. Higher adoption rates would still generate the greatest impacts, however. With 80% adoption, potential impacts of $108 per ha would be generated at an isolation distance of 50 m, which would be 37 and 67% higher than the impacts of $90 and $84 per ha under 50% and 20% adoption, respectively.

The significant effect of separation distance is also evident in the cumulative distribution of potential impacts (Figure 6). Farm size was randomly drawn in this scenario from the empirical distribution of field dimensions found in the transect surveys. In particular, the results find highly truncated cumulative distributions under the low adoption rate of 20%. At a separation distance of 100 m there is a 45% probability that potential impacts would be zero due to prohibitively high coexistence costs (Figure 6). Probabilities of zero impacts increase further when larger separation distances of 500 and 1,000 m are considered, with corresponding probabilities of 76 and 79%, respectively (Figure 6).

The effect of required isolation distance remains significant even at the higher levels of potential impacts. The greatest effect of isolation distance occurs at the 90% probability level, where potential impacts would fall from a maximum of $291 per farm without any required isolation to $29 per farm with an isolation distance of 1,000 m. Thus, while 90% of producers would receive potential benefits of $291 or less without any separation distance, under a 1,000 m required separation distance 90% of the producers would have a potential impact of only $29 or less on their farm. The effect would be somewhat less in moving from an isolation distance of 0 to 100 m. The difference in potential impacts in this case would occur at the 78% probability level, where potential impacts would be reduced from $192 to $49 per farm with an isolation distance of 100 m (Figure 6).

At higher adoption rates of 50 and 80%, separation distance has much less effect on the distribution of impacts, including distributions that are both closer together and less truncated than under a 20% adoption rate (Figure 6). A 100 m separation distance would result in only an 11% probability of zero potential impact with 80% adoption, compared to a 45% probability with 20% adoption (Figure 6). Similarly, at 500 and 1,000 m separation distances, probability of zero impacts would be only 19 and 20%, respectively, under 80% adoption, compared to 76 and 79%, respectively, with an adoption rate of 20%. Separation distance does have a modest effect on potential impacts in the range of impacts between $10 and $100 per farm (Figure 6). The maximum effect would be at the 70% probability level, where potential impacts would be $130 per farm with a separation distance of 0 m, compared to $75 per ha with a 1,000 m separation distance. The probability of having potential impacts of $100 or more, however, is nearly identical across separation distance (Figure 6).

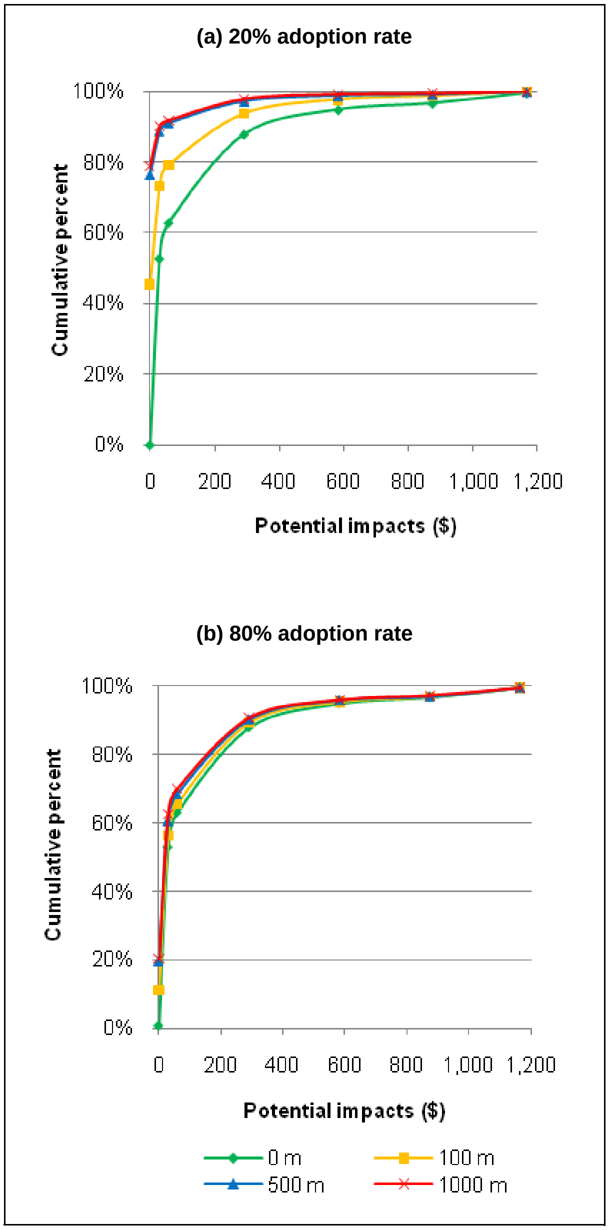
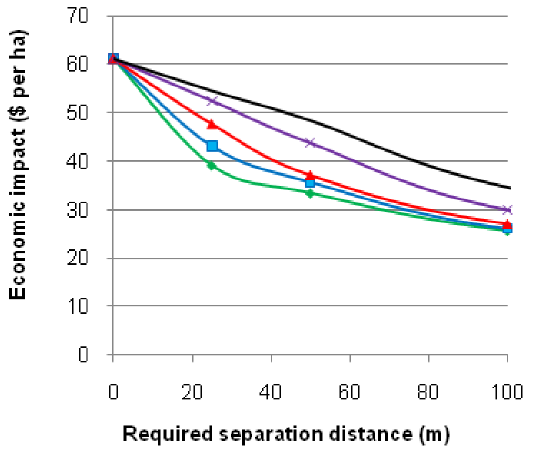


Figure 6. Distribution of potential impacts from Bt maize at 20 and 80% adoption.

Farm Size

Farm size also has an important effect on the costs of coexistence, with larger farms better able to capture potential benefits of Bt maize than smaller ones, even when scaling impacts on a component per ha basis. Figure 7 illustrates the effect of farm size on potential impacts at isolation distances of 0, 100, 500, and 1,000 m at a 20% adoption rate. Without any separation distance, potential impacts are scale neutral, with an expected impact of $65 per ha irrespective of farm size.

(a) Separation distance: 0 to 100 m



(b) Separation distance: 0 to 1,000 m

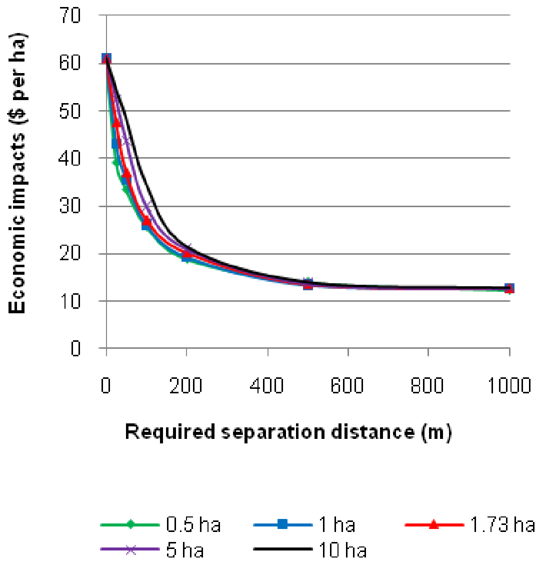
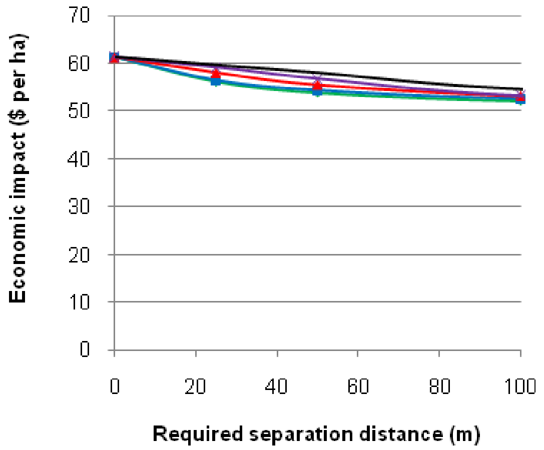


Figure 7. Potential economic impacts of Bt maize across varying farm size under 20% adoption.

(a) Separation distance: 0 to 100 m



(b) Separation distance: 0 to 1,000 m

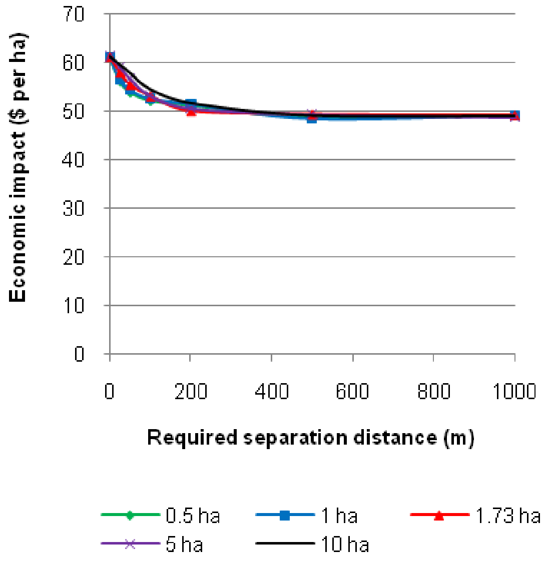


Figure 8. Potential economic impacts of Bt maize across varying farm size under 80% adoption.

Hence, farm size has no effect on unit (per ha) returns—nor does adoption rate—when isolation distances are not mandated.

The effect of farm size is clearly visible, however, even when modest isolation distances less than 100 m are considered (Figure 7). Because of greater land holdings (all else being equal), bigger farms have a higher likelihood than smaller farms of being able to self-manage required separation distances by constructing a buffer zone. Between 0 and 25m, for instance, a large farm with 10 ha of planted maize would retain 89% of the potential benefits, whereas a small farm with 0.5 ha, would only be able to retain 64% of the potential impacts (Figure 7). At 100 m, required isolation distance would begin to impact the larger farms as well. Here, a large 10 ha farm would retain 56% of the potential benefits, and a small farm would retain 45% of the potential benefits. Once isolation distances of 500 m and greater are reached, the effect of farm size nearly vanishes, as impacts grow indistinguishable across farm size (Figure 7). Here, impacts would be roughly $13.50 per ha for each farm size.

Higher adoption rates reduce the effect of farm size on coexistence costs (Figure 8). At the 80% adoption level, the increased likelihood of a farmer's nearest neighbors being potential adopters of Bt maize creates less need for establishing buffer zones. As a result, producers of all size are more or less equally able to comply with required separation distances, with only minimal differences in impacts across farm size (Figure 8). Moving the required separation distance from 0 to 25 m would reduce impacts of small farms (with 0.5 ha) by 9.1%—from $61 to $56 per ha. This is only a slightly larger decline than for larger (10 ha) farms, which would experience a 2.8% loss in potential impacts—from $61 to $59 per ha. The differences in impacts would grow even smaller as separation distance is increased. At a separation distance of 200 m, small farms with 0.5 ha would generate nearly identical potential impacts as larger farms with 10 ha, with the smaller farms having expected benefits of $51.09 per ha, just $0.67 per ha less than the $51.76 per in potential benefits of larger farms. With highly risk-averse separation distances (1,000 m) impact differences are indistinguishable across farm size (Figure 8). Potential impacts of about $49 per ha would be generated by each farm size.

Yield Performance

Required isolation distance would have only a minor effect on the potential impacts of Bt maize across an expected range of yield performance (Figure 9). Increasing isolation distance would result in larger absolute declines at the higher levels of yield performance, but in relative terms the changes would be nearly identical. Moving the isolation distance from 0 to 100 m would result in a decline of potential impacts of 53% under low-yield performance, with similar declines of 56 and 52% under average and yield performance conditions (Figure 9). Even with a large required isolation distance of 1,000 m, coexistence would impose nearly the same level of cost in relative terms, with declines of 20, 22, and 21% for low-, average-, and high-yield performance conditions, respectively. Hence, the results indicate that imposing isolation distances will have similar effects irrespective of expected performance, with producers in higher potential areas in no better position to manage isolation than producers in lower potential areas.

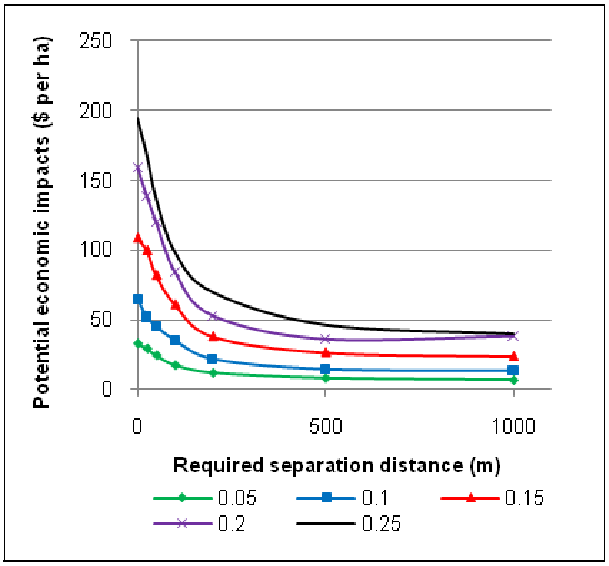


Figure 9. Potential economic impacts across an alternative range of Bt maize yield advantages under 20% adoption rate.

Discussion and Implication

The results suggest that in densely populated areas such as Kenya's coastal lowlands, implementing wide spatial separation measures (i.e., based on the Precautionary Principle) would result in substantial costs of coexistence, potentially jeopardizing the introduction of Bt maize. Following the more risk-averse (precautionary) separation distances used in other countries that range between 200 and 800 m, would be too stringent. For meaningful benefits to be generated, results suggest that Kenya's biosafety protocols will need to consider implementing much smaller distances, in the range of 25-75m.

High adoption rates can effectively shrink required separation distances by increasing the likelihood that neighboring producers are both potential adopters of Bt maize. However, technology diffusion typically proceeds in an orderly fashion, beginning with the more progressive producers, typically accounting for only about 20% of potential adopters. The model results indicate that a 20% adoption rate would do little to counteract the concentrated land holdings in the study area, and would likely make it difficult for even the more progressive producers to adopt. This would create a barrier for technology diffusion to proceed to the next stage of adoption, where average producers would begin to adopt. Hence, although an 80% adoption rate would be able to overcome much of the effect of separation distance, the model results suggest that policy would need to be introduced to quickly push adoption levels beyond a 20% adoption rate.

Conclusions

The purpose of this study was to describe the spatial distribution and concentration of open pollinated maize varieties in coastal lowland Kenya and analyze how this distribution would affect the economic feasibility of coexistence between GM and conventional maize varieties. The results suggest the critical role that adoption can play in reducing coexistence costs, implying the need for policy makers to consider adoption rates when establishing required isolation distances. Low adoption rates, likely to occur early in the diffusion process, would result in low potential benefits if isolation distances of 150 m or more were imposed on producers. Policy to encourage a wider adoption of Bt maize would enable more precautionary biosafety protocols.

As African countries approach large-scale commercial releases, biosafety protocols will continue to be an on-going area of concern. Once benefits become more visible, it is expected that stakeholders at all levels will be better able to make informed decisions to reach agreement on how to balance risks with the potential benefits. Future research can continue to assist in the decision-making process. This could include research on identifying other mechanisms by which GM and conventional varieties can coexist, such as alternative property rights and improved legal and institutional frameworks.

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