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Yield Perceptions, Determinants and Adoption Impact of on Farm Varietal Mixtures for Common Bean and Banana in Uganda

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Abstract: Crop variety mixtures (different varieties of a crop grown together in a single plot) have been successfully deployed in pathogen and pest management for several crops including wheat, common bean and rice. Despite the available evidence, promotion of this approach has remained limited in many countries, including Uganda. The factors that influence farmers' adoption of varietal mixtures for common bean and banana were assessed, as well as the perceptions of farmers on the effects of mixtures on yields, through household surveys and statistical modelling. A three-year yield increase in both common bean and banana varietal mixtures in farmer fields, of 5.2% and 28.6%, respectively, is realized using robust OLS estimates. The study reveals that accessing knowledge on the importance of crop varietal mixtures and the skills relating to the approach are crucial for their adoption. Location of the farm significantly determined the perceived yield change, which calls for more research into mixtures' suitability under particular contexts in respect to compatibility of genotypes, management practices and appropriate acreage for maximum impact. The positive effects of mixtures on yields make it an effective bioeconomy strategy. Policies that minimize the adoption barriers could improve the adoption of crop varietal mixtures on a wider scale.

Keywords: genetic diversity; landrace; traditional varieties; farmer; bio-economy; genetic mixtures; biologically friendly; pest; pathogen

1. Introduction

Many smallholder farmers in developing countries have limited access to adequate and diverse planting materials that are needed to improve the production of their staple crops [1]. In recent decades the focus of formal breeding coupled with the homogenization and reduction in number of seed companies, and the functioning of global markets, has led to the promotion of uniform planting of single varieties at the expense of access to crop variety diversity [2]. This trend has ignored fundamental issues of the availability and use of crop diversity by smallholder farmers, who often have distinct needs for a wider range of diversity adapted to their vulnerable ecosystems [3]. The diverse crop base of these smallholder farmers is further at risk due to new and exotic pests and pathogens spread through increased trans-boundary movements of living organisms brought about by globalization of trade and exacerbated by climate change [4]. The varietal diversity is one of the few assets available for smallholder farmers in developing countries to reduce pests and diseases damage in their crops, together with the knowledge to manage and deploy this diversity appropriately [5]. For the resource limited subsistence farmers, the use of varietal mixtures is one of the few options available to adapt to increasing climate instability, plant pests and diseases and decreasing water availability [5].

Generally, farmers reduce crop varietal diversity and specialize in monocultures, when private benefits, including subsidies, provide a comparative advantage [6]. In the long term, however, the loss of species diversity and their genetic variation, as well as associated ecosystem services, can have high costs to the society and the farmers themselves [7]. Monocultures facilitate the spread, multiplication and evolution of pests and diseases throughout the crops [4]. In such cropping systems, increased genetic uniformity, in the form of decreased numbers of varieties in farmers' fields, increases the risk of disease epidemics [8]. The Irish potato famine in the mid-1800s is a dramatic example of how uniformity of the potato crop (monocultures) resulted in a devastating crop loss [9]. Changes in the climate can potentially bring new pests and pathogens to the agricultural system, or increase the population and aggressiveness of existing populations with changes in temperatures [10]. Farmers are commonly recommended to use pesticides to control pests and diseases and to improve crop yields [6]. Combining pesticide use with appropriately improved commercial varieties of crops represents the standard practice in industrialized (high input) agriculture. The productivity of the system, however, can be short lived, with the pests and pathogens overcoming the resistance genes deployed over wide areas in a few years [11].

The large use of agricultural chemical products for intensive agricultural practices contrasts with the objectives of the United Nations' Framework on Climate Change, in particular with Article 2 of the Paris Agreement, and the accompanying decision 17 of the 21st Conference of Parties (COP21), on enhancing adaptive capacity, strengthening resilience and reducing vulnerability to climate change [12,13]. The latter also affects world food security and livelihoods [14]. Intensive agriculture can increase crop yields in the short run under accompanying cost effective chemical inputs, but in the long run, it generates several environmental problems [15]. Agricultural strategies that could simultaneously support landscape resilience, greenhouse gas mitigation and rural livelihoods, may represent the best solution for sustainable rural development [16,17]. Crop varietal diversification is one strategy considered important in ensuring the resilience of agro-ecosystems [10]. The genetic or varietal mixture approach, one of the approaches of crop diversification, has been successfully used and well documented in pathogen management in several crops including wheat, common bean and rice [18–27]. Genetic mixtures provide an effective buffering effect to pest damage and provide a yield advantage [27]. Tooker and Frank [6] compared pest and disease incidence in monocultures and diverse mixtures, and found that the latter reduced pest damage whilst increasing yields. The benefits of diversity and mixtures are also seen in enhancing ecosystem services [6,27].

The principle behind growing varietal mixtures over pure stands is to have resistant plants between the susceptible ones so as to slow down the spread of pests and diseases, and to minimize losses in yield due to epidemics [27–29]. The proportion of resistant varieties in a mixture and the arrangement determines the effectiveness of mixtures in reducing the damage from particular pests and diseases [30,31]. Mixtures of varieties enhance resilience to climate change like drought and freezing and thus offer greater yield stability as compared to pure strands [32]. Close to 50% of wheat fields in Europe and rice in China have been planted as mixtures of different varieties [33,34]. In the United States, 18% of soft winter wheat planted in Washington State in 2000 and 7% of Kansas wheat planted in 2001 were cultivar mixtures [26,29]. These mixtures were typically constructed as random mixtures of five cultivars that varied in susceptibility to important diseases (e.g., rusts, powdery mildew), and yielded nearly 30% better than monocultures when disease was present or even slightly improved yield when disease was absent [6,23,33–36].

Managing pests and diseases while ensuring resilience to climate change is more important for developing countries, where agriculture is pivotal to rural development and to guarantee food security. Agriculture in these countries is largely small-holder farm-led and mainly characterized by poor access to markets and limited technologies [36,37]. Despite this, the majority of varieties bred today are for large-scale farming solutions that assume predictable temperature and precipitation patterns [2]. Pests and diseases cause the largest loss of yield in East Africa, compared to other factors like drought and soil infertility [38]. In Uganda, the use of chemical products for managing pests and diseases is not common. Farmers often perceive that the cost of purchasing these chemicals may not compensate for the extra yields they garnish [39,40]. Non-chemical approaches for managing pests and diseases have been investigated for some of the important food crops in Uganda [38], such as common bean [28,41]. These varietal diversity approaches, including the use of mixtures, have been shown to reduce risk and vulnerability to pests and diseases on- farm [5,28,41].

Despite all of the above stated benefits of increasing varietal diversity on-farm, these approaches often entail considerable logistical and/or economic challenges. For example, growing more than one variety in a single field may not be compatible with modern agricultural equipment. Other challenges are associated with differing characteristics of varieties in terms of maturity period, growing character (bushy, climbing, tall, short etc.), cooking time, which make some varieties incompatible in terms of harvesting, marketing, cooking or growing together and therefore call for careful deployment on the farm as well as during post-harvest handling. Thus, with questionable economic benefits and considerable challenges, techniques to increase this diversity may be rarely implemented by some growers [6,10,42]. In contrast, logistics associated with mixtures (like mixing seeds, harvesting, marketing) have not hindered production, particularly with small grains where varietal mixtures have been most popular [6,29].

Banana and common bean were chosen for this study because they are the most important carbohydrate sources in Uganda, where more than 7 million people depend on them for their daily meals [43]. Common bean is also the most important and cheapest plant-based protein source for the people of Uganda [44,45]. Net production of both common bean and bananas within Uganda remains below their full potential, mainly due to losses from diseases and insect pests [45–47]. These crops are maintained as a mixture of different varieties in farmers' fields [43,48] in arrangements that include; random, rows, small plots, borders and rows in a plots according to Mulumba et al. [5]. There are different banana types including the brewing, cooking, desert, plantain; and there are different varieties within these types. An assessment of diversity done in 2008 and 2009 revealed that the average number of common bean varieties at community level in the three study sites of Nakaseke, Kabwohe and Rubaya was 22 and for banana in Nakaseke and Kabwohe was 32 [5]. Although previous studies have shown that mixtures reduce the damage caused by particular pests and diseases and increase yield [5,28,41], the adoption of mixtures in Uganda has not been steadfast. Therefore, this study carried out on both common bean and banana assessed the factors that influence the adoption of mixtures by farmers for the two crops and the farmers' perceptions about the effects of mixtures on yields. The aim of the study was to understand how the adoption of mixtures could be fast tracked in Uganda and in similar contexts in other countries.

2. Materials and Methods

The study was conducted in three sites with different tribes and climatic conditions: Nakaseke, Kabwohe and Rubaya (Figure 1 below). Nakaseke is located in central Uganda and is dominated by the Baganda tribe in the coffee-banana farming system. This site is in the Central Wooded Savannah agro-ecological zone with an altitudinal range of 1086–1280 masl, with an average rainfall of up to 1100 mm and temperature ranging between 16 and 30 Celsius. The soils in Nakaseke are sandy clay loam with low to medium productivity. Kabwohe is situated in western Uganda and is dominated by the Banyankole tribe, in a predominantly banana-cattle farming system. It is within the western medium–high farmlands agro-ecological zone with an altitude of 1400–1500 masl, and rainfall of up to 1100 mm. The soils in Kabwohe are sandy clay loams with alluvial parent rock of medium to high productivity. The average annual temperature in this site is between 12 and 28 degrees Celsius. Rubaya site is located in the south-western highlands of Uganda, with an altitude ranging between 1800–2200 masl, rainfall up to 1100 mm, and average annual temperatures between 11 and 25 Celsius. Rubaya is dominated by the Bakiga ethnic group and has volcanic soils with medium to high productivity. The common bean assessment was done in the three sites, while the banana assessment was only done in Nakaseke and Kabwohe sites because it is not an important crop in Rubaya. These sites were purposefully selected because farmers here grow banana and/or common bean and there were high levels of diversity in the two crops.

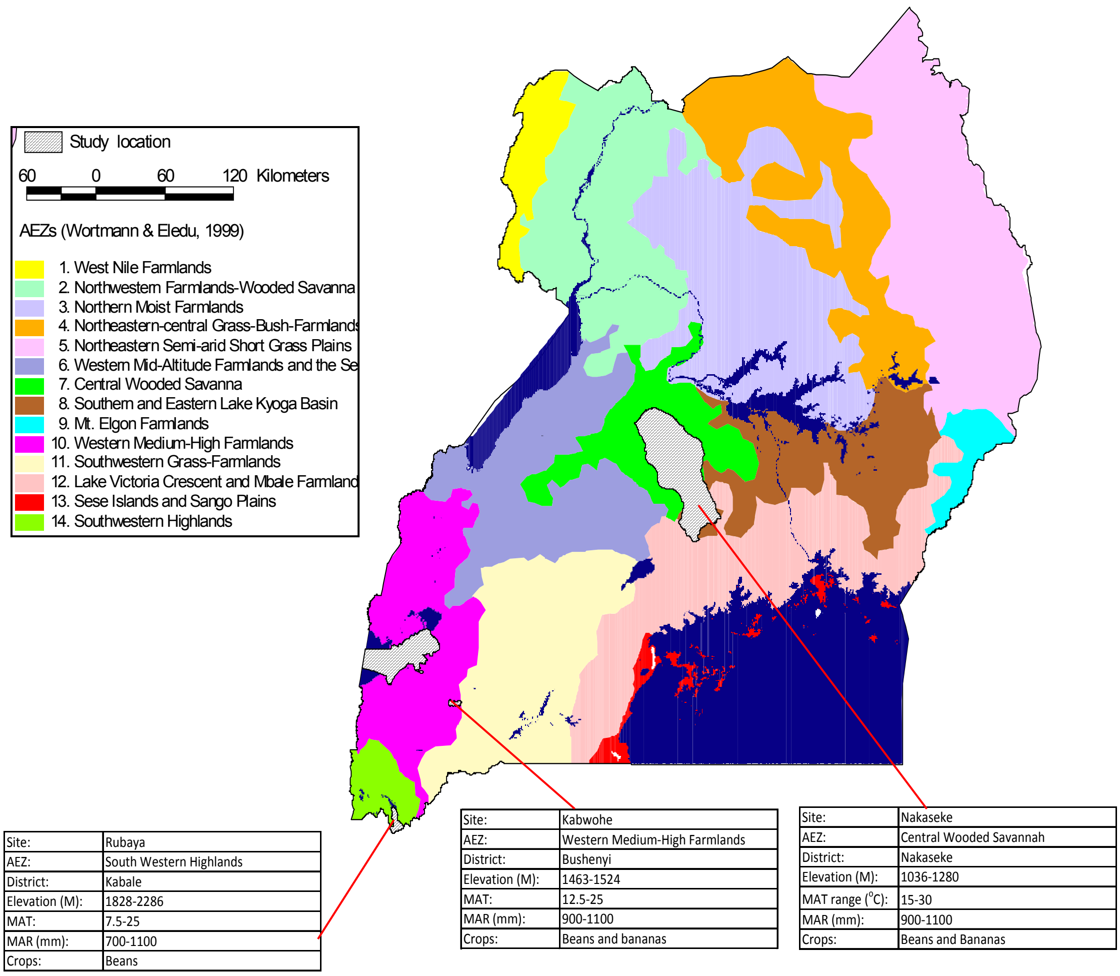


Figure 1. Map of Uganda showing location of the study sites.

The methodological approach involved household surveys through which information from farmers was collected on: socio-demographic characteristics; variety types and how they had been grown and changed over a period of five years; why farmers grew mixtures of varieties; what had been achieved from having many varieties on-farm; changes in yields in the five years and what led to these changes as well as the major pests and diseases and how they were being controlled. Households at each site were selected using a randomly stratified design (by village), to ensure geographic representation across the four target villages within each agro-ecological site, totalling 240 households (60 households for common bean only from Rubaya site and 180 households for common bean and banana from Kabwohe and Nakaseke sites). During the household surveys, a deliberate effort was made to ensure that both male and female farmers were involved in equal numbers as respondents;

regardless whether it was a male headed or female headed households. In this regard, for 50% of the households a woman was questioned to answer the survey.

The empirical analysis aims to identify factors that influence the adoption of crop mixtures by farmers involved in the survey. Variable names, and their descriptions are listed in Table 1. The analysis is pivotal to identify and to quantify barriers or constraints that may limit the mixtures adoption. We assume that observable characteristics of the *i*-th farmer influences his or her choice of adopting mixtures in terms of the probability of mixtures adoption. Empirically, since we are investigating choices, a qualitative dependent variable approach is taken.

$M_i{}^*$ is defined as stochastic variable that measures the propensity of the farmer to adopt variety mixtures. Propensity to adopt variety mixtures cannot be observed, but instead dichotomous variable is measured:

$$M_i = \begin{cases} 1 \text{ if } M_i{}^* > 0 \\ 0 \text{ if } M_i{}^* \leq 0 \end{cases} \quad (1)$$

The propensity that the *i*-th farmer adopted variety mixtures depends on a set of *k* explanatory variables as shown in Table 1 where $\mathbf{x}_i$:

$$M_i{}^* = \mathbf{x_i}'\boldsymbol{\beta} + u_i \quad \mathrm{i} = 1,\ 2,\ \ldots,\ \mathrm{n} \quad (2)$$

where $\boldsymbol{\beta}$ is a *k* vector of unknown parameters and u_i mbodies the unobservable characteristics distributed by the standard logistic distribution. This formulation describes a conventional logistic regression model where $\boldsymbol{\beta}$ estimates can be obtained using maximum likelihood estimator (MLE) [48,49].

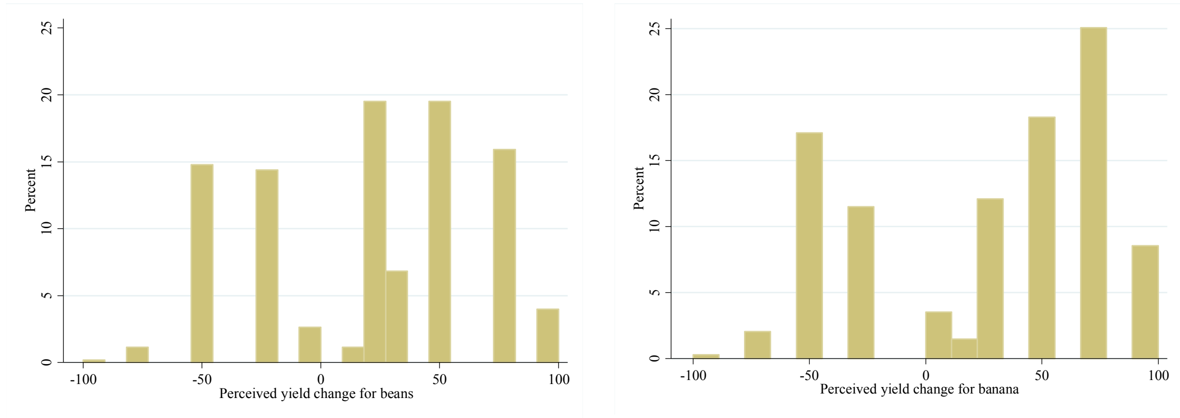
Table 1. Description of variables used to assess mixtures adoption determinants.

Variable Name	*Type*	*Variable Description*
M-Dependent Variable	Binary	Adoption of mixtures [1 = yes; 0 = No]
d_age1	Binary	Age [1 if famers age >40 & <61; 0 otherwise]
d_age2	Binary	Age [1 if famers age >60; 0 otherwise]
Gender	Binary	gender of respondent [1 = Male; 2 = Female]
Householdsize	Continuous	the number of components in the household
Agr_income	Binary	the major source of income [1 crop farming; 0 = other activity]
Cultivated_area	Continuous	total area cultivated with bean & bananas (acres)
Belongtofarmergroup	Binary	participation to farmer group [1 = yes; 2 = no]
site_1	Binary	geographical area where the household is [1 = Nakaseke; 0 otherwise]
site_2	Binary	geographical area where the household is [1 = Kabwohe; 0 otherwise]
Ban_producer	Binary	Producer of bananas [1 = yes; 0 = No]
Bean&ban	Binary	Joint producer of Bananas & Beans [1 = yes; 0 = No]

In a second model, the impact of the mixtures adoption on the farmer perceived yield change (*PYC*) is analysed. The *PYC* is the change in yields that the farmers reported to have realized in a period of five years. Following Gotor et al. [49] a perceived change is assessed, and not an actual change, since smallholder farmers in the study sites do not keep farm records. Previous research by Adesina and Baidu-Forson [50] indicated the significant role of farmers' perception of technology attributes like productivity in shaping farming decisions. In the same way, Negatu and Parikh [51] found out that the farmers' perceptions about grain yield affected the adoption decision of modern varieties of wheat in Ethiopia. Information on the *i*-th farmer *PYC* on the last one, three and five years was collected using the following questions; "Have your yields (productivity) increased or decreased over the last one, three and five years? And by what percentage has your bean or banana yield increased/ decreased?" Respondents could answer by indicating an increase or a decrease and then quantifying the perceived yield change using a scale ranging from 1 to 5 (1 = none; 2 = ±1–25%; 3 = ±26–50%; 4 = ±51–75%; 5 = ±76–100%). This data was used to build a continuous latent variable of perceived yield change, PYC_i ranging from −100% to +100%. The farmer perceived yield change was indexed by time, PYC_{it}

(t = 1, 3, 5) since each i-respondent indicated the perceived change of yield over three different time spans (last year, three and five years).

The observed variability in farmers *PYC* (Figure 2) was modelled as a linear function of m households time-invariant characteristics x_i (including household head age, gender, size, participation to farmers group, residence, number of years growing bean or banana, cultivated land area for bean or banana, the simultaneous presence of both bean and banana) and n time variant cropping systems characteristics (z_{it}) such as the number of used varieties of bean and banana, the incidence of improved varieties over the total employed and the incidence of varieties that were cultivated as varietal mixtures over the total varieties used. The latter variable was interpreted as a proxy of the degree of the commitment the farmer had to the adoption of varietal mixtures. The higher this value was, the greater was the use of mixtures by the farmer. Since the observed variability in farmers *PYC* could depend on time-dependent unobservable characteristics, time varying fixed effects ($\mathbf{T}_t$) were included.



(**A**) (**B**)

Figure 2. Unconditional frequency distribution of perceived yield change (%) for beans (**A**) and banana (**B**).

The linear relation function for PYC_{it} was written as follows:

$$PYC_{it} = \alpha + \mathbf{x_i}'\boldsymbol{\beta} + \mathbf{z_{it}}'\boldsymbol{\gamma} + \mathbf{T_t}'\theta + u_{it} \quad \mathrm{i} = 1,\ 2,\ \ldots,\ \mathrm{n};\ \mathrm{t} = 1,\ 3,\ 5 \tag{3}$$

where α is the intercept of the equation, $\boldsymbol{\beta}$, $\boldsymbol{\gamma}$ are respectively m and n vectors of unknown parameters to be estimated, representing the marginal effect of the explanatory variables on the *PYC*, $\boldsymbol{\theta}$ vector controls time-dependent unobservable characteristics, while u_{it} is the error term including the unobservable part of PYC_{it}. This model tested the hypothesis that the source of the observed variation of farmers *PYC* could be explained by the intensity of mixtures adoption measured as incidence of varieties that were cultivated as varietal mixtures over the total varieties. In order to identify some possible interactions between factors affecting adoption of mixtures on *PYC*, incidence of varieties in mixtures with the cultivated area, incidence of local varieties and years spent cultivating the crop; were finally added. Equation (3) was used for analysing *PYC* of both beans and bananas using OLS estimator. Table 2 below shows the descriptive statistics of the variables included in the two models.

Table 2. Descriptive statistics of the variables included in the two equations.

Variable	Bean [a]				Banana [b]			
	Mean	**Std.dev**	**Min**	**Max**	**Mean**	**Std.dev**	**Min**	**Max**
Perceived Yield Change (%)	20.48	45.90	−100	100	26.25	53.03	−100	100
d_age1—*Age: [1 if famers age >40 & <61; 0 otherwise]*	0.45	N.A	0	1	0.45	N.A	0	1
d_age2—*Age: [1 if famers age >60; 0 otherwise]*	0.15	N.A	0	1	0.18	N.A	0	1
Gender—*Gender of respondent [1 = Male; 2 = Female]*	1.60	N.A	1	2	1.63	N.A	1	2
Household Size—*The number of components in the household*	6.46	2.89	1	24	7.20	3.11	1	24
Agr_income—*The major source of income [1 = crop farming; 0 = other activity]*	0.93	N.A	0	1	0.95	N.A	0	1
Cultivated_area—*Total area cultivated with bean & bananas (acres)*	0.81	0.61	0	4	1.54	1.45	0.13	7
Belong to farmer group—*Participation to farmer group [1 = yes; 2 = no]*					1.05	0.21	1	2
Bean & banana—*[1 if famers grow both Bean and Banana; 0 otherwise]*	0.61	N.A	0	1	0.97	N.A	0	1
Site_1—*[1 = Nakaseke; 0 otherwise]*	0.32	N.A	0	1	0.46	N.A	0	1
Site_2—*[1 = Kabwohe; 0 otherwise]*	0.34	N.A	0	1	0.54	N.A	0	1
Site_3—*[1 = Rubaya; 0 otherwise]*	0.34	N.A	0	1				
Past experience—*Farmers experience in cultivating the crops [years]*	21.31	14.36	0	60	21.51	14.98	0	60
sh_mixtures—*Incidence of varieties cultivated as varietal mixtures over the total varieties*	0.45	0.42	0	1	0.86	0.25	0	1
sh_localvarieties—*Incidence of local varieties cultivated over the total varieties*	0.46	0.36	0	1	0.52	0.32	0	1
total_varieties—*Total number of used varieties*	3.97	2.06	1	12	6.11	2.64	2	16

[a] Sample size 172; [b] Sample size 108.

3. Results

3.1. Mixtures Adoption

Following studies with similar methodology [7,49], coefficients are considered significant at the 10% level, or better. The size of the household, negatively and significantly affected the farmer's decision to adopt mixtures, irrespective of the crop (Table 3). Age and gender of household head did not affect its propensity to adopt varietal mixtures. Participation in a farmers group had a positive influence on the decision to adopt mixtures (Figure 3). In addition, a greater propensity to adopt mixtures was observed among households that are mainly dependent on agriculture for their incomes, and in households that are producers of bananas. Location and size of the farm (in terms of total area cultivated) did not significantly affect the mixtures adoption.

Table 3. Factors affecting mixtures adoption. Logit estimate.

Variable	*Coef.*	*Std.dev*	*p-Value*
d_age1	0.421	0.450	0.350
d_age2	1.107	0.781	0.156
Gender	0.701	0.433	0.106
Household Size	−0.146	0.078	0.062 *
Agriculture income	1.744	0.830	0.036 **
Cultivated area	0.083	0.228	0.716
Belong to farmer group	1.983	1.067	0.063 *
site_1	−1.087	0.897	0.225
site_2	0.144	0.964	0.882
Banana producer	2.661	1.590	0.094 *
Bean &banana	−0.097	1.526	0.949
_cons	−4.061	1.888	0.031 **

* p-value < 0.1; ** p-value < 0.05.

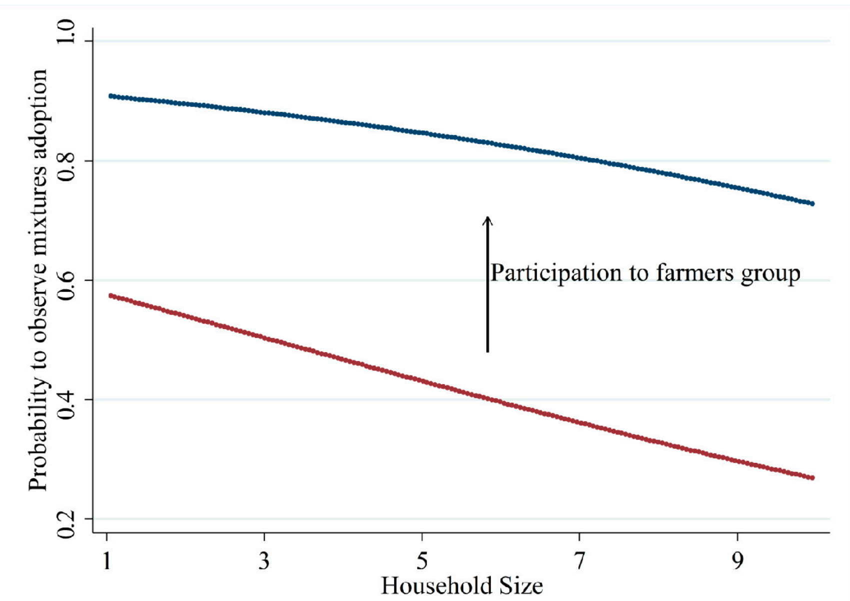


Figure 3. The estimated effect of "household size" and "participation in a farmers group" on the probability to observe mixtures adoption of farmers.

3.2. Effect of Mixtures on Perceived Yield

For both beans and bananas, incidence of varieties in mixtures positively and significantly affected the *PYC* as shown in Table 4 below. By estimating Equation (3), the per year (t) impact of incidence of mixtures (sh_mixtures) on *PYC* can be calculated as t × γ × sh_mixtures. The γ parameters of 3.85 and 11.09 indicated the average change in the percentage of perceived yield respectively for beans and bananas per year, in the case that the total varieties were used as mixtures (when sh_mixtures increases from 0 to 1). For instance, the observed average incidence of varieties in mixtures was 0.45 for beans and 0.86 for bananas. Thus, the impact of mixtures was estimated to increase yield in a period of three years equivalent to 3 × 0.45 × 3.85 = 5.2% for beans and 3 × 0.86 × 11.09 = 28.6% for bananas.

Other significant determinants of *PYC* for beans were: total area under cultivation, participation in a farmers group, both influencing positively the *PYC* and the location. Households located in Kabwohe and Rubaya experienced lower yields change compared to those located in Nakaseke. About 20% increase of the yield with the respect to a period of five years was imputed for time-dependent unobservable characteristics that were indicated in the model as θ parameters.

For banana, other significant determinants of *PYC* were: households head in the age range between 40 and 61 years old who experienced higher *PYC* (+18.1%) compared to the others; location where farmers located in Kabwohe reported a lower *PYC* compared to those living in the other regions (−22.8%).

Table 4. Determinants of Perceived yield change (%) for Beans and Banana—OLS estimates.

Parameters	Beans [a]				Banana [b]			
	Coef.	**Std.dev ***	***t*-Stat**	***p*-Value**	**Coef.**	**Std.dev ***	***t*-Stat**	***p*-Value**
β parameters								
d_age1	1.18	4.97	0.24	0.813	18.81	7.14	2.64	0.009
d_age2	5.49	8.82	0.62	0.534	15.17	10.01	1.52	0.131
Gender	−2.95	4.14	−0.71	0.477	9.73	6.38	1.52	0.128
Household Size	−0.30	0.86	−0.35	0.724	−0.42	0.96	−0.44	0.659
Agr_income	−8.40	6.92	−1.21	0.226	−10.02	13.46	−0.74	0.457
Cultivated_area	13.87	5.19	2.67	0.008	12.61	11.27	1.12	0.264
Belongtofarmergroup	20.31	6.50	3.12	0.002	−6.19	14.19	−0.44	0.663
bean&ban	−17.07	11.51	−1.48	0.139	−8.00	16.78	−0.48	0.634
Past experience (years cultivating the crop)	−0.04	0.24	−0.16	0.869	0.25	0.66	0.38	0.706
Site_2	−15.21	6.83	−2.23	0.026	−22.76	7.76	−2.93	0.004
Site_3	−26.77	11.80	−2.27	0.024				
γ parameters								
sh_mixtures (incidence of varieties in mixt.)	3.85	2.13	1.81	0.071	11.09	4.83	2.3	0.022
sh_locvarieties (incidence of loc. var.)	1.60	1.82	0.88	0.378	1.00	3.58	0.28	0.779
total_varieties (total of varieties)	−0.35	0.29	−1.24	0.215	−0.42	0.39	−1.09	0.278
Interaction terms								
sh_mixtures × sh_loc. Varieties	−0.92	11.21	−0.08	0.935	−36.39	15.16	−2.4	0.017
sh_mixtures × Cultivated Area	−1.93	7.67	−0.25	0.801	−3.33	11.74	−0.28	0.777
sh_mixtures × Past experience	−0.40	0.30	−1.32	0.186	−1.06	0.68	−1.55	0.122
θ parameters								
T_3	9.25	6.01	1.54	0.125	−7.36	12.97	−0.57	0.571
T_5	20.95	7.51	2.79	0.005	−24.61	22.80	−1.08	0.281
A	17.70	18.02	0.98	0.326	51.94	31.21	1.66	0.097

Note: [a] $N = 516$, $R^2 = 0.12$; [b] $N = 324$, $R^2 = 0.16$. * Robust standard errors clustered at the household level to account for the fact that households are represented thrice in the data. In bold are reported significant variables.

4. Discussion and Conclusions

This study revealed that a number of factors influence the farmers' decision to grow varietal mixtures of common bean and banana. Participation in a farmers' group had a positive influence on the decision to adopt mixtures (Figure 3). This could be attributed to the fact that in farmers groups, there is exchange and sharing of practical knowledge and experiences about the value of growing mixtures, thereby influencing member farmers to adopt the technique and realize increased yields. According to the study by Mwaura [52], membership in farmer groups was observed to lead to achievement of higher yields for banana in Uganda. This is consistent with results of other studies, where group extension had been associated with superior adoption rates of agricultural technologies [53].

A greater propensity to adopt mixtures was observed among households that are mainly dependent on agriculture for their primary incomes. Households depending on agriculture as their primary source of income have a greater necessity to understand what approaches, techniques and methods could work better so as to realize the best returns on their efforts. Households who are not purely dependent on agriculture have less investment in agricultural practices since they can look elsewhere to support their livelihoods. Households that are producers of bananas were more likely to adopt mixtures than those households growing beans, possibly because traditionally, banana growing in Uganda has been done in mixtures [48], and even the commercialization of bananas has not changed this practice much. The reverse is true for beans where subsidies and single variety seed access for commercialization has had a negative influence on availability of planting materials for the growing of mixtures.

Location and size of the farm (in terms of total area cultivated) did not significantly affect the mixtures adoption. This is similar to the findings of Jarvis et al. [54], in their global synthesis of 24 crops, that farmers' growing more varieties of a crop did not necessarily know total area cultivated. This indicates that mixtures may be adopted regardless of where the farm is located and regardless of its area of coverage. The size of the household negatively affected the farmers' decision to adopt mixtures. This is in agreement with the study by Shiferaw and Holden [55] which established that for a given land-man ratio, households with larger families seem to accept less risk in experimenting with technologies.

Age and gender of household head did not affect its propensity to adopt varietal mixtures. According to the findings by Asiedu-Darko [56], gender had no significant effect on the adoption of agricultural technologies in Ghana while age correlated negatively with adoption, where older farmers were more likely to stick to use of traditional farming methods whereas younger farmers preferred use of modern methods of farming. However, age was found to positively influence adoption of sorghum in Burkina Faso [46], therefore the relationship between age and adoption of agricultural technologies varies with the type of technology being introduced [50]. For both beans and bananas, incidence of varieties in mixtures positively affected the perceived yield change (*PYC*). The observed average incidence of varieties in mixtures was 0.45 for beans and 0.86 for bananas. The mixtures were estimated by our models to increase yield in a period of three years equivalent to $3 \times 0.45 \times 3.85 = 5.2\%$ for beans and $3 \times 0.86 \times 11.09 = 28.6\%$ for bananas. The difference in the two percentages could imply that there are differences in the diffusion of mixtures among the two crops, but this requires a validation study. This difference could be brought about by several factors including the intrinsic ability for a given crop to respond to the mixture advantage, the annual or perennial nature of the crop as well as the agronomic practices employed, among others. This is in agreement with Doring et al. [57] who observed that the risk of low yields decreases by using varietal mixtures, and that this advantage is more pronounced under higher variability conditions. As one variety fails, another one compensates for the failure; the genotype diversity provides insurance against environmental fluctuations.

Other significant determinants of *PYC* for beans included the relationship between total area under cultivation and yields. The results imply that farmers perceive that the bigger the area that was planted with common bean mixtures, the greater the yields should be, considering the productivity per unit area. Site location significantly determined the *PYC*, in that households located in Kabwohe and Rubaya perceived lower yields change for both beans and bananas compared to those located in Nakaseke. This could be attributed to many factors including soil type, agronomic practices, inputs, the compatibility of the genotypes put in the mixtures, the management accorded to them and the climatic conditions of particular sites, among others. This is in agreement with the findings by Andow [58], Baggen and Gurr [59], that effectiveness of crop varietal diversity approaches can be context dependent. It was also noted by Wilhoit [60] that varietal mixtures should contain varieties with compatible agronomic characteristics that do not require farmers to change production practices such as planting and harvesting time, nor any economic investment in new equipment.

Head of banana households in the age range between 40 and 61 years showed a higher *PYC* (+18.1%) from growing mixtures compared to the other age groups. The practical knowledge and experience of this age group in managing agricultural crops seems to include an increased profit from the use of mixtures. The study by Edmeades et al. [61] demonstrated positive associations between the age of the banana plantation, variety diversity and age group. The older the plantation, the longer the time span families have had to accumulate diverse banana types within and over generations of managers. Factors that may have influenced the *PYC* are the actual yields respondents obtained, the food security realized, as well as the income earned from the surplus production over the period of five years.

A limitation of this study was the unavailability of empirical yield data to validate the change in yield perception over the period of five years, as assessed. Despite this, our study has confirmed that the incidence of mixtures, and the yields accruing from the cultivated area, in the context of site location and age of farmers, do determine the farmers' perceptions on yield. From these results we recommend that when promoting mixtures, the site location and age of farmers should be scrutinized to ensure that the varieties grown in the mixtures are suitable, and that, furthermore, these mixtures will lead to improved productivity per unit area planted. In this regard, more research into mixtures suitability for different environments in respect to the compatibility of the varieties, suitable management practices and most appropriate acreage for optimum yield is needed. This would include empirical measurements of yield and yield stability over time when collecting farmer perceptions.

This study has confirmed that farmers do perceive that varietal mixtures can increase yields. It therefore points to the potential of further mixture adoption, which has been confirmed by other studies showing that mixtures can increase yields in addition to making agro-ecosystems more resilient and less vulnerable to pests and diseases [5,28,41]. Access to crop varietal diversity also provides an opportunity for Ugandan growers to identify varieties that have the higher resistance to insects, diseases and abiotic stress, so they may use these varieties in their production fields to increase yields, quality and economic return.

Awareness creation about the importance of crop varietal mixtures as well as the practicability and knowledge of applying them is crucial for their adoption as seen from the way membership to a farmer group influenced positively the decision to adopt them. Given that adoption of mixtures did not appear to be largely influenced by size and location of the farm provides opportunity for expansion of mixtures to a wide cross-section of farm holdings. The positive effects of bean and banana mixtures estimated by OLS models on yields confirm that mixtures of bean and banana varieties could be considered an effective bio-economy strategy [62,63]. Implementing policies and strategies that minimize barriers to adoption of mixtures could improve their adoption on a wider scale, thereby optimizing the positive impacts.

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References

1. Coomes, O.T.; McGuire, S.; Garine, E.; Caillon, S.; McKey, D.; Demeulenaere, E.; Jarvis, D.; Aistara, G.; Barnaud, A.; Clouvel, P.; et al. Farmer seed networks make a limited contribution to agriculture? Four common misconceptions. *Food Policy* **2015**, *56*, 41–50. [CrossRef]
2. López-Noriega, I.; Dawson, I.K.; Vernooy, R.; Köhler-Rollefson, I.; Halewood, M. Agricultural diversification as an adaptation strategy. *Agric. Dev.* **2017**, *30*, 25–28.
3. Jarvis, D.I.; Hodgkin, T.; Sthapit, B.R.; Fadda, C.; Lopez-Noriega, I. A Heuristic Framework for Identifying Multiple Ways of Supporting the Conservation and Use of Traditional Crop Varieties within the Agricultural Production System. *Crit. Rev. Plant Sci.* **2011**, *30*, 301–349. [CrossRef]
4. Finckh, M.R.; Wolfe, M.S. Diversification strategies. In *The Epidemiology of Plant Disease*; Cooke, B.M., Gareth Jones, D., Kaye, B., Eds.; Springer: New York, NY, USA, 2006; pp. 269–308.
5. Mulumba, J.W.; Nankya, R.; Adokorach, J.; Kiwuka, C.; Fadda, C.; De Santis, P.; Jarvis, D.I. A risk-minimizing argument for traditional crop varietal diversity use to reduce pest and disease damage in agricultural ecosystems of Uganda. *Agric. Ecosyst. Environ.* **2012**, *157*, 70–86. [CrossRef]
6. Tooker, J.F.; Frank, S.D. Genotypicaly diverse cultivar mixtures for insect pest management and increased crop yields. *J. Appl. Ecol.* **2012**, *49*, 974–985. [CrossRef]
7. Bellon, M.R.; Gotor, E.; Caracciolo, F. Assessing the effectiveness of projects supporting on-farm conservation of native crops: Evidence from the High Andes of South America. *World Dev.* **2015**, *70*, 162–176. [CrossRef]
8. Schumann, G.L. *Plant Diseases: Their Biology and Social Impact*; APS Press: St. Paul, MN, USA, 1991.
9. Marshall, D.R. The advantages and hazards of genetic homogeneity [Plant resistance to diseases]. *Ann. N. Y. Acad. Sci.* **1997**, *287*, 1–20. [CrossRef]
10. Lin, B.B. Resilience in agriculture through crop diversification: Adaptive management for environmental change. *BioScience* **2011**, *61*, 183–193. [CrossRef]
11. Buitatti, M.; Ingram, D.S. Phytotoxins as tools in breeding and selection of disease-resistant plants. *Cell. Mol. Life Sci.* **1991**, *47*, 811–819. [CrossRef]
12. United Nations Framework Convention on Climate Change (UNFCCC). *Report of the Conference of the Parties on Its Twenty-first Session, Held in Paris from 30 November to 13 December 2015. Decision 17/CP.21*; UNFCCC: New York, NY, USA, 2015.
13. Adamo, S.B. About mitigation, adaptation and the UNFCCC's 21st Conference of the Parties. *Rev. Bras. Estud. Popul.* **2015**, *32*, 609–618. [CrossRef]
14. Hedger, M.; Campbell, B.M.; Wamukoya, G.; Kinyangi, J.; Verchot, L.; Wollenberg, L.; Loboguerrero, A.M. Progress on Agriculture in the UN Climate Talks: How COP21 Can Ensure a Food-Secure Future. 2015. Available online: https://ccafs.cgiar.org/publications/progress-agriculture-un-climate-talks-how-cop21-can-ensure-food-secure-future#.WXfjaKKL64s (accessed on 26 July 2017).
15. Mäder, P.; Fliessbach, A.; Dubois, D.; Gunst, L.; Fried, P.; Niggli, U. Soil fertility and biodiversity in organic farming. *Science* **2002**, *296*, 1694–1697. [CrossRef] [PubMed]
16. Giller, K.E.; Witter, E.; Corbeels, M.; Tittonell, P. Conservation agriculture and smallholder farming in Africa: The heretics' view. *Field Crops Res.* **2009**, *114*, 23–34. [CrossRef]
17. Caracciolo, F.; Lombardi, P. A new-institutional framework to explore the trade-off between Agriculture, Environment and Landscape. *Econ. Policy Energy Environ.* **2012**, *3*, 135–154.
18. Bryan, E.; Ringler, C.; Okoba, B.; Koo, J.; Herrero, M.; Silvestri, S. Can agriculture support climate change adaptation, greenhouse gas mitigation and rural livelihoods? Insights from Kenya. *Clim. Chang.* **2013**, *118*, 151–165. [CrossRef]

19. Wolfe, M.S.; Finckh, M.R. Diversity of host resistance within the crop: Effects on host, pathogen and disease. In *Plant Resistance to Fungal Diseases*; Hartleb, H., Heitefuss, R., Hoppe, H.H., Eds.; Fischer Verlag: Jena, Germany, 1997; pp. 378–400.
20. Finckh, M.R. Evolutionsverbot per Gesetz, oder: Die Konsequenzen der Verhinderung der Ko-Evolution in der Landwirtschaft. In *Kant, das Prinzip "Vorsorge" und die Wiederentdeckung der "Allmende"*; Lange, B., Ed.; Ergon Verlag: Würzburg, Germany, 2000; pp. 109–120.
21. Finckh, M.R.; Wolfe, M.S. The Use of Biodiversity to Restrict Plant Diseases and Some Consequences for Farmers and Society. In *Ecology in Agriculture*; Jackson, L.E., Ed.; Academic Press: San Diego, CA, USA, 1997; pp. 203–237.
22. Abate, T.; van Huis, A.; Ampofo, J.K.O. Pest management strategies in traditional agriculture: An African perspective. *Ann. Rev. Entomol.* **2000**, *45*, 631–659. [CrossRef] [PubMed]
23. Garrett, K.A.; Mundt, C.C. Epidemiology in mixed host populations. *Phytopathology* **1999**, *89*, 984–990. [CrossRef] [PubMed]
24. Mundt, C.C.; Leonard, K.J. Analysis of factors affecting disease increase and spread in mixtures of immune and susceptible plants in computer simulated epidemics. *Phytopathology* **1986**, *76*, 832–840. [CrossRef]
25. Pyndji, M.M.; Trutmann, P. Managing angular leaf spot on common bean in Africa by supplementing farmer mixtures with resistant varieties. *Plant Dis.* **1992**, *76*, 1144–1147. [CrossRef]
26. Zhu, Y.; Chen, H.; Fan, J.; Wang, Y.; Li, Y.; Chen, J.; Yang, S.; Hu, L.; Leung, H.; Mew, T.W.; et al. Genetic diversity and disease control in rice. *Nature* **2000**, *406*, 718–722. [CrossRef] [PubMed]
27. Bowden, R.; Shroyer, J.; Roozeboom, K.; Claassen, M.; Evans, P.; Gordon, B.; Heer, B.; Janssen, K.; Long, J.; Martin, J.; et al. *Performance of Wheat Variety Blends in KANSAS*; Keeping Up with Research 128; Kansas State University Agricultural Experiment Station and Cooperative Extension Service: Manhattan, KS, USA, 2001.
28. Ssekandi, W.; Mulumba, J.W.; Nankya, R.; Karungi, J.; Otim, M.; Fadda, C.; Jarvis, I.D. The use of common bean (*Phaseolus vulgaris*) traditional varieties and their mixtures with commercial varieties to manage bean fly *(Ophiomyia spp.*) infestations in Uganda. *J. Pest Sci.* **2016**, *89*, 45–57. [CrossRef] [PubMed]
29. Beddington, J.R. *The Future of Food and Farming: Challenges and Choices for Global Sustainability*; Final Project Report of the UK Government Foresight Global Food and Farming Futures; Government Office for Science: London, UK, 2011.
30. Regmi, A.; Rojas, T.; Kleinwechter, U.; Conwell, A.; Gotor, E. Integrating biodiversity and ecosystem services into the economic analysis of agricultural systems. *Biovers. Int.* **2016**. [CrossRef]
31. Hajjar, R.; Jarvis, D.I.; Gemmill-Herren, B. The utility of crop genetic diversity in maintaining ecosystem services. *Agric. Ecosyst. Environ.* **2008**, *123*, 261–270. [CrossRef]
32. De Vallavieille-Pope, C. Management of disease resistance diversity of cultivars of a species in single fields: Controlling epidemics. *C. R. Biol.* **2004**, *327*, 611–620.
33. Mundt, C.C. Use of multiline cultivars and cultivar mixtures for disease management. *Ann. Rev. Phytopathol.* **2002**, *40*, 381–410. [CrossRef] [PubMed]
34. Wolfe, M.S. The current status and prospects of multiline cultivars and variety mixtures for disease resistance. *Annu. Rev. Phytopathol.* **1985**, *23*, 251–273. [CrossRef]
35. Martinelli, J.A.; Brown, J.K.M.; Wolfe, M.S. Effects of barley genotype on induced resistance to powdery mildew. *Plant Pathol.* **1993**, *42*, 195–202. [CrossRef]
36. Smithson, J.B.; Lenne, J. Varietal mixtures: A viable strategy for sustainable productivity in subsistence agriculture. *Ann. Appl. Biol.* **1996**, *128*, 127–158. [CrossRef]
37. Utz, R.J. *Tanzania: Sustaining and Sharing Economic Growth*; World Bank: Washington, DC, USA, 2007.
38. Pretty, J.; Toulmin, C.; Williams, S. Sustainable intensification in African agriculture. *Int. J. Agric. Sustain.* **2011**, *9*, 5–24. [CrossRef]
39. Bonabana-Wabbi, J. Assessing Factors Affecting Adoption of Agricultural Technologies: The Case of Integrated Pest Management (IPM) in Kumi District, Eastern Uganda. Ph.D. Thesis, Virginia Polytechnic Institute and State University, Blacksburg, VA, USA, 2002.
40. Bekunda, M.A.; Woomer, P.L. Organic resource management in banana-based cropping systems of the Lake Victoria Basin, Uganda. *Agric. Ecosyst. Environ.* **1996**, *59*, 171–180. [CrossRef]
41. Olango, N.; Tusiime, G.; Mulumba, J.W.; Nankya, R.; Fadda, C.; Jarvis, I.D.; Paparu, P. Response of Ugandan common bean varieties to *Pseudocercospora griseola* and Angular leaf spot disease development in varietal mixtures. *Int. J. Pest Manag.* **2016**, *63*, 201. [CrossRef]

42. Letourneau, D.K.; Armbrecht, I.; Rivera, B.S.; Lerma, J.M.; Carmona, E.J.; Daza, M.C.; Escobar, S.; Galindo, V.; Gutierrez, C.; Lo´pez, S.D.; et al. Does plant diversity benefit agroecosystems? A synthetic review. *Ecol. Appl.* **2011**, *21*, 9–21. [CrossRef] [PubMed]
43. Tushemereirwe, W.K.; Kashaija, I.N.; Tinzara, W.; Nankinga, C. *A Guide to Successful Banana Production in Uganda: Banana Production Manual*, New 2nd ed.; NARO: Kampala, Uganda, 2003.
44. Buah, S. Genetic Diversity of Common Beans as Impacted on by Farmer Variety Selection for the Management of Bean Root Rots in South Western Uganda. Master's Thesis, Makerere University, Kampala, Uganda, 2010.
45. Kimani, P.M.; Buruchara, R.; Ampofo, K.; Pyndji, M.; Chirwa, R.M.; Kirkby, R. Breeding beans for smallholder farmers in Eastern, Central, and Southern Africa: Constraints, achievements, and potential. In *Pan-African Bean Research Network (PABRA) Millennium Workshop, Novotel Mount Meru, Arusha, Tanzania, 28 May–1 June 2001*; CIAT: Kampala, Uganda, 2005.
46. Wortman, C.S.; Kirkby, R.A.; Aledu, C.A.; Allen, D.J. *Atlas of Common Bean (Phaseolus vulgaris L.) Production in Africa*; Centro Internacional de Agricultura Tropica (CIAT): Cali, Columbia, 1998.
47. Singh, S.P. Broadening the genetic base of common bean cultivars: A review. *Crop Sci.* **2001**, *41*, 1659–1675. [CrossRef]
48. Nantale, G.; Kakudidi, D.A.; Karamura, E.; Karamura, D.; Soka, G. Scientific basis for banana cultivar proportions on-farm in East Africa. *Afr. Crop Sci. J.* **2008**, *16*, 41–49. [CrossRef]
49. Gotor, E.; Caracciolo, F.; Cantoa, G.M.B.; Al Nassiri, M. Improving rural livelihoods through the conservation and use of underutilized species: Evidence from a community research project in Yemen. *Int. J. Agric. Sustain.* **2013**, *11*, 347–362. [CrossRef]
50. Adesina, A.; Baidu-Forson, J. Farmers perceptions of new agricultural technology– evidence from analysis in Burkina Faso and Guinea, West Africa. *Agric. Econ.* **1995**, *13*, 1–9. [CrossRef]
51. Negatu, W.; Parikh, A. The impact of perception and other factors on the adoption of agricultural technology in the Moret and Jiru Woreda (district) of Ethiopia. *Agric. Econ.* **1999**, *21*, 205–216. [CrossRef]
52. Mwaura, F. Effect of farmer group membership on agriculture technology adoption and crop productivity in Uganda. *Afr. Crop Sci. J.* **2014**, *22*, 917–927.
53. Gotland, E.M.; Sadoulet, E.; De Janvry, A.; Murgai, R.; Ortiz, O. The impact of farmer field schools on knowledge and productivity: A study of potato farmers in the Peruvian Andes. *Econ. Dev. Cult. Chang.* **2004**, *53*, 63–92. [CrossRef]
54. Jarvis, D.I.; Brown, A.H.D.; Cuong, P.H.; Collado-Panduro, L.; Latourniere-Moreno, L.; Gaywali, S.; Tanto, T.; Sawadogo, M.T.; Mar, I.; Sadiki, M.; et al. A global perspective of the richness and evenness of traditional crop variety diversity maintained by farming communities. *Proc. Natl. Acad. Sci. USA* **2008**, *108*, 5326–5331. [CrossRef] [PubMed]
55. Shiferaw, B.; Holden, S.T. Resource degradation and adoption of land conservation technologies in the Ethiopian Highlands: A case study in Andit Tid, North Shewa. *Agric. Econ.* **1998**, *18*, 233–247. [CrossRef]
56. Asiedu-Darko, E. Effects of gender, education and age on the adoption of agricultural technologies in Ashanti, Northern and Eastern regions of Ghana. *J. Appl. Sci. Res.* **2014**, *2*, 112–118.
57. Döring, T.F.; Knapp, S.; Kovacs, G.; Murphy, K.M.; Wolfe, M.S. Evolutionary Plant Breeding in Cereals—Into a New Era. *Sustainability* **2011**, *3*, 1944–1971. [CrossRef]
58. Andow, D.A. Vegetational diversity and arthropod population response. *Ann. Rev. Entomol.* **1991**, *36*, 561–586. [CrossRef]
59. Baggen, L.R.; Gurr, G.M. The influence of food on *Copidosoma koehleri* (Hymenoptera: Encyrtidae), and the use of flowering plants as a habitat management tool to enhance biological control of potato moth, *Phthorimaea operculella* (Lepidoptera: Gelechiidae). *Biol. Control* **1998**, *11*, 9–17. [CrossRef]
60. Wilhoit, L.R. Evolution of herbivore virulence to plant resistance: Influence of variety mixtures. In *Plant Resistance to Herbivores and Pathogens: Ecology, Evolution and Genetics*, 3rd ed.; Fritz, R.S., Simms, E.L., Eds.; University of Chicago Press: Chicago, IL, USA, 1992; pp. 91–119.
61. Edmeades, S.; Smale, M.; Karamura, D. Biodiversity of bananas on farms in Uganda; In Promising crop biotechnologies for smallholder farmers in East Africa: Bananas and maize. In *Genetic Resource Policies 2006*; Brief 24; International Food Policy Research Institute and the International Plant Genetic Resources Institute: Washington, DC, USA, 2006.

62. Sheppard, A.W.; Gillespie, I.; Hirsch, M.; Begley, C. Biosecurity and sustainability within the growing global bio economy. *Curr. Opin. Environ. Sustain.* **2011**, *3*, 4–10. [CrossRef]
63. Zilberman, D.; Kim, E.; Kirschner, S.; Kaplan, S.; Reeves, J. Technology and the future bio economy. *Agric. Econ.* **2013**, *44*, 95–102. [CrossRef]

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