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Participatory Plant Breeding and Selection Impact on Adoption of Improved Sweetpotato Varieties in Uganda

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Abstract: This study analyzed the impact of participatory plant breeding (PPB) and participatory variety selection (PVS) on the adoption of improved sweetpotato varieties (ISPV) in central Uganda. The study quantitatively assessed how the two approaches influence farmers' uptake of the improved sweetpotato varieties and also determined other factors influencing this adoption. This was done by estimating a robust standard errors logit model. Both PPB and PVS positively and significantly influenced the likelihood of adoption of improved sweetpotato varieties at 5% and 10% levels, respectively. Other variables that positively influenced the adoption are extension services, training in sweetpotato production, farming experience, and off-farm income of the household. Farmers who participated in the plant breeding and variety selection processes were 37 and 6.7 times more likely to adopt the improved sweetpotato varieties than those who had not, respectively. Farmers who were trained specifically in sweetpotato production were 8.8 times more likely to adopt the improved varieties than those who had not received this type of training.

Key words: Participatory plant breeding, varietal selection, adoption, improved sweetpotato varieties.

1. Introduction

Farmers are increasingly participating in agricultural research due to the fact that scientists and development workers have become more aware of the philosophy of "farmer first and its effectiveness" [1]. Many approaches are possible in farmer participatory research to improve crop cultivars for farmers. They are broadly categorized into farmer participatory plant breeding (PPB) and participatory varietal selection (PVS) since they conveniently define two approaches that are very different, and are likely to have very different impacts. PVS and PPB methods employ different levels of farmer participation and researcher inputs. Depending on the situation, either approach may be the most appropriate method to be used. PPB often follows from the successful participatory identification of cultivars [2]. Employing such methods helps to reduce the possibility of farmers being given unacceptable varieties to test. The National Agricultural Research Organization (NARO) in Uganda and other collaborating organizations working with the sweetpotato programme used these approaches in the transfer of improved sweetpotato varieties to rural communities. These improved varieties included NASPOT 1 to NASPOT 11, Sowola, and PPB clones not yet released [3-6].

PVS has been extended to PPB on the assumption that if it is desirable to involve farmers in selection of cultivars then there should not be any waiting until there are finished products. In PPB, farmers are involved at a much earlier stage whilst the material is still segregating, that is, the materials are still at seedling stage before selection of the promising lines. Farmers are involved in the raising of seedlings and

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monitoring their performance in the field in terms of drought tolerance and disease resistance, yield, vigor, maturity period, size of roots, and color among important attributes. Farmers are also involved in monitoring the performance of the potential varieties in terms of taste. The Sweetpotato Programme of NARO based at the National Crops Resources Research Institute (NaCRRI), Namulonge, Uganda, has combined the two approaches, PPB and PVS, in the testing and transfer of improved sweetpotato varieties.

PPB also termed collaborative plant breeding (CPB) or farmer participatory breeding (FPB) and also known as participatory crop improvement (PCI), evolved from a participatory research model initially referred to as the "farmer-back-to-farmer" model [7, 8]. PPB has since been used to bring farmers, researchers, extension agents and other beneficiaries of plant breeding together in the process of developing new crop varieties [9, 10]. It has been claimed that PPB facilitates close interaction among farmers, researchers and other actors in crop genetic improvement allowing researchers to respond more closely to the needs and preferences of resource-poor farmers and their market clients [2, 11-13]. It is also claimed that PPB gives a better identification of criteria that are important to the local community and the targeted local environmental conditions. The varieties obtained from this process are developed more rapidly, are more diverse and have higher adoption rates [1, 9, 14-16]. Farmer selection of finished or near-finished varieties is termed PVS, as opposed to farmer selection of segregating materials with a high degree of genetic variability also known as PPB. Witcombe et al. [15], Gibson et al. [6] and Ceccarelli et al. [17] also described testing and selecting in the different locations representative of the target-breeding environment as decentralised breeding.

It is generally observed that many new agricultural technologies are available but are not being used by farmers as they should despite the fact that new technologies offer an opportunity to increased agricultural production and income. This has been partly attributed to limited resources allocated to activities related to promoting adoption of proven technologies particularly in the developing world and especially under conditions with low inputs and abiotic stress [18]. Since the majority of the population in developing countries derives its livelihood from agricultural production, there is a realization that concerted effort be directed towards enhancing adoption of proven agricultural technologies that lead to improved production and income [19]. The decision to adopt or not adopt an innovation by individual farmers is preceded by careful evaluation of a number of technical, economic and socio factors [20-22]. Farmers will continue using the innovation depending on how well the change satisfies their needs [23]. Several factors influence the scope, degree and patterns of adoption of new technologies. Lionbreger and Gwin [24] noted that the adoption of agricultural technologies by farmers is influenced by general factors, which relate to the farmer concerned and the situation in which the farmer and the technology interact.

Studies elsewhere identified and categorised factors influencing adoption of new agricultural technologies into farm and farmer associated attributes, technology associated attributes and the farming objective [1, 25, 26]. Similarly, Ruttan [27] identified personal, socio-economic, cultural, communication and situational factors as having significant impact on adoption processes. Bisanda et al. [28], on the other hand, highlighted farm size, experience, education, agricultural extension services, household size, access to input sources, hired labour and access to credit as factors that influence farmers' adoption decision. They observed that educational level increased the probability of adoption of recommended technologies since it increased farmers' ability to obtain, process and use information relevant to the adoption of a given technology.

Adoption also depends much on farmers' characteristics concerning education, age, gender, farm resources, the farming system, post harvest utilisation and market availability, plus information sources. Farmer characteristics concern the specific conditions that influence the farmers' acceptance to make technology generation more efficient and explain differences between adopters [20]. Colman and Young [21] listed age, experience and education as farmers' characteristics that might determine awareness, interest and ability of the farmer to implement a new technology. Formal education helps an individual to acquire knowledge and it is considered a prerequisite for economic and socio-change. Farm resources make it easier or more profitable for a farmer to change practice and they include farm size, which reflects a farmer's farm management ability, labour availability that may affect ease with which a technology can be accepted because it can affect labour input, plus division of labour [20, 29]. For a peasant small holder farmer, the family is the major source of labour [23]. Hired labour usually supplements family labour particularly during critical labour demand times. However, Byerlee [30] observed that it was the farmers' objective to increase the utilisation of family labour and maximize output with low cost inputs.

Bashaasha et al. [31] indicated that despite considerable amount of research and introductions of improved sweetpotato varieties, the rate of adoption by farmers was low. The major reason advanced for such behaviour is lack of farmer participation in screening and selection of varieties and declining productivity due to the devastating effects of sweetpotato weevil and sweetpotato virus disease (SPVD). It was against this background that NARO used participatory approaches in disseminating the improved sweetpotato varieties. However, there are no known previous studies that have been carried out to quantitatively assess the impact of these two different approaches on adoption of improved sweetpotato varieties. There is also lack of information about other factors that influence adoption of these improved sweetpotato varieties under PPB and PVS approaches. This study was therefore carried out to evaluate the impact of the PPB and PVS approaches employed by the Uganda Sweetpotato Programme on adoption of improved sweetpotato varieties. This study hypothesized that adoption of improved sweetpotato varieties is positively affected by the two participatory approaches.

2. Materials and Methods

2.1 Field Methods

This study was carried out in the districts of Luwero, Kiboga and Mpigi located in the central region of Uganda. These districts were chosen because efforts in PPB and PVS approaches in sweetpotato research and dissemination have been made extensively. In addition, the districts represent several agro-ecological diversities. Three groups of farmers were purposively selected; the first group was one of PPB farmers, the second group was one of PVS farmers and the third group was one of non-participating farmers in each of the three districts. The second stage involved randomly sampling 20 farmers from each of the nine groups. Thus a total of 180 individual respondents were selected from three districts. Primary data were collected using a structured questionnaire that was directly administered.

2.2 The Model

We hypothesize that farm households make a decision of choosing whether or not to adopt improved sweetpotato varieties. This decision represents the choice between improved and traditional varieties. This decision is examined by formulating a logistic function of household adoption behavior. Following Judge, et al. [32], Kennedy [33] and Maddala [34], this study assumes that the utility derived from a choice by the household head is governed by the attributes of the choice and the individual making the decision. For the ***i***th head of the household, denote the utility of option 1 (the decision to adopt improved sweetpotato varieties) as U_1 and that of option 2 (the decision to not adopt improved sweetpotato varieties) as U_2. Then,

$$U_1 = \mathbf{X}_i'\boldsymbol{\beta}_1 + \varepsilon_1 \quad (1)$$

$$U_2 = \mathbf{X}_i'\boldsymbol{\beta}_2 + \varepsilon_2 \quad (2)$$

where $\mathbf{X}_i$ is a vector of characteristics and $\boldsymbol{\beta}_j$ (j = 1,2) is a vector of parameters. It is assumed that the random disturbances (ε_1 and ε_2) are independently and identically distributed and they are drawn from a log-Weibull distribution [35]. The log-Weibull distribution for the residuals ε_j (j = 1, 2) has its cumulative density function as $F(\varepsilon_j < \varepsilon) = \exp(-e^{\varepsilon j})$; and probability density function as $f(\varepsilon_j) = \exp(-\varepsilon_j - e^{-\varepsilon j})$. This type I extreme-value distribution has the property that the cumulative density of the difference between any two random variables with this distribution is given by the logistic function [33]. The utilities U_1 and U_2 are random variables and the ***i***th head of household is assumed to adopt improved sweetpotato varieties (option 1) if and only if $U_1 > U_2$.

That is, $\mathbf{X}_i'\boldsymbol{\beta}_1 + \varepsilon_1 > \mathbf{X}_i'\boldsymbol{\beta}_2 + \varepsilon_2 \Rightarrow \varepsilon_2 - \varepsilon_1 < \mathbf{X}_i'(\boldsymbol{\beta}_1 - \boldsymbol{\beta}_2)$.

The probability, P_1, that the head of the household will adopt improved sweetpotato varieties (option 1) is given by the cumulative density of ($\varepsilon_2 - \varepsilon_1$) to the point $\mathbf{X}_i'(\boldsymbol{\beta}_1 - \boldsymbol{\beta}_2)$. The cumulative density function of the difference ($\varepsilon_2 - \varepsilon_1$) is given by the logistic function. By setting $(\boldsymbol{\beta}_1 - \boldsymbol{\beta}_2)$ equal to $\boldsymbol{\beta}$, we get

$$P_1 = \exp\{\mathbf{X}_i'\boldsymbol{\beta}\} / [1 + \exp\{\mathbf{X}_i'\boldsymbol{\beta}\}] \quad (3)$$

The corresponding likelihood function is

$$L = \Pi_j\{e^{\mathbf{x}'\boldsymbol{\beta}}/(1 + e^{\mathbf{x}'\boldsymbol{\beta}})\}\Pi_k\{1/(1 + e^{\mathbf{x}'\boldsymbol{\beta}})\} \quad (4)$$

where j denotes the household heads that adopt improved sweetpotato varieties and k denotes those heads that choose to use traditional sweetpotato varieties (option 2). The objective is to maximize the likelihood function with respect to the vector $\boldsymbol{\beta}$. Empirically the model for the ***i***th househead can be specified as

$$y_i = \mathbf{X}_i'\boldsymbol{\beta} + u_i \,; \ (i = 1 \ldots n) \quad (5)$$

where y_i is the binary dependent variable that takes a value of 1 if the household head is an adopter of improved sweetpotato varieties and zero if otherwise. $\mathbf{X}_i$ is a vector of explanatory variables and $\boldsymbol{\beta}$ is a vector of parameter estimates. The explanatory variables include household size (HHsize); off-farm income (Offfarmincom); land size in acres (Landsize); level of education measured as the years of formal schooling (Educ); number of extension visits received (Extension); farming experience as the years of farming (Farmexp); a dummy variable for training related to sweetpotato production, which takes a value of 1 and zero if there is no sweetpotato training (training); a dummy for participation in plant breeding which takes a value of 1 if farmers participated and zero otherwise (PredPPB); a dummy variable for participation in variety selection which takes a value of 1 if farmers participated and zero otherwise (PredPVS). To cater for endogeneity of the PPB and PVS as regressors in the adoption equations, in this study we used as instruments, land size, level of education, location of farm household and sex of the respondent. The predicted values from these PPB and PVS equations where the two appear as the dependent variables are instead used in the adoption models. STATA version 9.0 and SPSS version 15.0 software packages were used to conduct the analysis.

3. Results and Discussion

3.1 Factors Affecting Adoption of Improved Sweetpotato Varieties

Tables 1-3 show that both PPB and PVS led to increased adoption of sweetpotato varieties among participating farmers. These results are in agreement with various other authors who have advanced different reasons in support of participatory approaches. The need to reduce external inputs in agricultural systems throughout the world is a challenge for both plant breeders and farmers. Including farmers in the research and breeding process will help to meet this challenge by developing varieties

Table 1 Factors affecting adoption of improved sweetpotato varieties (combined) (Robust Standard Errors).

Variable	Coefficient	Exp (Coeff)	Std. Err.	*t*-value	*P*-value
Training	2.173***	8.785	0.507	4.29	0.000
Extension	0 .870*	2.387	0.476	1.85	0.064
Offfarmincom	1.764***	5.836	0.516	3.41	0.001
Farmexp	0.047**	1.048	0.019	2.45	0.014
Landsize	-0.080	1.083	0.064	-1.25	0.212
PredPPB	3.616**	37.189	1.424	2.54	0.011
PredPVS	1.897*	6.666	1.113	1.70	0.088
HHsize	-0.591	1.806	0.085	-0.69	0.490
Constant	-6.264	-	-1.419	0.00	

***, **,* denotes significance at 1%, 5% and 10%, respectively;
Number of observations = 161;
Log likelihood = -56.229;
Prob > chi^2 = 0.0000;
Pseudo R^2 = 0.449.

Table 2 Impact of participatory plant breeding on adoption of ISPV (Robust Standard Errors).

Variable	Coefficient	Exp (Coeff)	Std. Err.	*t*-value	*P*-value
Training	2.469***	11.811	0.484	5.10	0.000
Extension	0.851***	2.342	0.474	1.80	0.072
Offfarmincom	1.654***	5.228	0.483	3.43	0.001
Farmexp	0.048**	1.049	0.019	2.48	0.013
Landsize	-0.090	1.094	0.064	-1.42	0.156
PredPPB	1.829**	6.228	0.765	2.39	0.017
HHsize	-0.068	1.07	0.083	-0.82	0.411
Const	-3.623	-	-4.02	0.000	

***, **,* denotes significance at 1%, 5% and 10%, respectively;
Number of observations = 161;
Log likelihood = -57.439;
Prob > chi^2 = 0.0000;
Pseudo R^2 = 0.437.

that are well suited to particular cropping systems and environments. PPB can benefit farmers in marginal environments in both developed and developing countries, and also those farmers who seek to lower their synthetic inputs for environmental or economic reasons [8]. The main purpose of PPB is high client orientation [36]. PPB has been promoted for its advantage for clients of increasing genetic diversity (biodiversity) within the farming system due to the development and adoption of many different genotypes, each with different specific adaptations to different regions of the target area [18].

Table 3 Impact of participatory variety selection on adoption of ISPV (Robust Standard Errors).

Variable	Coefficient	Exp (Coeff)	Std. Err.	*t*-value	*P*-value
Training	2.735***	15.410	0.484	5.65	0.000
Extension	0.964**	2.622	0.460	2.10	0.036
Offfarmincom	1.712***	5.540	0.498	3.44	0.001
Farmexp	0.044**	1.045	0.019	2.33	0.020
Land	-0.068	1.070	0.059	-1.14	0.254
PredPVS	0.999*	2.716	0.540	1.85	0.064
Family size	-0.073	1.076	0.083	-0.87	0.384
Const	-3.623	-	-4.020	0.000	

***, **,* denotes significance at 1%, 5% and 10% , respectively;
Number of observations = 161;
Log likelihood = -59.554;
Prob > chi^2 = 0.0000;
Pseudo R^2 = 0.416.

Participatory breeding approaches are advocated, where conditions on-farm may differ considerably from those on research stations, genotype x environment interactions resulting in cultivars selected on-station being poorly adapted to conditions on-farm [37]. Breeders mainly targeting yield can overlook other key attributes important to farmers and consumers, or even when aiming to address farmers' and other end-users' needs, may lack the skill and training needed to elicit them [38]. There are doubts as to whether on-farm environments, especially those of rain-fed marginal agriculture, can be simulated adequately on-station and whether even national scientists can appreciate the wide range of needs and circumstances of largely subsistence farmers [6]. According to Witcombe et al. [2], participatory breeding approaches are essential or highly desirable when one or more of the following apply:

There is "market failure" where supply of new varieties fails to meet the demand from farmers.

It is cheaper to conduct PPB than on-station research using available resources.

Consumer perceptions of grain or product quality are important and too complex (determined by many traits) to be selected for on the basis of laboratory basis alone.

Farmers have selection criteria where they trade off characteristics among themselves.

The objective is to gain more knowledge from farmers about selection criteria and preferred traits.

The aim of breeding activity is to empower farmers in skills and knowledge for utilizing genetic diversity, and on processes of maintaining and exchanging seed of preferred varieties.

However, there has been evidence against PPB, PVS or farmer participatory approaches due to: basic research being a need; precision and reproducibility are questioned; degeneration of genetic material during the process of PPB; the lack of a "one-size-fits-all"; where farmers' selection criterion is only one factor; market demand strongly influences farmers' selection criteria; and where the expected impact and output are not realized. Despite the growing recognition of the potential of integrative, farmer participatory research, many institutions and researchers still choose to use approaches dominated by narrow technical and economic perspectives, neglecting complementary social and more macro perspectives. This could be due to the valid reason that basic disciplinary research is needed, or that researchers have not been trained to deal with, or do not feel comfortable with, holistic and social dimensions [7]. Furthermore, the scientific value of PPB and participatory research approaches are often questioned, especially from the standpoint of precision, research detachment, control, and reproducibility. An additional quality concern is to what degree participatory research generates theories that have predictive capacity [17].

In case studies true potato seedling tubers were given to about 600 true potato seed (TPS) experimenters across Indonesia. Monitoring of TPS experimenters later showed they were no longer sure of its profitability, as seedling tuber yields declined more rapidly than conventional seed with successive multiplications. TPS (i.e. using PPB) was subsequently abandoned in Indonesia [13]. This TPS case helps to illustrate why PPB or highly client-oriented breeding cannot be described as a "one-size-fits-all" model, because modifications are expected in different crops grown in different environmental and socioeconomic settings [39]. In addition, breeders in this case are well aware of the farmers' selection criteria, where farmers' criterion is just one factor, such as seed-color, the need for PPB or PVS might diminish [38].

When farmers' selection criteria are strongly influenced by market demand, temporal and spatial effects have little bearing except adaptation. Therefore, breeders and collaborating investigators are less challenged in bringing a mix of complex traits into a single variety. In such a scenario breeders need increased knowledge of farmers' selection criteria rather than using the PPB approach [16].

Table 1 shows the results from the combined logit model where both variables of participation in plant breeding and variety selection processes are included together in the same model. Tables 2 and 3 are logit models with only one of each of the two variables. In Table 1 the results show that participation in plant breeding and variety selection are both statistically significant at 5% and 10% levels, respectively. Other variables that positively influence adoption of improved sweetpotato varieties are extension services, training in sweetpotato production, farming experience, off-farm income, at 10%, 1%, 5% and 1%, respectively, in the combined logit model. The log-odds ratio in Table 1 shows that farmers who were trained specifically in sweetpotato production were 8.8 times more likely to adopt the improved varieties than those who had not received this type of training. Farmers who participated in the plant breeding and variety selection processes were 37.2 and 6.7 times more likely to adopt the improved sweetpotato varieties than those who had not, respectively. An increase in the level of off-farm income by one unit increases the odds of adopting improved sweetpotato varieties by a factor of 5.5 times. This is in line with the observation made by Savadogo et al. [40] that non-farm incomes can influence technology adoption decisions. A plausible explanation for this is that off-farm income enables the farmer to raise the level of his/her disposable income and thus enables him/her to purchase farm inputs. The combined regression shows that the most important factors in increasing the likelihood of adoption of improved sweetpotato varieties are: (1) training in sweetpotato production, (2) farmers' participation in the plant breeding and plant variety selection processes, and (3) the level of off-farm income of the household. Tables 2 and 3 have similar results. Essentially, the probability of adoption of improved sweetpotato varieties is most affected by farmer participation in technology development and transfer. This reinforces and signifies the principle of participation of resource-poor farmers in the implementation of sweetpotato project at grass-root levels in Uganda that was adapted by the Uganda Sweetpotato Program.

The study also reveals that farmers who participate in the plant breeding process have a higher likelihood of adoption than those who participate in the variety selection processes. This is in congruence with Witcombe et al. [41] who showed that PVS was a more rapid and cost-effective way of identifying farmer-preferred cultivars if a suitable choice of cultivars existed. If this is impossible, then the more resource-consuming PPB is required to be used, as parents, cultivars were identified in successful PVS programs. Compared with conventional plant breeding, PPB is more likely to produce farmer-acceptable products hence higher probability of uptake, particularly for the marginal environments.

Farmers who participated in varietal selection were involved in the research at an advanced stage. They were given finished or near finished materials by researchers for evaluation compared to farmers who participated in the plant breeding process. The latter were involved at a much earlier stage when materials were still segregating. The difference in the probability of adoption of improved sweetpotato varieties may be as a result of farmers in PVS being given materials that do not suit their interest such as color, taste, maturity period among important characteristics. However, farmers in PPB feel that they own the varieties since they are involved right from seedling stage and choose clones that they feel meet their demands or interests as they discard those that are not popular.

4. Conclusions

Training related to sweetpotato production should be emphasized either through extension services since it has also been shown to be a crucial factor in increasing the likelihood of uptake of sweetpotato technologies. Although PPB and PVS approaches require more resources for their implementation, research efforts should employ these approaches for transferring of technologies to farmers as shown by the results of this study. These approaches are a vital means of improving the likelihood of adoption of improved sweetpotato technologies. This implies that the link between research and development effort and adoption should be strengthened. This stems from the fact that the collaborating farmers do receive more information from research and development agents that facilitate their appreciation of the value of improved sweetpotato varieties. Thus, the results attest to the importance of adapting participatory approaches in the transfer of technologies. Consequently, farmer participation can be seen to play a role in the Uganda Sweetpotato Program in the identification of research priorities and evaluation of technology performance and transfer to end-users.

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