Factors Influencing Diversity of Farmers' Varieties of Sweet Potato in Uganda: Implications for Conservation[1]

Barbara M. Zawedde[2,3], Craig Harris[4], Agnes Alajo[5], Jim Hancock[2], and Rebecca Grumet*[,2]

[2]Graduate Program in Plant Breeding, Genetics and Biotechnology, and Department of Horticulture, Plant and Soil Science Building, Michigan State University, 1066 Bogue Street, East Lansing, 48824, USA
[3]Present Address: Uganda Biosciences Information Center (UBIC), National Crop Resources Research Institute, Namulonge, 9 km Gayaza-Zirobwe Road, Uganda
[4]Department of Sociology, Berkey Hall, Michigan State University, East Lansing, 48824, USA
[5]National Sweetpotato Program, National Crop Resources Research Institute, Namulonge, Gayaza-Zirobwe Road, Uganda
*Corresponding author; e-mail: grumet@msu.edu; phone: 517-355-5191

Factors Influencing Diversity of Farmers' Varieties of Sweet Potato in Uganda: Implications for Conservation. There is increasing concern that agricultural intensification is causing loss of crop biodiversity due to displacement of traditional farmers' varieties by a small number of improved cultivars. Using ethnobotanical surveys, we assessed the implication of adoption of new sweet potato (*Ipomoea batatas*) cultivars on the maintenance of farmers' varieties in Uganda. Other factors influencing varietal diversity were also assessed. A total of 102 farmer households distributed in the top three sweet potato production agro-ecological zones were interviewed. With the exception of released cultivars, very few varieties appeared in more than one region. The majority of the respondents indicated that they continue to plant some of the existing varieties when they adopt new cultivars. Loss of planting materials due to drought was a major constraint to maintaining varietal diversity for this vegetatively propagated crop. Limited land and lack of access to best management practices were also key constraints to maintenance of farmers' varieties. The primary criteria for adopting new cultivars were higher yield, taste, and duration to maturity. Yield stability, tolerance to native biotic and abiotic stresses, and good taste were important for maintenance of currently grown varieties. Overall, criteria for variety selection varied with household characteristics including farmer age and gender, uses of the crop, micro-climatic conditions in the farmers' fields, and level of access to agricultural extension. The observed heterogeneity in selection criteria, influence of social ties, and the role of environment in varietal maintenance have important implications for establishing breeding priorities and preservation of crop diversity.

Key Words: Crop biodiversity, cultivar adoption, farmers' varieties, *Ipomoea batatas*, land races, ethnobotany.

Introduction

High crop diversity enables agricultural systems to maintain productivity over a wide range of environmental conditions (Carpenter 2011; Ratnadass et al. 2012; Thomas et al. 2011). There is increasing concern, however, that agricultural intensification is

[1] Received 7 April 2014; accepted 13 August 2014; published online 22 August 2014.

Electronic supplementary material The online version of this article (doi:10.1007/s12231-014-9278-3) contains supplementary material, which is available to authorized users.

causing displacement of farmers' varieties by a few improved cultivars, leading to loss of crop biodiversity (Carpenter 2011; Pautasso et al. 2013). In this work, we use the term "variety" to mean a product of natural and human selection that occurs in the farmer's field, and the term "cultivar" to mean a product of formal crop improvement or a farmer's variety released by the national variety release committee. Loss of crop diversity is a particular concern in centers of origin and secondary centers of diversity where varieties have evolved with high adaptability to the local environment (Mercer and Perales 2010), as well as in developing countries where farmers rely on crop diversity for food security (FAO 2007). However, some evidence shows that while varietal substitution is a common practice in such areas, complete displacement of traditional varieties and landraces is not likely, because farmers tend to maintain a diverse pool of varieties in their field even when they adopt new cultivars (Enjalbert et al. 2011; Gepts and Papa 2003). In this study, we assessed the effects of adoption of new sweet potato (*Ipomoea batatas* [L.] Lam.) cultivars on the maintenance of farmers' varieties in Uganda.

Sweet potato is the fifth most important food crop in terms of weight harvested in eastern Africa (FAO 2012). It was ranked among the top three food crops in Burundi, Tanzania, and Uganda. Uganda is among the top five global producers of sweet potato in terms of quantities produced. Reduced ability to produce cassava due to a virus epidemic, and maize due to rapid spread of the parasitic weed *Striga hermonthica* (Delile) Benth., has further increased the importance of sweet potato as a food security crop in Uganda (Ndolo et al. 2007). Price fluctuations for cash crops also influence sweet potato production. For example, many farmers in Kumi district switched to sweet potato when there was a decline in price for cotton (Abidin et al. 2005). More recently, sweet potato has also been promoted as a source of pro-vitamin A (Namanda et al. 2011).

Sweet potato was introduced to East Africa from Central or South America by Portuguese explorers in the 16th century (Loebenstein 2009). Over time, the region accumulated a large number of landraces and farmers' varieties that are adapted to the local growing conditions and native pests and diseases; thus, East Africa is considered a secondary center of diversity for sweet potato (Gichuki et al. 2003; Mwanga et al. 2001a; Yada et al. 2010). As part of the global effort to preserve this crop diversity, in 2005 the National Sweetpotato Program at the National Crops Resources Research Institute (NaCRRI) collected over 1,300 accessions from farmers' fields (Yada et al. 2010). These accessions were evaluated at three sites for selection of superior varieties for use in crop improvement programs. Up to 100 of the identified superior accessions are now being used for population improvement, and the rest of the germplasm is being maintained in a screen house and field at NaCRRI. However, some accessions have been lost. Losses experienced by *ex situ* conservation, particularly for vegetatively propagated crops that, unlike seed-propagated crops, cannot be stored for long periods of time, indicate the importance of *in situ* approaches to conservation of crop diversity (Khoury et al. 2010; Rao and Campilan 2002).

Individual farmers and farming communities play an important role in conserving sweet potato diversity at both the local and country level (Lebot 2010; Rao and Campilan 2002). Farmers' decisions regarding variety choice and crop management systems are based on goals, resources, and constraints. Their decisions are also influenced by local knowledge and/or information provided by technical institutions and extension services, as well as experiences of previous generations and members of their community or other communities. This knowledge influences morphological characteristics considered during variety selection, location and size of the area allocated for cultivation, source of the planting material, and crop management practices (Enjalbert et al. 2011; Pautasso et al. 2013). Understanding of farmers' local knowledge and how it influences decision-making is a necessary step for prioritization of crop improvement to assure that new varieties meet farmers' needs and to facilitate preservation of the landraces.

A farmer's survey was conducted in four of Uganda's agro-ecological zones between 1989 and 1992 to determine the role of sweet potato in the farming and food systems of Uganda (Bashaasha et al. 1995). Sweet potato was found to be one of the top three food crops in the central, eastern, and northern regions. The average number of varieties grown by each farmer was five. The eastern region had the highest production per unit area. The high average yield in this region may be attributed to large sections of sandy loam (Uganda Government 1967), which is favorable for storage root growth (Dantata et al. 2010).

At the time of the 1995 study, farmers depended on traditional sweet potato varieties because they did not have access to improved cultivars. The first

improved cultivars were released by the National Sweetpotato Program in 1995 (Mwanga et al. 2001b). Other studies assessed farmers' knowledge of the crop diversity and farming systems during the process of germplasm collection (Abidin et al. 2005; Yada 2009). Farmers were able to describe the key morphological characteristics of each variety, such as time to maturity, resistance to pests and diseases, tolerance to drought, soil type suitability, and culinary quality. However, these studies did not investigate how adoption of new varieties or cultivars influences farmers' decisions to maintain or discard current varieties or cultivars.

This study assessed varietal diversity in farmers' fields in Uganda, documented local knowledge related to this germplasm, and examined factors influencing decisions about whether to maintain, incorporate, or discard varieties or cultivars. We also explored the crop management system and investigated how various sociological factors, including planting material exchange practices, source of information, land ownership and size, and market access, affect diversity of sweet potato varieties and cultivars grown by farmers in Uganda.

Materials and Methods

Regions Surveyed

Ethnobotanical surveys were conducted in three agro-ecological zones (AEZs) selected by area allocated for sweet potato production (UBOS 2010), and whether sweet potato was among the three most important food crops (Bashaasha et al. 1995; Yada 2009). The AEZs, as demarcated by the Ministry of Agriculture, Animal Industries and Fisheries, included the northwestern savanna grasslands (northern region), the Kyoga plains (eastern region), and the Lake Victoria Crescent (central region). Altitude, weather patterns, soil type, and farming systems for the AEZs are provided as Electronic Supplementary Material (ESM) Table 1. Districts within each AEZ (Table 1) were selected based on importance of sweet potato as a staple crop (Yada 2009) and proximity to the national research institutes.

Survey Methodology

A survey using structured questionnaires was conducted to assess varietal diversity in farmers' fields and to determine how farmers make decisions about maintaining, incorporating, or discarding varieties. The survey methods were approved by the Institutional Review Board of Michigan State University, and the questionnaire was pretested with 20 respondents from Mukono and Luwero districts. Based on feedback from the pretest, the final questionnaire was prepared. Data were collected on: age and gender of the respondent; size and ownership of land cultivated with sweet potato; characteristics of varieties currently grown; varieties dropped and reasons for dropping; criteria for adopting new varieties; proportion of land allocated to new versus old varieties; criteria for maintaining old varieties; challenges with adopting/maintaining varieties; farmers' variety exchange practices; common crop management practices and challenges associated with crop management; and the role of extension service in variety selection. All questions were open-ended. Household was taken as the sampling unit for the study.

Table 1. Number of respondents and percentage of respondents based on gender and membership in farmers' groups, in each district in Uganda.

Region	District	Proximity to research institute	No. of farmers interviewed	Women (%)	Members of farmers' groups (%)
Central	Luwero	Close	15	87	26.7
	Mukono	Close	10	80	0.0
	Rakai	Distant	15	71	33.3
Eastern	Bukedea	Distant	15	33	60.0
	Kumi	Distant	10	60	0.0
	Soroti	Close	15	74	13.3
Northern	Apac	Distant	10	50	0.0
	Lira	Close	12	75	0.0
Total			102	67	20
Mean			13	66.3	19.6

Face-to-face interviews were conducted in seven districts between January and June 2012, and in Bukedea in December 2012. The survey was done in collaboration with the National Sweetpotato Program. A minimum of ten households were sampled per district (Table 1) and two to three sub-counties were randomly selected from each district. In each sub-county, interviews were performed at two to five households that were located at least five km from each other. To allow for evaluation of key morphological traits onsite, only households that were growing sweet potato at the time of the interview were selected. Farmers were queried systematically using key crop descriptors. These data were used to identify names that referred to varieties not grown at the time of the interview and to verify variety identity. A sweet potato specialist from the National Program and an extension worker participated to ensure that farmers' descriptions were captured accurately and to act as interpreters when necessary. In a few cases where morphological indicators were similar, genetic fingerprinting was performed to determine whether the same variety had different names in different regions (Zawedde 2013).

Data were analyzed using the Statistical Package for Social Sciences (SPSS). One-way analysis of variance (ANOVA) was performed for continuous variables. Chi-squared analysis was performed for categorical variables, and eta-squared test was used to test relationships between nominal or ordinal variable and categorical variables. Definitions and rating scheme for factors influencing adoption of new varieties/maintenance of current varieties are provided in ESM Table 2.

Results and Discussion

This study investigated factors influencing Ugandan farmers' decisions to adopt new varieties of sweet potato or retain current varieties. A total of 102 respondents participated in the study (Table 1). A higher percentage of sweet potato farmers in most districts, except Bukedea, were women. This is consistent with prior reports indicating that sweet potato cultivation in Uganda was mainly done by women (Bashaasha et al. 1995; Namanda et al. 2011).

Reasons for Sweet Potato Production and Land Allotted to Sweet Potato Production

The main reasons given for sweet potato production were food security or home consumption (Fig. 1). While only approximately 20% of the farmers produced sweet potato specifically for market, 56% of the respondents indicated that they sold sweet potatoes if there was surplus, thus it was also a source of income. In all regions, sweet potato was consumed fresh. Farmers used a piecemeal harvesting method (i.e., only roots for immediate consumption are harvested and the rest are "stored" in-ground). In eastern and northern Uganda, the roots were processed into dried chips or meal to lengthen the storability and reduce post-harvest losses. In northern and some parts of eastern Uganda, young leaves are consumed as leafy vegetables. In all regions, leaves and damaged roots are used as animal feed. Similar observations were reported by the National Agricultural Census (UBOS 2010).

The land used for sweet potato production in a given farm ranged from 0.1 to 5.0 hectares (ha). The average area allocated to sweet potato production in the study area (0.43 ha) was higher than the national average of 0.20 ha (UBOS 2010). The average land size reported to be allocated to sweet potato production in Apac, Lira, and Luwero districts is similar to that stated by Bashaasha et al. (1995).

Varietal Diversity on Farm and at Regional Level

Varieties or cultivars grown were introduced through farmer-to-farmer exchange, selected from chance seedlings, or released by the national program (complete list is provided in ESM Table 3). Some cultivars were scientifically evaluated and released by the National Program as advanced

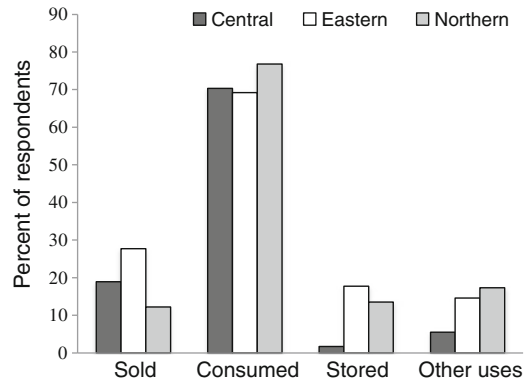

Fig. 1. Use of sweetpotato storage roots in the study areas of Uganda. Some respondents used the sweetpotato storage roots in more than one way. Total number of respondents was 102.

cultivars for country-wide cultivation based on criteria of consumer acceptance, consistently high yields, and disease resistance across a wide variety of agro-ecological zones in Uganda (Mwanga et al. 2011).

The number of varieties and cultivars per household ranged from 1 to 12 (Table 2) with an average of 6 per household. The majority (74%) of the respondents planted traditional farmers' varieties with or without released cultivars. Overall 78% of the diversity found in farmers' fields consisted of farmers' varieties. Respondents in Apac reported no newly-bred cultivars, while the majority of the farmers (87%) interviewed in Bukedea were growing predominantly orange-fleshed cultivars (NASPOT 9 and 10, Kakamega and Ejumula). Farmers in Luwero, Mukono, Soroti, and Lira districts, who are close to the research institutes, tended to grow more released cultivars than respondents in distant districts, indicating uneven distribution of released cultivars across the various districts.

Seventy-six unique varieties or cultivars were recorded: 68 farmers' varieties and 12 released cultivars (Table 2; ESM Table 3). With the exception of released cultivars, very few appeared in more than one region. In a few cases where morphological indicators were similar, genetic fingerprinting indicated that the same variety had different names in different regions (Zawedde 2013). The central region did not have any farmers' varieties in common with northern or eastern Uganda; four were in common between the eastern and northern regions. Minimal overlap among regions could be a result of variation in climate and soil types (ESM Table 1), lack of exchange among the regions, or sample size used in the study.

Overall, 82% of the varieties recorded in this study also were reported in the same region by Yada in 2005 (Yada 2009). However, 18 varieties were no longer grown by any of the respondents. Extension workers and farmers' leaders suggested that some of these varieties were most likely lost from the region. Some varieties were lost due to prolonged droughts resulting in loss of the planting materials. Other varieties were lost or dropped due to susceptibility to insects or viral infection, or proven superiority of a new variety. Some farmers' varieties were displaced by cultivars demanded by the markets; for example, increased cultivation of the orange-fleshed cultivars contributed to displacement of certain varieties in the eastern region. Some varieties dropped in certain regions were introduced into other regions, possibly due to differences in production constraints as observed by Veasey et al. (2008).

Impact of Variety Exchange

Exchange of planting materials is a known source of diversification on farms at the household level (Pautasso et al. 2013; Veasey et al. 2008). Of the

Table 2. Level of sweet potato diversity at district level: number of farmers' varieties and released cultivars at district level, total number of varieties and cultivars, and the average number and range of varieties grown per household in each district.

Region	District	No. of farmers' surveyed	Farmers' varieties	Released cultivars[1]	Total varieties/ cultivars	Average no. of varieties per HH[2]	Range of varieties/ HH
Central	Luwero	15	13	7	20	5	1–8
	Mukono	10	8	7	15	3	1–6
	Rakai	15	15	1	16	6	2–8
Total unique varieties			25	10	35		
Eastern	Bukedea	15	6	4	10	4	2–6
	Kumi	10	14	2	16	6	3–8
	Soroti	15	23	5	28	7	1–12
Total unique varieties			27	9	36		
Northern	Apac	10	15	0	15	7	5–8
	Lira	12	10	3	13	5	2–8
Total unique varieties			16	6	23		
Overall total unique			64	12	76		

[1] Released cultivars include newly bred cultivars and farmers' varieties with superior desirable traits promoted by the national program.
[2] HH – Household

respondents in this study, 92% engaged in this practice. The flow of materials between farmers occurred as gifts or barter exchange, or by purchase. About 36% of the farmers used both channels to access planting materials. Challenges identified by farmers engaged in material exchange were transmission of pests and diseases, lack of accurate information about the variety, financial constraints, lack of cooperation among farmers, and access to planting materials to ensure timely planting (Fig. 2A). Farmers indicated that, in many cases, buying material can provide access to the desired variety, but it requires purchasing power. Lack of accurate information about the variety is also a critical challenge, especially if the farmer purchased the planting material and it performed poorly in the local environment. Farmers who did not engage in material exchange indicated that they avoided this

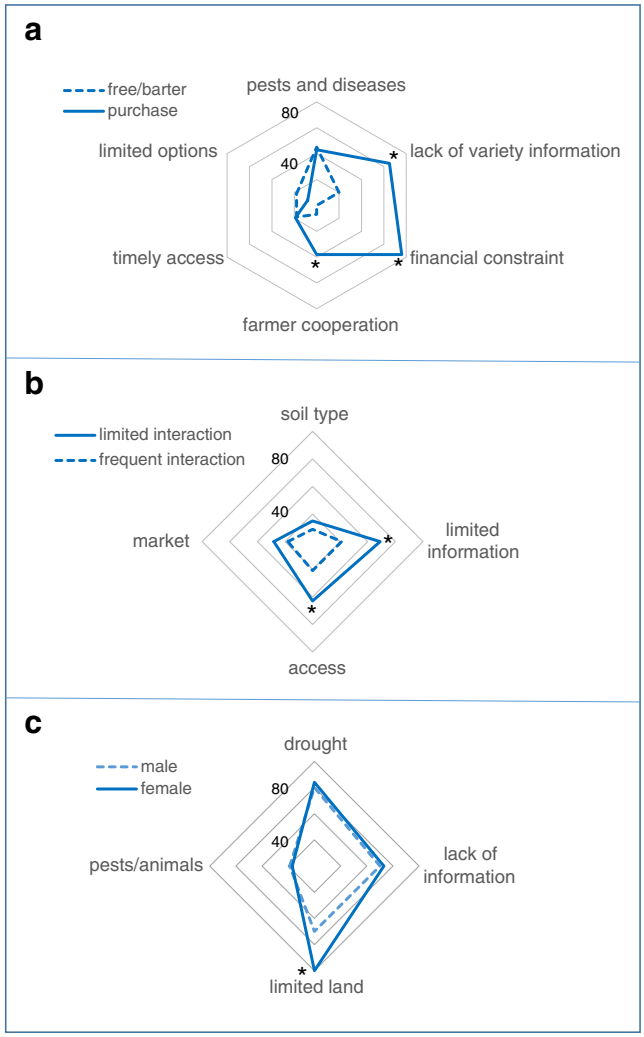

Fig. 2. Key challenges faced by farmers during sweet potato plant material exchange (A); adoption of new varieties/cultivars (B); and retention of current varieties when adopting new varieties/cultivars (C). (A) Material exchange. Farmers were asked to provide up to three key challenges and indicate whether they engaged free or barter exchange or purchase. Six farmers carrying out the exchange practice indicated that they had no challenges. (B) Adoption of new varieties/cultivars. Respondents were asked to identify two key challenges and to indicate whether they had limited or frequent interaction with extension service. Total number of respondents was 102. (C) Maintaining current varieties. Respondents were asked to identify two key challenges. Total number of respondents was 96. Radar axis shows the percentage of farmers who selected the variable as a key challenge. * denotes significance by Chi square analysis at 5%.

practice because they think it promotes spread of plant pests and diseases. Instead, they access material from the national research institutes.

Plant material exchange is usually most challenging following a long dry spell. Only farmers who own or can rent portions of the wetland to preserve their future planting materials or can afford irrigation have ready access to planting material in the next season. In many cases, this meant that better-off farmers were the suppliers of the planting material, as has been reported by Cromwell (1996) and McGuire (2008). However, more affluent farmers indicated that they conserve planting material for their own use in the next season and have little or nothing to share. This may be the reason why other farmers indicated lack of cooperation by fellow farmers as a key constraint for material exchange. Gaining access to seed or planting materials has also been identified as a major challenge in other crops (Sperling et al. 2008).

Factors Influencing Adoption of New Varieties or Improved Cultivars

The three criteria leading most respondents to adopt new varieties or cultivars were yield followed by taste and duration to maturity (Fig. 3A). Market demand and tolerance to biotic and abiotic stresses were also important. Abidin et al. (2005) and Gibson et al. (2008) similarly observed yield, taste, maturity time, resistance to pests and diseases, and ability to store roots in-ground for piecemeal harvesting as key factors. In some cases, however, selection was driven by accessibility to disease-free planting materials at the time of planting, rather than varietal preference or suitability to the environment.

Consideration of market demand, which is most relevant for farmers with access to markets and those expecting to sell a significant portion of their crop, was important to a lower number of respondents. There was a significant difference ($P < 0.05$) in consideration of market demand between male and female farmers. Of the male respondents, who typically produce sweet potato for commercial production, close to 70% ranked market demand as a key consideration for adopting new varieties or cultivars. In contrast, only 22% of the female farmers, who primarily grow sweet potato for home consumption and food security, considered market demands as a key factor. Subsistence-oriented farmers tend to focus on consumption attributes such as good taste, high dry matter or beta-carotene content, and piecemeal harvesting ability.

The respondents ranged from farmers growing sweet potato for the first time, to farmers who have not adopted new varieties or cultivars in more than five years and sometimes even more than ten years. More than half of the respondents cultivated the same varieties for over three years before adopting new varieties or cultivars. A substantial number of respondents (22%) adopted new varieties or cultivars whenever they identified one that performed better than their current varieties. Gender did not influence frequency of adoption of new varieties or cultivars, while farmer age was significant (Table 3). A majority of the farmers above the age of 50 had reduced frequency of adoption. Farmers that were members of farmers' groups or interacted more frequently with an extension service (at least once a year) tended to change their varieties and cultivars more frequently. Asrat et al. (2010) also observed that in Ethiopia, teff and sorghum farmers with frequent interaction with extension services adopt new varieties more frequently.

Land area allocated to sweet potato did not significantly influence frequency of adoption of new varieties and cultivars. The low measure of association (Eta = 0.155) is largely attributed to Bukedea districts, where the majority of respondents have cultivated the same orange-flesh sweet potato varieties for at least five years, regardless of the land size. If the Bukedea district was excluded from the analysis, there was an increased association (Eta = 0.473; $P < 0.01$) between the size of land and frequency of adoption of new varieties or cultivars. This is probably because the larger farms are more market-oriented and tend to interact more frequently with extension service than subsistence farms.

Challenges to Adoption of New Varieties or Cultivars

Inadequate information was indicated as the main challenge to adoption of new varieties or cultivars, followed by access to planting materials (65% of the respondents) (Fig. 2B). However, the proportion of respondents who considered limited information and lack of access as key constraints was significantly less ($P < 0.05$) for farmers that frequently interacted with extension services. Farmers that rarely met with extension services relied on information provided by the source of planting material, usually a fellow farmer or merchant. However in some cases such information is biased to performance in one or a few location(s) or season(s) (McGuire 2008) and may result in unreliable

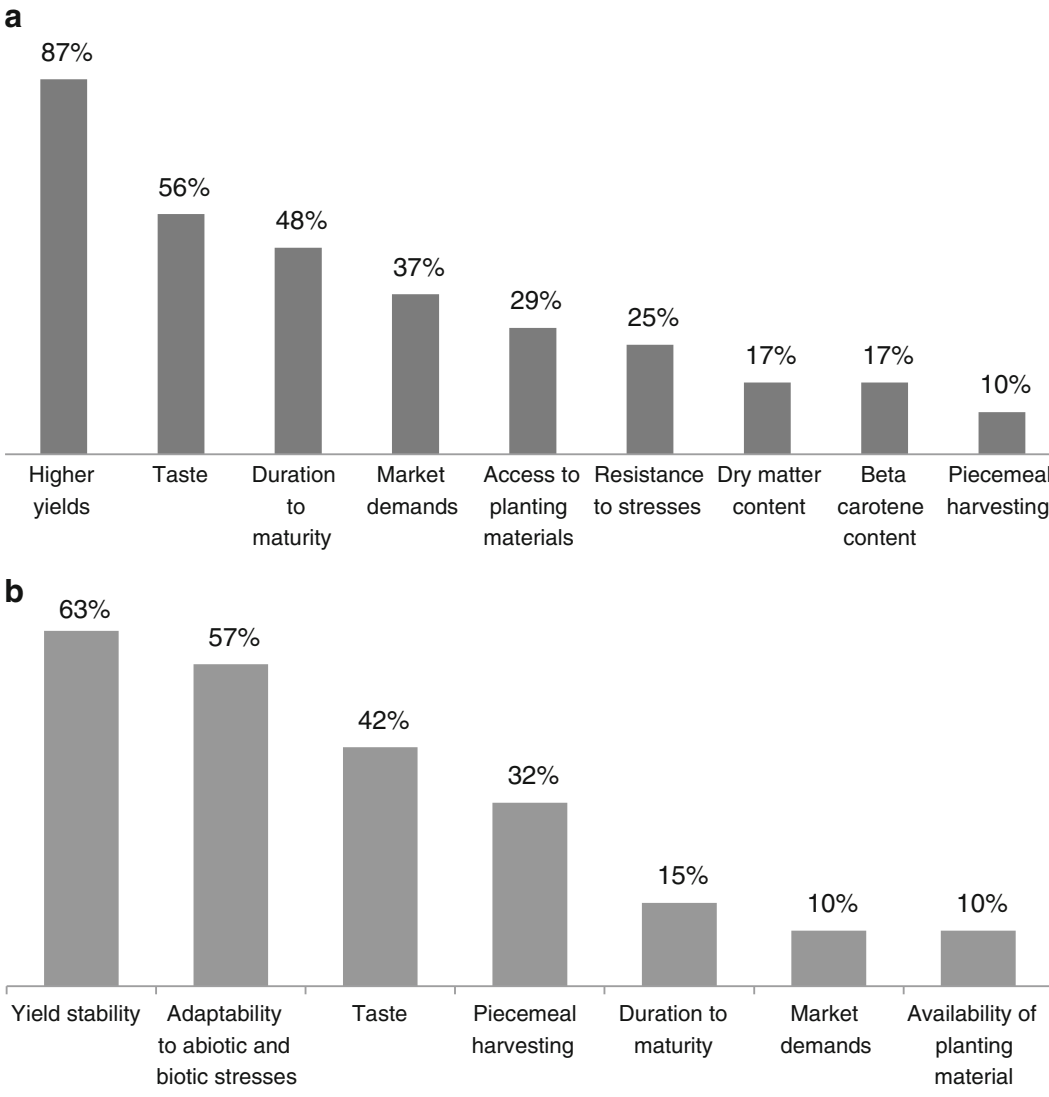

Fig. 3. Criteria for selection of A) new varieties/cultivars, and B) maintenance of current varieties. Numbers above the peaks indicate percentage of the total number of respondents (102) that selected the variable as a key factor in their decision-making.

information about the variety. There was a strong association between membership in farmers' groups and frequency of interactions with extension providers (Table 3). This may explain why respondents in farmers' groups did not consider limited information and access to better varieties as the major challenges. These findings support the hypothesis that weakening social ties among farmers cause farmers to miss opportunities to obtain information about better or new diversity, and to access this diversity (Bellon 2001; Winters et al. 2006).

Market issues such as access to market outlets and price fluctuations were also key challenges for 46% of the respondents, regardless of the frequency of interaction with extension providers. In many cases farmers are not provided with sufficient information regarding the supply, demand, and price of a product (Moulin et al. 2012; Van Dusen and Taylor 2005). Because sweet potato production is largely dependent on rainy seasons, if many farmers grow the same varieties, there is a glut at harvest time, leading to low prices or inability to sell produce.

Table 3. MEASURE OF ASSOCIATION BETWEEN DIFFERENT VARIABLES THAT INFLUENCE CROP DIVERSITY.

Variable 1[1]	Variable 2	Measure of association[2]
Membership in farmer' groups	Interaction with extension service	0.703***
Frequency of adoption of new varieties	Age of farmer	0.580***
	Gender of farmer	0.285
	Land ownership	0.420*
	Land size	0.155
	Land size (without Bukedea district)	0.473**
	Membership in farmers' groups	0.488***
	Interaction with extension service	0.419**
	Market access	0.425*
	Weather conditions	0.504*
Maintenance of current varieties when adopting new variety	Age of farmer	0.615***
	Gender of farmer	0.304*
	Land ownership	0.370*
	Land size	0.247
	Membership in farmers' groups	0.229
	Interaction with extension service	0.248
	Market access	0.400*

***, ** and * denote significance at 0.1%, 1% and 5%, respectively.

[1] Variable definitions and scoring system are provided in ESM Table 2.

[2] Phi was used as the symmetric measure of association, based on chi-square, between nominal variables. Eta was used as the measure of association between one nominal and one interval variables.

This challenge is worst for farmers where distances between production areas and main markets are greatest. Production of sweet potato by many households in the same community makes marketing to the surrounding communities a big challenge; thus farmers have to rely on distant traders (Abidin 2004). These observations suggest that crop diversity maintenance may be enhanced by providing farmers with solutions to the market issues, including innovations that facilitate non-rain-fed production, and increased ability to store long-term, as well as develop new sweet potato products and processed forms.

The majority of the respondents (73%) indicated that they first evaluate performance of new varieties by planting a few mounds. Some farmers (28%) further test the varieties in multiple locations in their field based on slope, soil structure, or amount of organic matter. On-farm evaluation of variety performance by individual farmers is a common practice that has been reported in other crops (e.g., Mikkelsen and Langohr 2004; Smale et al. 2001).

CRITERIA FOR MAINTAINING A VARIETY IN THE FARMERS' FIELDS

The criteria used for maintaining older varieties when adopting new varieties or cultivars (Fig. 3B) were different from considerations for adopting new varieties (Fig. 3A). The largest number of respondents considered yield stability, including tolerance to native biotic and abiotic stresses (e.g., disease, drought, poor soils, weedy fields), as critical, but this had to be supplemented by good taste. Farmers indicated that in most cases the new varieties or cultivars are not adapted to the local environment; thus their higher performance tends to diminish over time. Asrat et al. (2010) observed that the majority of the teff and sorghum farmers considered environmental adaptability to extreme conditions more critical than routinely high yield. Increased desire for environmental adaptability was attributed to the increasing frequency of environmental stresses such as prolonged drought events, soil degradation, and lack of resources and technologies to help farmers overcome these stresses.

Piecemeal harvesting capability was also considered a key factor by a substantial number of the respondents (32%). Most of the new varieties were not considered to have good piecemeal harvesting characteristics. Other factors considered when selecting varieties to conserve included early maturity, market demand, and availability of planting materials. These findings indicate important considerations, both for conservation of genetic diversity and establishment of breeding priorities for varietal development.

IMPACT OF ADOPTION OF NEW CULTIVARS OR VARIETIES ON MAINTENANCE OF EXISTING VARIETIES IN THE FARMER'S FIELD

The majority of the respondents (73%) kept some of the existing varieties in their field when adopting new varieties or cultivars: 14% allocated > 0.5 ha; 33% 0.25–0.5 ha; and 27% allocated less than 0.25 ha. Other respondents (27%) completely replaced their current varieties because of limited land resources and/or poor performance of the current varieties. Poor

performance most frequently resulted from reduced tolerance to local stresses, especially pests and diseases.

The challenges identified as key for maintaining varietal diversity were different from those indicated for adopting new diversity. The major challenges for maintaining varieties were: land limitation (identified by 70% of the respondents); loss of planting material due to prolonged drought events (63%); lack of training in better conservation techniques (47%); and loss of planting materials due to animals and pests (19%) (Fig. 2C). Respondents who rented land and female farmers whose husbands allocate land use indicated land limitation as a key constraint. The male owner tended to have different priorities for land use compared to the woman farmers, influencing the size of land allocated for sweet potato production, and potential for diversity preservation on-farm. This may explain the significant association between land ownership and maintenance of varieties (Table 3).

Prolonged drought events have resulted in loss of planting material in farmers' fields. To cope with this constraint, respondents use various strategies, including planting the vines near wetlands, on riverbanks, or within banana plantations. However, very few of the respondents had access to wetlands or had resources for irrigation. Lack of information about conservation methods, which was cited by nearly 50% of the farmers, indicates that there is need to incorporate training on conservation of planting material as part of any new sweet potato variety release package. Inadequate training of farmers in conservation practices has also been identified as a key constraint to *in situ* conservation of other crops such as coffee in El Salvador (Méndez 2008), potato in the Andes (De Haan 2009), and teff and sorghum in Ethiopia (Asrat et al. 2010).

Conclusions

Several studies have characterized sweet potato diversity in regions of Central and South America, Africa, and Asia, and have emphasized the important role that farmers play in maintaining diversity (e.g., Camargo et al. 2013; Elameen et al. 2011; Moulin et al. 2012; Roullier et al. 2013). An earlier study interviewing 33 households in Brazil found that overall diversity of crops and varieties cultivated, including sweet potato, was declining as a result of limited land, changing economic conditions, and legal constraints (Peroni and Hanazaki 2002). For those families, exchange with neighbors or relatives was the primary source of new varieties or replacement of losses. In this study we investigated the factors that influence farmers' ability to access and utilize new sweet potato varieties along with those that drive choice of the specific varieties to be introduced, discarded, or maintained.

In most districts surveyed, farmers were currently growing a combination of farmers' varieties and released cultivars. However, it should be noted that the ecological and socioeconomic conditions favoring cultivation of farmers' varieties and landraces are not fixed (Enjalbert et al. 2011; Thomas et al. 2011). Rapid population growth, land use intensification, market driven changes, and climate change will all necessitate increasing agricultural productivity per unit area, thus encouraging adoption of modern agricultural technologies and practices (Pautasso et al. 2013). Such interventions could have great impact on traditional varietal diversity.

Key criteria for variety selection varied based on household characteristics, available land, intended uses of sweet potato, micro-climatic conditions, and level of access to agricultural extension. Preference for sweet potato varieties with high environmental adaptability and yield stability may explain why there has been a low adoption rate or abandonment of the high-yielding modern cultivars released in Uganda over the past two decades. This points to the need for breeding programs to prioritize traits that will enhance adaptability to common stresses of the receiving environment under minimal input conditions. Economic conditions, such as financial constraints to adopt modern farming technologies or inputs, also favor cultivation of traditional varieties. Farmers will only adopt technologies if they are convinced that the benefits outweigh the costs (Pannell et al. 2006). Therefore, a key responsibility of the extension service should be to ascertain whether new technologies have net benefits to the farmers under their jurisdiction before they embark on education and promotional activities.

Prior studies have indicated a positive relationship between genetic diversity and strong social ties (Pautasso et al. 2013). This was also observed for the Ugandan sweet potato farmers in this study. Networking among farmers enabled sharing of experiences and information about available diversity and its management, strengthened planting material exchange, and facilitated collective action to access superior varieties and markets beyond the surrounding community.

Maintenance of farmers' sweet potato varieties was influenced by a combination of ecological conditions, socioeconomic factors, and crop management practices. Drought was the major factor attributed to complete loss of certain varieties in these regions and thus environmental conditions may play a significant role in ability to maintain diversity *in situ*. Lack of access to information about conservation practices was also a key constraint to maintenance of farmers' varieties. Ultimately, farmers will only maintain varieties that meet their needs because it is not the farmers' responsibility to maintain diversity (Asrat et al. 2010; Roullier et al. 2013). Thus some varieties will be lost due to poor performance under local conditions, while others will be dropped based on human preferences. In the absence of appropriate incentive mechanisms to encourage farmers to implement *in situ* conservation strategies, crop diversity will be dependent on farmers' choices. Geographical distribution of allelic diversity and decentralization of *ex situ* conservation (by the assemblage and evaluation of available varieties and cultivars in nearby research stations) can be possible alternatives to facilitate preservation of useful diversity in the local environments (Roullier et al. 2013).

In conclusion, these results suggest that as the country's agriculture develops to meet the challenges of a growing population and changing environment, there will be need for a national policy to ensure effective conservation of varieties that possess unique desirable traits. Conservation policies must consider strategies that will facilitate preservation in the face of environmental and agronomic constraints such as limited land, losses to diseases, unreliable weather, and prolonged drought events, as well as financial constraints such as market access and price fluctuation.

Acknowledgments

This research was in part supported by the Norman E. Borlaug Leadership Enhancement in Agriculture Program (LEAP). We are very grateful to the staff of the Uganda National Sweetpotato Program, and the district agricultural extension service for the districts that we visited, who provided technical advice on the survey methodology. Our sincere thanks the farmers who participated in the research. We also thank Drs. Russell Freed, Jim Kelly (Michigan State University), and Hector Quemada (Danforth Foundation) for their valuable feedback and suggestions.

Literature Cited

Abidin, P. E. 2004. Sweetpotato breeding for northeastern Uganda: Farmer varieties, farmer-participatory selection, and stability of performance. Ph.D. thesis, Wageningen University, Wageningen.

———, F. A. van Eeuwijk, P. Stam, P. C. Sturik, M. Malosetti, R. O. M. Mwanga, B. Odongo, M. Hermann, and E. E. Carey. 2005. Adaptability and stability of sweetpotato varieties for low-input systems in Uganda. Plant Breeding 124:491–497.

Asrat, S., M. Yesuf, F. Carlsson, and E. Wale. 2010. Farmers' preferences for crop variety traits: Lessons for on-farm conservation and technology adoption. Ecological Economics 69:2394–2401.

Bashaasha, B., R. O. M. Mwanga, C. Ocitti p'Obwaya, and P. T. Ewell. 1995. Page 63 Sweetpotato in the farming and food system in Uganda: A farm survey report. CIP, sub-Saharan African region, Nairobi, Kenya /National Agricultural Research Organization, Kampala, Uganda.

Bellon, M. R., 2001. Demand and supply of crop infraspecific diversity on farms: Towards a policy framework for on-farm conservation. CIMMYT Economics Working Paper 01-01. Mexico, D.F.: CIMMYT

Carmargo, L. K. P., A. F. Mogor, J. T. V. Resende, and P. R. Da-Silva. 2013. Establishment and molecular characterization of a sweet potato germplasm bank of the highlands of Parana State, Brazil. Genetics and Molecular Research 12:5574–5588.

Carpenter, J. E. 2011. Impact of GM crops on biodiversity. GM Crops 2:7–23.

Cromwell, E. 1996. Governments, farmers, and seeds in a changing Africa. CABI, Wallingford, U.K.

Dantata, I. J., F. E. Babatunde, S. Mustapha, and A. S. Fagam. 2010. Influence of variety and plant spacing on tuber size, tuber shape and fresh marketable yield of sweetpotato in Bauchi Nigeria. Biological and Environmental Science Journal for the Tropics 7:140–144.

De Haan, S. 2009. Potato diversity at height: Multiple dimensions of farmer-driven in-situ conservation in the Andes. Ph.D. thesis, Wageningen University, Wageningen.

Elameen, A., A. Larsen, S. S. Klemsdal, S. Fjellheim, L. Sundheiim, S. Msolla, E. Masumba, and O. A. Rognli. 2011. Phenotypic

diversity of plant morphological and root descriptor traits within a sweet potato, *Ipomoea batatas* (L.) Lam., germplasm collection from Tanzania. Genetic Resources and Crop Evolution 58:397–407.

Enjalbert, J., J. C. Dawson, S. Paillard, B. Rhone, Y. Rousselle, M. Thomas, and I. Goldringer. 2011. Dynamic management of crop diversity: From an experimental approach to on-farm conservation. Comptes Rendus Biologies 334:458–468.

FAO. 2007. Report of panel of eminent experts on ethics in food and agriculture. Rome: Food and Agriculture Organization of United Nations. November 2007.

——— 2012. FAO crop production statistics. Food and Agriculture Organization of the United Nations. http://faostat.fao.org/ (3 March 2013).

Gepts, P. and R. Papa. 2003. Possible effects of (trans) gene flow from crops on the genetic diversity from landraces and wild relatives. Environmental Biosafety Research 2:89–103.

Gibson, R. W., E. Byamukama, I. Mpembe, J. Kayongo, and R. O. M. Mwanga. 2008. Working with farmer groups in Uganda to develop new sweet potato cultivars: Decentralisation and building on traditional approaches. Euphytica 159:217–228.

Gichuki, S. T., M. Berenyi, D. Zhang, M. Herman, J. Schmidt, J. Glossl, and K. Burgh. 2003. Genetic diversity in sweetpotato (*Ipomoea batatas* [L.] Lam.) in relationship to geographic sources as assessed with RAPD markers. Genetic Resources and Crop Evolution 50:429–437.

Khoury, C., B. Laliberte, and L. Guarino. 2010. Trends in ex situ conservation of plant genetic resources: A review of global crop and regional conservation strategies. Genetic Resources and Crop Evolution 57:625–639.

Lebot, V. 2010. Sweet potato. Pages 97–125 in Bradshaw, ed., Root and tuber crops: Handbook of plant breeding. J. E. Springer, New York.

Loebenstein, G. 2009. Origin, distribution and economic importance. In: The sweetpotato, eds. G. Loebenstein and G. Thottappilly, 9–12. Springer. DOI 10.1007/978-1-4020-9475-02, C _ Springer Science+Business Media B.V.

McGuire, S. J. 2008. Securing access to seed: Social relations and sorghum seed exchange in Eastern Ethiopia. Human Ecology 36:217–229.

Méndez, V. E. 2008. Farmers' livelihoods and biodiversity conservation in a coffee landscape of El Salvador. Pages 207–236 in C. M. Bacon, V. E. Méndez, S. R. Gliessman, D. Goodman, and J. A. Fox, eds., Confronting the coffee crisis: Fair trade, sustainable livelihoods and ecosystems in Mexico and Central America. MIT Press, Cambridge, Massachusetts.

Mercer, K. L. and H. R. Perales. 2010. Evolutionary response of landraces to climate change in centers of crop diversity. Evolutionary Applications 3:480–493.

Mikkelsen, J. H. and R. Langohr. 2004. Indigenous knowledge about soils and a sustainable crop production: A case study from the Guinea Woodland Savannah (Northern Region, Ghana). Danish Journal of Geography 104:1326.

Moulin, M. M., R. Rodrigues, L. S. A. Goncalves, C. P. Sudre, M. H. dos Santos, and J. R. P. da Silva. 2012. Collection and morphological characterization of sweet potato landraces in north of Rio de Janeiro state. Horticultura Brasileira 30:286–292.

Mwanga, R. O. M., B. Odongo, C. N. Ocitti p'Obwoya, and G. M. Turyamureba. 2001a. Sweetpotato (*Ipomoea batatas* [L.] Lam.). In: Agriculture in Uganda. Vol. II: Crops. National Agricultural Research Organisation (NARO)-CTA, ed. J. K. Mukiibi, 233–251. Kampala, Uganda: Fountain Publications.

———, ———, ———, R. W. Gibson, N. E. J. M. Smith, and E. E. Carey. 2001b. Release of five sweetpotato cultivars in Uganda. Horticultural Science 36:385–386.

————, C. Niringiye, A. Alajo, B. Kigozi, J. Namakula, I. Mpembe, S. Tumwegamire, R. W. Gibson, and G. C. Yencho. 2011. NAPOT 11," a sweetpotato cultivar bred by a participatory plant-breeding approach in Uganda. Horticultural Science 46:317–321.

Namanda, S., R. Gibson, and K. Sindi. 2011. Sweetpotato seed systems in Uganda, Tanzania, and Rwanda. Journal of Sustainable Agriculture 35:870–884.

Ndolo, P. J., R. A. Nungo, R. E. Kapinga, and S. Agili. 2007. Development and promotion of orange-fleshed sweetpotato varieties in Western Kenya. Proceedings of the 13th ISTRC Symposium, 689–695.

Pannell, D., G. Marshall, N. Barr, A. Curtis, F. Vanclay, and R. Wilkinson. 2006. Understanding and promoting adoption of conservation practices by rural landholders. Australian Journal of Experimental Agriculture 46:1407–1424.

Pautasso, M., G. Aistara, A. Barnaud, S. Caillon, P. Clouvel, O. T. Coomes, M. Deletre, E.

Demeulenaere, P. De Santis, T. Doring, L. Eloy, L. Emperaire, E. Garine, I. Goldring, D. Jarvis, H. I. Joly, C. Leclerc, S. Louafi, P. Martin, F. Massol, S. McGuire, D. McKey, C. Padoch, C. Soler, M. Thomas, and S. Tramontini. 2013. Seed exchange networks for agrobiodiversity conservation. A review. Agronomy for Sustainable Development 44:151–175.

Peroni, N. and N. Hanazaki. 2002. Current and lost diversity of cultivated varieties, especially cassava, under swidden cultivation systems in the Brazilian Atlantic forest. Agriculture Ecosystems and Environment 92:171–183.

Rao, R. and D. Campilan, eds. 2002. Exploring the complementarities of ex situ and in situ conservation strategies for Asian sweetpotato genetic resources. Proceedings of the 3rd International Workshop of the Asian Network of Sweetpotato Genetic Resources (ANSWER). IPGRI-APO, Serdang, Malaysia.

Ratnadass, A., P. Fernandes, J. Avelino, and R. Habib. 2012. Plant species diversity for sustainable management of crop pests and diseases in agroecosystems: A review. Agronomy for Sustainable Development 32:273–303.

Roullier, C., R. Kambouo, J. Paofa, D. McKey, and V. Lebot. 2013. On the origin of sweetpotato (*Ipomoea batata* [L.] Lam.) genetic diversity in New Guinea, a secondary center of diversity. Heredity 110:594–604.

Smale, M., M. R. Bellon, J. Alfonso, and A. Gómez. 2001. Maize diversity, variety attributes, and farmers' choices in south-eastern Guanajuato, Mexico. Economic Development and Cultural Change 50:201–222.

Sperling, L., H. D. Cooper, and T. Remington. 2008. Moving towards more effective seed aid. Journal of Development Studies 44:586–612.

Thomas, M., J. C. Dawson, I. Goldringer, and C. Bonneuil. 2011. Seed exchanges, a key to analyze crop diversity dynamics in farmer-led on-farm conservation. Genetic Resources and Crop Evolution 58:321–338.

UBOS. 2010. Uganda Census for Agriculture, 2008/09. Vol. IV: Crop area and production report. Uganda Bureau of Statistics (UBOS).

Uganda Government. 1967. The soil maps of Africa. European Digital Archive of Soil Maps. EuDASM. http://eusoils.jrc.ec.europa.eu/esdb_archive/eudasm/africa/lists/cug.htm (14 August 2012).

Van Dusen, M. E. and T. E. Taylor. 2005. Missing markets and crop diversity: Evidence from Mexico. Environmental Development and Economics 10:513–531.

Veasey, E. A., A. Borges, M. S. Rosa, J. R. Queiroz-Silva, E. D. A. Bressan, and N. Peroni. 2008. Genetic diversity in Brazilian sweetpotato (*Ipomoea batatas* [L.] Lam., Solanales, Convolvulaceae) landraces assessed with microsatellite markers. Genetics and Molecular Biology 31:725–33.

Winters, P., R. Cavatassi, and L. Lipper. 2006. Sowing the seeds of social relations. ESA Working Paper No. 06-16. FAO, Rome.

Yada, B. 2009. Characterization and evaluation of sweetpotato genetic potential in Uganda using agro-morphological and molecular approaches. M.Sc. thesis, Makerere University, Kampala, Uganda.

———, P. Tukamuhabwa, A. Villordon, A. Alajo, and R. O. M. Mwanga. 2010. An online database of sweetpotato germplasm collection in Uganda. Horticultural Science 45:153–153.

Zawedde, B. M. 2013. Environmental risk assessment for introduction of genetically engineered weevil resistant sweetpotato in Uganda. Ph.D. thesis, Michigan State University, East Lansing.